EFFECT OF SITE, VARIETY AND STORAGE ENVIRONMNET ON YIELD AND QUALITY OF SEED POTATO IN THE NORTH RIFT REGION OF KENYA

BY

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DECLARATION

Declaration by Student

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Declaration by Supervisors

This thesis has been submitted with our approval as university supervisors.

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DEDICATION

This Thesis is dedicated to my parents who although never went to school ensured that I went to learn. To them they wanted their son to study and secure a good paying job for their support in old age. In the same vein I also dedicate to my wife, Stella and our siblings, Ken, Rowlands and Mercy who continued inspiring me during my prolonged study.

ABSTRACT

Potato is the second most important food and nutrition crop in Kenya. It is grown largely by small scale farmers using recycled seed often diseased leading to low yields. Availability of certified seed is highly limited by land subdivision and change of use in traditional seed production areas which took place from mid 1980s. Consequently, there is urgent need to explore other suitable areas where potato has not been widely grown as in the North Rift. However, current varieties were not evaluated for their performance in the region and hence it is incumbent to identify suitable varieties with preferred quality characteristics for the region. Three experiments were conducted using local varieties to evaluate the seed yield potential, their field performance in different altitudes and pre-harvest handling characteristics. In the first experiment, eight potato varieties were grown in Kitale to assess stand establishment, number of stems/plant and foliage, tuber yield and yield distribution. Seed grade tubers were stored at ambient conditions to physiologically sprouted stage. In the second experiment, these tubers were planted at Kitale, Kapcherop and Kibigos and similar parameters as was in the first experiment were undertaken other than weight of foliage. In the third experiment ten kg seed size graded tubers of each variety from second experiment were stored *in situ* in the dark, diffuse and open environments replicated twice in a CRD. Tuber weight was taken at specific days for 117 days in storage. Data was subjected to Sheffe's test using SAS 9.3 Version and presented in ANOVA and C.V %. Means were separated by Sheffe's critical mean differences. At 27 days after planting (DAP), plant emergences was statistically similar ($p = <0.05$) for all varieties other than Pimpernel and Kenya Baraka. However, at 42 DAP all had passed 89 % plant emergence while Pimpernel had reached 9 %. In terms of ground cover Asante, Dutch Robjin, Tigoni1and Kenya Karibu were statistically similar 42 DAP but differed from the rest at 56 DAP and remained so even at 65 DAP. Asante had the highest number of tubers per plant at Kitale site. Plant emergence was slowest at Kibigos and fastest at Kitale. Dutch Robjin had the highest stem density per unit area and number of tubers per plant in seed size category across the sites. Most of varieties had tubers in seed grade at Kitale compared to the other sites. Tuber weight loss took place in the first 30 days irrespective of variety, site or store environment. Dutch Robjin had the highest dry matter at all the sites while Asante had the lowest. Introduction of potato in the region should be preceded by evaluation to identify suitable varieties.

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LIST OF ABBREVIATIONS AND ACRONYMS

ABA: Abscissic Acid

ADC: Agricultural Development Corporation

Anon: Anonymous

DAP: Days after Planting

DOS: Days of Storage

ERS: Economic recovery strategy

FAO: Food and Agriculture Organization of the United Nations

FAO STAT: Food and Agriculture Organization statistics

CIP: International Potato Centre

C.V: Coefficient of Variation

DM: Dry Matter Content

GIZ: German International Development Agency

GTZ-PSDA: German Development Corporation- Private Sector Development in Agriculture

KARI: Kenya Agricultural Research Institute

KFA: Kenya Farmers Association

LH1: Lowland sub-zone 1

LH3: Lowland sub-zone 3

LH4: Lowland sub-zone 4

LM5: Low Midland sub-zone 5

LM4: Low Midland sub-zone 4

MDG: Millennium Development Goal

MoA: Ministry of Agriculture

MCD: Minimum Critical Difference in Sheffe's test

S.G: Specific Gravity

SRA: Strategy for Revitalization of Agriculture

TAI-TAII: Tropical alpine sub-zone I and II

UM4: Upper Midland sub- zone 4

UH 1-2: Upper Highland sub-zone 1 and 2

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CHAPETR ONE

INTRODUCTION

1.1 Origin of diversity and spread of potatoes

Potato is of ancient origin in South America (Harris, 1992) and was dispersed by man over considerable area by the Spaniards' arrival in 1600 AD. Data from early Spanish Post–Conquest chronicles and archaeological remains indicate that potato was domesticated in the Andes of Peru and Bolivia where many wild species are found. Archaeological evidence from antiquity of potato cultivation shown by ceramics from Northern Coast of Peru belonging to the *Moche, Chinu*, and *Inca* cultures (400 AD), in form of potatoes have been described and analysed in some detail by Harris, (1992). Earlier on potatoes had been grown at high altitudes where they played a central role in household economies. Studies of starch and cell structures using light scanning microscope and radio carbon techniques have identified the origin of potatoes to be Chilca valley near Lima dating back to 7,000 years ago (Martins, 1976). Ugent *et al.* 1982 and Ugent *et al.*, 1987, described potatoes at Casma (Peru), as of wild potatoes from Chile that had apparently been eaten although not cultivated. However, more recent studies by Devaux *et al.* (2009) put the origin of potatoes as the Andes and having been cultivated for over 8,000 years and their ancestors were probably the wild species *Solanum leptophyes.*

Form the foregoing studies on distribution of land races of potatoes and wild species it suggests that the potato was most probably first domesticated in the Northern Bolivia region of Lake Titicaca/Lake Poopo (Harris, 1992).

The potato belongs to *Solanum tuberosum,* L. species. The genus *Solanum* contains over 1,000 species spread all over the world except far North and South, with strong concentration of species diversity in South and Central America. In addition to *S. tuberosum*, there are other six cultivated species and over 230 wild species. However, the rest of the genus, such as the species, S. *nigrum,* are non- tuber forming species. The floral organs of *Solanum tuberosum* are considered of great importance in distinction, as no species of *Solanum* differ essentially from one another. The plant bears white to purple flowers with yellow stamens. Some cultivars bear small green fruits each containing up to 300 seeds (*www.wikipedia.org*).

The first recorded cultivated potatoes outside South America showed that it was first introduced into England (1558-9), the Canary Islands around 1562, then into Spain by 1570. From Spain it diffused into Continental Europe and parts of Asia by 1621and those from England spread to Ireland, Scotland, Wales and parts of Northern Europe. Those from British sources reached British Colonies of England via Bermuda in the USA, most likely in a ship's stores from Colombia and were of Columbian or possibly Peruvian origin as they were primarily tetraploid Group *Andigena* potatoes (Harris, 1992). Then the growing of potatoes spread north-eastwards across Europe and became adapted to the long summer days of northern Europe.

1.2 Transition to a major food crop

After its introduction to Europe, the potato remained essentially a plant of botanic curiosity, being grown and studied in gardens for interest and medicinal properties. In 16th century countries of Europe develop widespread political and commercial interests in the rest of the world and these European colonists and missionaries took with them their common crops which included potatoes (Burton, 1989).

However, its potential as a food crop was first accepted in Ireland at the end of the 17th century and throughout the 18th century it gained in importance as a staple crop in

Ireland when their population in 17th Century increased from 2 million to 8.5 million. They relied mainly on the potato as their sole food crop by 1845 (Reader, 2008; Burton, 1989). However, the late blight epidemics of 1845 and 1846 resulted in famine in Ireland with profound societal consequences.

In 18th century, potato was generally acknowledged as a foodstuff throughout Europe and by 19th century potato became a major food crop (Burton, 1989), before it declined in production and consumption in developed world during the 20th Century. Elsewhere, potato production expanded in China and India during the second half of the 20th Century (FAO STAT, 2013) that has led these countries to be the first and third most important producers in the world, respectively

1.3 Importance of the Potato

The potato (*S.tuberosum* L.) is the world's fourth most important food crop after wheat, rice and maize (Chemeda *et al*. 2014) with annual production ranging from 322 million tonnes fresh-weight in about 140 countries of which more than 100 countries are in the tropical and sub-tropical zones (Beukema and Van der Zaag, 1990) to about 324 million tonnes in 2010 (FAO STAT, 2013).

Among the vegetable crops, potato ranks first in production and the world's most widely grown among the tuber crops and it contributes immensely to human nutrition and food security (Karim *et al.* 2010)

The high nutritional value of the tubers and the simplicity in propagation by vegetative means has made potato a popular food crop in third-world countries (Alisdair and Willmitzer (2001). Other attributes that has made potato a very important crop include high yields per unit area, short maturity period (Adane *et al*. 2010) and a broad array of culinary fresh uses. Potato is also widely used as raw material for processing into various products (Sen *et al*. 2010). Recent data indicates that potato produces 75 % more food energy per unit area than wheat and 58 % more than rice. It has also produces 54 % more protein per unit area than wheat and 78 % higher than rice. In fact, no other food crop can match the potato in its production of food energy per unit area (Bushway, 2010). Potato matures in 3-4 months with potential tuber yield of up to 40 t/ha (FAO STAT, 2008), thus makes ideal in places where land is limiting. It is widely used as animal feed in Russian Federation and other East European countries where as much as half of the potato is grown (FAO STAT, 2008). Potato starch is extensively used in the pharmaceutical, textile, wood and paper industries as an adhesive and filler, as well as in oil drilling firms to wash bore holes. In Canada, for example, it is estimated that 440, 000 tonnes of peels from potato processing industries is used to produce 4 to 5 million litres of ethanol (FAO STAT, 2008). Of the world potato production, Europe accounts for 50 % while Asia (25 %) and Africa a paltry 3.2 % (Kabira *et al.* 2003). However, potato production has increased over the past years in both developed and developing countries much faster than other tuber or root crops because of its high tuber productivity per unit area, deployment of higher-yielding varieties together with the widespread use of fungicides, fertilizers and irrigation (White *et al*. 2007). This has largely contributed to developing countries' potato production to almost double in the world since 1991, with corresponding increase in consumption, employment and income (Hoffler and Ochieng, 2008). Globally, potato production is estimated to grow at 2.7 % annually until the year 2020 when it will exceed all major food crops (Saunders, 2007 and Scott *et al.,* 2000). In Sub Saharan Africa, the growth is estimated at 250 % between 1993 and 2020, taking

1993 as base year (Scott *et al.* 2000). In Uganda, for example, population growth and urbanization are the main drivers for demand and supply, which is mostly met through expansion of production into the mid-altitude areas, where the crop is being promoted as food and cash crop (Ferris *et al*. 2001). Further increases in potato production are certainly going to be needed to meet increased demand for food due to population growth, particularly in Asia, Africa and Latin America. In fact, over the next 40 years, world food security will be threatened by a number of developments such as world population which is estimated to reach 9.2 billion in 2050 with growth entirely in the developing countries of which 70 % of population will be living in urban areas (Rosegrant *et al.* 2008). FAO projects that by then food production must have increased by 70 % globally and by about 100 % in developing countries in order to meet food demand, excluding additional demand for livestock feeds and bio-fuel production (Briunsma, 2009). The challenge of meeting future food demand sustainably is even going to be difficult owing to combined effects of climate change, energy scarcity, and resource degradation. According to International Food Policy Research Institute (IPRI), world real food prices are estimated to increase by 59 % for wheat, rice (78 %) and maize (106) %. The report concluded that rising food prices is a reflection of unrelenting pressure on the world food system driven by population and income growth. The potato is expected to play a pivotal role in ameliorating food shortage, relieving the pressure of increasing cereal prices on the poorest people and contributing significantly to food security (Nelson *et al* 2010).

1.4 Introduction of the potato into Kenya

Potato was introduced in Kenya in the late 19th Century in Kiambu, Muranga and Nyeri districts by European settlers initially for domestic consumption and later for export

(Kabira and Njoroge,1982). In 1903, new potato varieties were introduced at the National Agricultural Laboratories, Kabete and at Plant Breeding Station, Njoro in 1907, of which the main variety was Kerr's Pink**.**

Indigenous Kenyan farmers started potato growing in 1920 and by 1923, the potato entered export market. Between 1925 and 1930 potato exports ranged from 1,700 to 4,000 tonnes per year and to 7,000 tonnes by 1960. The average yield was 6.6 tonnes per hectare. In 1970, area under potato cultivation was estimated at 5,100 hectares with total production of 408,000 tonnes. However, exports declined sharply, dropping to 600 tonnes by 1975 due mainly to viruses and bacteria infections (Kabira and Njoroge, 1982). In 1945, vegetable dehydration plants were established in Kerugoya (Kirinyaga) and Karatina (Nyeri) to meet the food needs of British armies in Northern Africa and Asia. At that time about 5,000 tonnes of potatoes were being processed every six months which was lower than demanded. To address this, new varieties were introduced (Roslin Eburu, Dutch Robjin, Anett, Feldeslohn and Desiree) from Europe to Meru and Molo.

In 1963, the government undertook to promote potato production by introducing varieties from Germany and in 1967; a potato development programme was established. In spite of this, potato production potential has not been fully realised due to myriads of challenges such as soil infertility, poor agronomic practices, undeveloped markets and poor post-harvest handling practices. Potato is a highly perishable crop which requires cool storage facilities such as those by Agricultural Development Corporation (ADC). Unfortunately in the 1990's, these facilities were ran down and even the once vibrant marketing association (Kenya Farmers Association, KFA) could not obtain adequate seed supply for distribution to farmers.

1.5 Importance of potatoes in Kenya's National Economy

In recent years, processed potato products such as crisps and French Fries have gained importance due to the changes in consumption habits mainly by urban middle income population made up of youth with substantial disposable incomes. Currently, there is a number of fast food establishments in potato value addition which include local hotels and international ones such as Kentucky Fried Chicken, Subway, Pizza and Chicken Inn and it may not take long to see others like McDonald's setting base in Nairobi (Janssens *et al.* 2013). In terms of employment and income generation, approximately 800,000 people are directly engaged in potato production and over 2.5 million are employed in the potato value chain (Kaguongo *et al.* 2008). Annual potato production has reached 2.06 metric tonnes value at Ksh. 10 billion at farm gate price and about KSh. 28.2 billion per year at various markets (Anon. 2013). Beyond the farm, the industry employs thousands as market agents, transporters, processors, vendors and exporters (Kaguongo *et al.* 2008). The effects on income flow are considerable as the farmer enjoys a farm family income of Ksh.288, 500 per hectare; equivalent to Ksh. 704 per family labour day which is about four times higher than what a casual laborer can earn. Its ability to produce large volumes of consumable products from a small unit area makes it an attractive commodity for enhanced food and nutrition security (Janssens *et al.* 2013). Labour studies by GIZ-PSDA Kenya (2011) showed that potato enterprises engage 51 % and 49 % women and men, respectively (Ndegwa *et al.* 2013). In deed potato is an important food and cash crop for smallholder farmers in the highlands of Kenya (Gildemacher *et al.* 2007).

Potato yields averages 7.7 tons per hectare in Kenya, but often fluctuates considerably from 7.5 ton/ha to over 9.5 ton/ha (FAO STAT, 2008). However, there has been a steady increase in area put to potatoes from 120,246 ha (2009), 121542 ha (2010) and a big jump to 123,390ha (2011). Consequently, the yields have risen from 2,299,806 tonnes to 2,365,263 tonnes in 2011 giving an average yield of 19.17 tonne/ha (Anon, 2011).

The areas of production are in the cooler highlands (1,500-3,000 metres above sea level) where over 70 % is grown above 2,1000m (Janssens *et al.* 2013). The leading counties are Nyandarua (29.8 %), Nakuru (18.9 %) and the least being Nyeri (3.6 %) (Table 1). Potato production in Kenya is by small scale farmers (98 %) cultivating less than 0.2ha and 250 large scale farmers (2 %) who cultivate an average of 10 hectares (Janssens *et al.* 2013).

In terms of seed sources, about 1% of potato seed comes from formal certification system and are highly priced thus few farmers can afford (Ogola *et al*. 2012). The rest (96 %) comes from informal (farm-saved, local markets or neighbours) and 3% from semi-formal (clean seed, positive selection, negative selection or single plot technics) (Kaguongo *et al*. 2008). The low yields have been attributed to poor agronomic practices such as, practising intensive cropping systems that like double or relay potato cropping without a fallow period (Kaguongo *et al.* 2008), low soil fertility, limited use of fertilizers and access to good quality seeds. It is aggravated by diseases especially bacterial wilt, late blight and viruses as well as insect pests such as tuber moth infestation (MOA, 2005; Machangi, *et al*. 2003).

Table 1: Production of Irish potatoes by selected Counties in Kenya, 2011- 2013

County	2011			2012			2013			% share
	Area (Ha)	Qty (MT)	Value (Million Ksh.)	Area (Ha)	Qty (MT)	Value (Million Ksh.)	Area (Ha)	Qty (MT)	Value (Million Ksh.)	
Nyandarua	23385.0	342600.0	3869.9	22059.0	297482.0	2392.0	30508.0	525120.0	5050.6	17.9
Nakuru	21803.0	255223.0	1074.2	13675.0	252751.0	2335.7	20373.0	263401.0	2317.4	8.2
Meru	11234.0	149522.0	4006.2	10842.0	133704.0	3331.9	11503.0	148991.0	3663.5	13.0
Kiambu	14138.0	131140.0	1888.6	13671.0	126055.0	2005.0	12479.0	143431.0	1956.2	6.9
Elgeyo Marakwet	13324.0	217516.0	2571.6	15817.0	258129.0	4092.6	18355.0	302305.0	4577.6	16.2
Bomet	3540.0	46040.0	2868.4	2847.0	43600.0	1019.6	3924.0	74504.0	1477.3	5.2
Narok	6023.0	100704	1835.0	6297.0	86382.0	550.3	7560.0	226518.0	2819.7	10.0
Nyeri	10440.0	105141.0	1215.1	9826.0	112868.0	1396.0	11216.0	131364.0	1926.4	6.8
Bungoma	6322.0	57025.0	831.1	7015.0	63330.0	837.3	7316.0	74205.0	845.5	3.0
Muranga	5923.03	31241.0	626.9	6423.0	34952.0	674.0	6570.0	50387.0	1213.7	4.3
Baringo	1525.0	50813.0	420.2	1714.0	25909.0	513.7	1707.0	26803.0	611.9	2.2
Uasin-Gishu	986.0	11785.0	135.6	913.0	13531.0	199.3	1145.0	28025.0	541.3	1.9
Nandi	301.0	5954.0	140.6	471.0	9220.0	188.4	547.0	10983.0	329.5	1.2
Others	4925.1	89208.9	806.5	5116.0	88087.2	887.8	6329.05	58507.4	919.2	3.3
Totals	**124,269**	**159,3913**	**22,290**	**116,686**	**1,546,000**	**20,423.7**	**139,532**	**2,064,544**	**28,249.8**	**100.0**

Source: Ministry of Agriculture Horticulture Validated Report 2013, Nairobi, Kenya

1.6 Statement of the Problem

In spite of its economic importance to Kenya in terms of food, feed, employment, income and social well-being, ware potato supply is constrained by unavailability of certified seed as planting material at appropriate physiological age. The area under potato has expanded from 87,846 ha in 1990 to 120,000 ha in 2008 and 158,000 ha by 2013 (Janssens *et al.* 2013). At a rate of 2 tons of seed per hectare, the total annual certified seed requirement is estimated to have risen from 175,692 in 1990 to 240,000 and 316,000 tonnes in 2008 and 2013, respectively. Inspite of this, the effective seed potato demand is much lower because farmers renew their seed stocks after every four seasons of planting due to seed degeneration (Lungaho *et al.* 2010). According to Anderson (2010), the major challenge potato faced by growers are increasing field productivity, improving production systems, linking farmers to markets, developing public-private partnership as well as creating and enhancing public awareness on potato as a global food security crop.

Seed potato production and supply was once the preserve of state farms held by ADC in the highlands of Central Rift and Central Provinces. These large tracks of farms were the ones owned by white farmers but reverted to government soon after Independence in 1963. In the 1970s and 1980s, the supply of certified seed potato was well organized. The ADC would produce all certified seed on these farms while the breeders' seed came from public research station (Tigoni and its sub centres). Marketing was by KFA through it nationwide network of stores with the railways serving as means of delivery. The mid-1980s and 1990s saw these state farms sub divided and given out to individuals. This resulted in further land subdivision by new owners into small parcels and often changed use to non-agricultural, thus creating shortages of suitable land for seed production.

Consequently, the ware producers resorted to use of farm saved seeds/road site purchases which status cannot be ascertained. Lack of adequate suitable land also led to reduced rotation period and compounded by recycling of seed tubers thus enhancing disease build up leading to low yields (GIZ-PSDA, 2011). Other challenges of seed potato shortages include the short interval between harvest of the long rains season crop and planting of the second crop which forces farmers to use physiologically young tubers resulting in poor crop establishment and ultimately low yields. Use of chemicals like ‘rindite’ to break dormancy and promote sprouting has been discontinued because they are environmentally hazardous leaving the only viable option of long storage for seed to be physiologically ready for planting in the following season. The shortage of suitable land for seed production has necessitated the search for areas to bulk potato seed in the North Rift where potatoes have not been extensively grown (Kwambai and Komen, 2010). Although this area has some disease free areas, current varieties were not evaluated in this region. In fact, the traits of interest have been tuber yield, disease resistance, adaptability but rarely on various market niches. Furthermore, research on storage has not been extensively documented for both seed potatoes and ware at farm level. In depth studies are required on how small scale farmers may store their potatoes at farm level awaiting better prices or preparing for planting. There is also limited information on determining when various growth stages such as plant emergence, first sprays, plant stand (plant population), top dressing, haulm killing and harvesting should be taken. These would help in planning for timely operation for better results.

Justification of the study

Potato value chain employs over 2.5 million people (Anon, 2009) with approximately 800,000 growing the crop on about 158,000 hectares annually as subsistence, commercial ware or seed. The average yield is less than 10 tons per hectare (GIZ-PSDA, 2011). This requires over 316,000 metric tons of well-sprouted seed tubers on a regular basis. However, supply of certified or disease free seeds at appropriate physiological age is constrained by the tuber multiplication methods, production sites and short period for breaking dormancy between harvest and the next planting season which is hardly more than 30 days. According to Anderson, (2010) the demand for certified seed potato in Kenya is 99 % compared to China (40 %) while in UK (34 %) and The Netherlands (1%). Attempts in the recent past by the Ministry of Agriculture to introduce seed potato production in the North Rift region found that seed for the short season is not physiologically ready for planting yet if kept to the next long rainy season planting (approximately 8 months), the seed will be senile, exposed to aphid and tuber moth attack (Kwambai and Komen, 2010). Such seeds have low vigour, less uniform stand, small foliage, low harvest index, and mature early resulting in low yields.

The Ministry of Agriculture with a support from GTZ, the predecessor of GIZ brought together all stakeholders and developed the Potato Policy in 2005 which among other issues handled include improved potato productivity, increased quantities of certified seed and release of more potato varieties suitable to specific market niches. Limited information is, however, available on the suitability of these varieties. This Policy document is consistent with global, national and agriculture sector policies such as The Millennium Development Goal (MDG1) on Eradication of Extreme Poverty and Hunger by 2015; The Economic Recovery Strategy for Wealth and Employment Creation (ERS) 2003-2007 as well as the strategy for Revitalizing Agriculture (SRA) 2004 - 2014 which emphasises the role of potato as an important food crop (MOA, 2005) and the Vision 2030.

Potato has spread into relatively warmer, humid climates that harbour pest and diseases not encountered in traditional production areas such as the highlands where farmers retain a substantial part of their harvest to use as seed in the subsequent planting season (Lungaho *et al.* 2010). Commercial potato varieties where mainly evaluated for yields, disease resistance and less on tuber qualities and dormancy period. Recent changes in weather patterns require varieties which mature early and with limited amount of precipitation or supplementary irrigation, where possible. Currently, there are only few varieties released by KALRO which are under seed certification (Kabira, 2000). However, no National Performance Trial sites of these potatoes varieties were conducted in the North Rift yet the area has favourable conditions for seed production (KEPHIS, 2010). It is imperative to evaluate potato varieties to know the suitable ones in the region before availing seed of suitable varieties at appropriate qualities and physiological age to farmers for planting on a regular basis.

1.7 Objectives

Overall Objective

To identify suitable variety, site and storage environment for seed potato production in the North Rift region of Kenya

1.7.1 Specific Objectives

1. Identify suitable potato varieties for seed potato production in the North Rift region
2. Identify suitable site for seed potato growing in the North Rift region
3. Determine suitable site and storage environment for seed potato in the North Rift region.

1.7.2 Research hypotheses

Ha. There are differences in seed yield and yield attributes of different potato varieties

Ha. There are differences in seed yield of potato varieties grown at different sites in the North Rift region.

Ha. There are changes in seed tuber quality of potato varieties stored at different storage environments.

CHAPTER TWO

LITERATURE REVIEW

2.1 Propagation of Potato

Worldwide potato is propagated by tuber either planted wholly as in Europe and Africa or cut into pieces as in North America (Vreugdenhil *et al*. 2007). The size of tubers planted ranges from 25 - 60mm (10 - 150 g) when planted whole or up to 100 mm or more (300-400g) when cut. It has been found that bigger tubers give rise to higher yields (Masariramba *et al*. 2012). These tubers are first sprouted to the stage where they have multiple sprouts. Each sprout has the potential of giving rise to a stem and subsequently a number of daughter tubers. According to Struik (2007), the sprouts, which are crucial for the performance of the seed tuber, develop on the seed tuber as it ages. This occurs when the eyes (dormant buds) on the potato tuber surface, give rise to new shoots under suitable conditions after it breaks its dormancy. Growth occurs in sequence with one stage leading chronologically to the next as sprout development, plant establishment, tuber initiation, tuber bulking, and tuber maturation.

2.2 Potato Growth Stages

2.2.1 Sprouting

Freshly harvested potato tubers are dormant and will not sprout even if placed in suitable environmental conditions for growth (Delaplace *et al.* 2008; Mani *et al*. 2014; Sonnewald and Sonnewald, 2014). This stage has been found to be under the influence of both pre- and post-harvest environments (Suttle, 2004) and differs among cultivars.

It takes 18 to 33 weeks to break dormancy but is usually 20 to 23 weeks in supra-optimum temperatures (Anon, 2007). From a biological stand point, seed tuber longevity need not exceed 8–9 months after which, sprout number and vigor drops substantially. Studies by Suttle (2007) and Suttle and Jeffrey (2004) reported that tubers cannot sprout during rest period (5-9 weeks) after harvesting depending on pre-harvest conditions and post-harvest handling. The failure to sprout may be due to dormancy caused by inability of tubers to supply buds with metabolites essential for growth (Baskin and Baskin, 2004); balances of inhibiting and promoting substances or endogenous Abscissic acid (ABA) and Giberrelic acid (GA)(Majeed and Bano, 2006 and Ali-Rached *et al*.2004). This is at a stage in potato life cycle when all sessile organs must cope with adverse environmental conditions by adjusting their physiological status. Salimi *et al.* (2010) and Johansen *et al*. (2008) suggested that seed producers may have to accelerate or retard sprout development depending upon the time of year and the intended market. Plant hormones are generally considered the most important endogenous regulators of tuber dormancy (Mani *et al*. 2012). A widely accepted hypothesis suggests that potato tuber dormancy is controlled by a balance between sprouting promoters and inhibitors. Shift in ratio in favour of promoter leads to release of tubers from dormancy and vice versa (Sorce *et al.* 2009). ABA is thought to be responsible for maintenance of bud dormancy (Mani *et al*. 2012; Suttle *et al.*, 2012), hence the main sprout inhibitor in potato tuber (Ewing *et al*., 2004). According to Sarath *et al*. (2007), Indole acetic acid (IAA) as well as cytokinins and ABA, may be involved in the cessation of apical dominance. Once the dormancy has been broken, tubers sprout even when kept at low temperature.

The duration of apical dominance as well as the number of sprouts per tuber is a varietal characteristic (Carlo *et al*. 2012).

The control of tuber dormancy is fundamental in both seed and ware potatoes (Veerman and Wustman (2005). Storage of tubers in different conditions influences the duration of the dormancy period. Thus, tubers stored in dark conditions result in increased sprouting and number of sprouts per tuber (Menza *et. al*. 2008). However this differs from been Gachango *et al.* (2008) who reported that seed tubers stored under natural diffused light increases sprout number, reduces total storage losses and increases yields due to improved seed vigor. High storage temperature accelerates the physiological ageing processes within the tuber thus reducing the dormancy period whereas cold weather increases dormancy (Muthoni *et al.* 2014). The ending of dormancy is critical in areas where two crops are grown annually as in the Rift Valley. Chemicals like thiourea, ethylene chlorohydrite, rindite and methyl bromide can be used but are dangerous to handle (Pérez and Lira, 2005 and Shibairo *et al*. 2006) or leads to deterioration in quality during potato tuber storage (Mark *et al.* 2008). Rindite, which has previously been in use, is toxic, environmentally unfriendly and a health hazard. Duration to sprouting ends when the longest sprout is 3 mm and is influenced by seed crop husbandry; although the real causes remain obscure (Aksenova *et al*. 2013). It has been established that sprouting begins earlier in warmer conditions (Carlo *et al*. 2002) while the duration from initiation to sprouting is reduced by early defoliation (Warren *et al.* 2000); though the effects are insignificant on dormancy breaking (Shibairo,*et al*. 2006). Manipulation of planting time is potentially effective in altering the onset of sprouting to achieve tubers of appropriate physiological age at the subsequent planting season (Eremeev *et al*. 2008).

In cases where longer sprouts are desired, prolonged sprouting period is necessary. Another way of achieving this is through choice of warm production site, early defoliation and increase in storage temperature (Masarirambi *et al.* 2012). Experiments conducted by Hamouz *et al*. (2005), concluded that potato clones grown in spring had shorter dormancy duration, higher dry matter, starch content, and respiration rates but had lower reducing sugar and total polyphenol content than clones grown in autumn. Furthermore, it has been shown that the dormancy of small tubers is longer than that of the big ones (Vreugdenhil, *et al.* 2007).

High temperature during potato growing, low soil moisture and decreased nitrogen fertilizer application has been found to advance onset of sprout growth in progeny tubers of several varieties (Delapace *et al*. 2008 and Alexopoulos *et al*. (2008). This agrees with the earlier finding by Nora and Andrew (2002) were it appears that the seed growing conditions, in particular the accumulation of heat units, impacts seed tuber physiology on dormancy break. However, before any release of potato variety to farmers, its dormancy period and sprouting behavior should be considered as a major criterion during selection of clones (Viratanen *et al*. 2013)

Storage regime is therefore an important factor that influences length of the dormancy period. Diffused light storage of seed potato in the tropics require 7-8 months to complete sprouting even at lower elevation (Potts, 1983) but tuber moth and aphids are difficult to control. Diffuse light may prevent rapid ageing of seed tubers (Viratanen *et al*. 2013). Seed lots of small size tubers ranging from 60 to 110 g can produce plants with high vigour, increased stem counts, increased tuber set but smaller tubers due to heavier set (Delanoy *et al*. 2003).

2.2.2 Plant emergence and stem development

The number of leaf primordia in the sprouts at planting increases with increasing sprouts length and delay in planting. The rate of sprout growth is linearly related to temperature over a range usually experienced in storage (4 - 6 ^{o}C). Emergence and field growth are affected by sprout growth at planting. This has been confirmed by Allen *et al.* (1991), who showed that increasing physiological tuber age, increases sprout length at planting and hastens emergence, tuber initiation and early leaf growth but produces lower peak leaf area index and often leads to early senescence. The seed tuber plays a major role in growth of crop and thus is crucial to successful potato production. Increasing sprout length and/or late planting results in more below ground nodes per main stem. The storage also affects the number of underground nodes which influence the number of stolons and potential tuber sites.

The rate of plant emergence is influenced by variety and environmental conditions (Allen *et al.* 1991). In cold or dry soils, emergence is slow but rapid in moist warm soils. The effects of high temperatures are primarily manifested on emergence, tuber initiation, net dry matter production and senescence. Soil temperature during the day appears to be more important than at night in regulating plant emergence (Midmore, 1984). The interval from planting to emergence is prolonged by low soil temperature and results in shorter stems and lower leaf area index, thus interfering with the functions and architecture of the plant leading to low yields.

2.2.3 Seed rate and plant density

Conventionally, seed rate is the number of tubers planted per unit area. However, for potatoes, tuber produces sprouts which give rise to primary stems each capable of producing roots, stolons and eventually tubers independent of the other sister sprouts. Main buds usually grow from eyes and ultimately result in complete stem structure which encompasses subterranean scale and above ground leaves, stolons, tubers and terminal floral structures. While crops grown from non-sprouted and heavily sprouted tubers can both achieve complete ground cover, origins of leaves differ as apical differentiation continues during pre-sprouting growth (Oliveira *et al*. 2012). The origin of the two canopies comprising leaves are of quite different architecture and consequently affect tuber yield as is determined by amount of radiation intercepted and efficiencies of its conversion (Getachew *et al*. 2012). Usually after emergence, main stems arising from the seed tuber assume independent existence from the mother plant resulting in a collection of competing stems. Consequently this gives more plants per unit area than the number of seed tubers initially planted. Bussan *et al*. (2007), found a general principle that plant density – yield relationship in potato is specific to variety, location and age of seed tuber. They further found that plant density scale involving stems relates more to tuber yield than the seed rate. From their studies on several varieties, they concluded that stem density was more accurate in establishing plant population per unit area than on the number of seed tubers planted. This allows for easy interpretation of the effects of seed size within- row spacing and seed rate via their effects on stem density. Acceptance of stems as the most appropriate theoretical effective unit rather than seed rate which has limitation had been arrived by Wurr *et al*. (2001) who observed that most stems in commercial crop arise from apical complex as majority of the eyes on seed tuber do not grow. Later, Masarirambi *et al*. (2012) while studying relations between tuber size and stem density found that high stem numbers result from bigger tubers compared to smaller ones at the same physiological age and they concluded that the total yield and yield of smaller tubers increases with the increase in tuber size to a maximum and then decreases. Similar findings had earlier been arrived at by Bussan *et al*. (2007). Reducing with-in row spacing has also similar effects as increasing tuber seed size and generally, large seed tubers produce more stems than small tubers due to more eyes spread over the surface which influence stem arrangement per hill. The differential stem arrangement on a seed tuber gives rise to different stem densities based on the tuber size and its effect is termed clumping. In practice, plant density is manipulated through the number and size of seed tubers planted. A high stem density gives rise to small tubers and reduced number of tubers per plant (Güllüoglu and Arıoglu, 2009). The number of main stems per seed tuber is determined at an early stage and it increases slowly for almost two months after emergence. The optimum stem density (plants/ha) influences the tuber sizes per plant and hence the market for which the harvest is destined (Shayanowako *et al*. 2014). According to field trials by Roy *et al*. 2015indicate that the total tuber yields is influenced by the size of the seed tuber used.

With adequate precipitation and sunshine, emerged plants give rise to several stems (primary and adventitious). Primary stems originate from the seed tuber while the others branch from the latter below the soil surface. When conditions are ideal and plants are widely spaced, secondary stems may arise from both the primary and the adventitious stems. Normally the number of stems per plant ranges from 3-6 and rarely 9. Each node on the stem give rises to leaves which at emergence are simple and the later ones are compound which are acropetally arranged. Each stem ends with a flower and the node below also grows, produces flowers and repeats until maturity. Depending on the variety, physiological state of the tuber at planting, complete ground cover occurs from 45- 50 days (Getachew *et al*. 2012).

2.2.4 Tuber initiation

When tubers are grown under appropriate conditions, a stage will reach when tuber initiation takes place. When tips of stolons form "hook" like growth and begin to swell, it is the tuber initiation phase (Alisdair and Willmitzer, 2001). This occurs when stolons start swelling and go through different phases of tuber set, tuber growth and tuber maturation. Stolons are diageotropic (or plagiotropic) shoots or stems, with strongly elongated internodes and rudimentary (scale) leaves. Three stolons per node may arise; one main stolon and two from the axillary buds at the same node. Stolonization starts at the nodes proximal to the seed tuber and progresses acropetally; growing faster and longer than later initiated ones (Kloosterman and Bachem, 2014). For many cultivars, this occurs during early flowering, although there is no causal relationship between the two events. Tuberization is triggered by long cool nights especially of those plants which are from physiologically advanced seed tubers (Jackson, 1999). The number of tubers set by a potato plant is determined by variety, stem density, spatial arrangement and environmental conditions. Any increase in stem density over a commercial range results in a reduction in tuber set and the number of tubers per plant which increases despite reduction in number of tubers per stem. Getachew *et al*. (2012) found that high stem density produces tubers with low specific gravity akin to low dry matter content. They further observed that tuber progenies of similar size grown at low stem densities affects tuber size distribution. The number of daughter tubers produced usually depends on the cultivar, stem density and external environmental conditions; many of which are beyond the control of the grower (Wurr *et al*. (2001). Seed of same size and stored at similar conditions will therefore produce significantly different number of tubers in different seasons due to growing conditions during tuber initiation. The final number of tubers to be produced is determined shortly after canopy closure and the end of tuber initiation.

2.2.5 Tuber Bulking

Tuber bulking occurs when tuber growth rates remain relatively constant (referred to as the linear tuber growth phase). It is influenced by solar energy intercepted by the photosynthetic active foliage, respiration, translocation and accumulation in the tubers (Mihovilovich *et al*. 2009). This is the critical growth period for both tuber yield and quality and varies according to varieties (Kleinkopf, 2010). For instance, under optimal growing conditions, Russet Burbank variety in Southern Idaho will typically add about 786 kg per hectare per day (Kleinkopf *et al.* 2003). Similar studies conducted earlier by Beukema and Van der Zaag, 1990 in the Netherlands indicate that tuber bulking rate during favourable conditions can reach 800-1000kg/ha/day. However, any interruption of ideal conditions can result in reduced tuber growth rates and leads to losses in both tuber yield and quality. The photosynthetic activity and duration of the leaf canopy as well as the length of the linear tuber growth phase leads to production of photosynthates at a relatively high rate resulting in maximum rates of tuber bulking. Tuber bulking rate and duration can be influenced by several environmental and cultural factors. Studies in The Czech Republic by Stefl and Juzl, (2002) on the relationship between leaf area index

(LAI) and tuber yield shows that current varieties require high levels of management to maximize on the solar radiation so as to increase dry matter content. These authors further found that tuber yield is determined by net difference of photosynthates and respiration and is influenced by genotypes, the growing conditions of the year and location. Temperature also influences the ultimate tuber yield. Optimum temperatures for tuber bulking usually lie in the range of 14–22 ^{o}C (Timlin *et al*. 2006). High temperature causes reduction in starch content, increase in sucrose content and lowering of the tuber dry matter content (Thornton, 2003).

2.2.6 Tuber Maturation

The final growth stage is maturation where potato vines die back; the skin or periderm thickens and hardens. At this time, specific gravity and hence dry matter has reached the maximum level. This is when most of the free sugars have been converted to starch. Dehaulming is usually done at 75-80 days after planting and 10-20 days before harvesting of potatoes to allow for skin set, especially for mechanical harvesting. This depends on degree of maturity of the crop (Khan *et al*. 2011), type of harvester and soil conditions (Mahmud *et al*. 2009). By knowing how the management activity will affect the plant, growers can make proper decisions that result in maximum tuber number that leads to highest tuber yield and quality at harvest. Potato yields are usually measured in physical weight per unit area. Thus total yield is determined by the length of the growing season and the average tuber production per day (Kleinkopf *et al.* 2003). It also depends on the number of stems per seed tuber; that is the stem density based on the variety, number of viable sprouts planted per unit area, the sprout damage during planting and the growing conditions (Horton, 1987).

2.3 Qualities of the seed potato tuber

These are the sum total of all the characters that determine tuber suitability for the intended purpose e.g. propagation, processing or fresh consumption.

Potatoes are affected by many pests which decimate tuber yields and quality. The causative organisms are air, seed or soil borne pathogens. These pathogens include fungi (*Phytopthora infestans* and *Verticillium dahlia*), bacteria (*Ralstonia solanacearum*) and viruses (Gudmestad *et al*. 2007) and also insects. Seed tubers are the major source of survival structures or inocula that transfer and spread mostly these diseases from one generation to the other. It is aggravated by use of recycled seed from previous harvests on the same field which causes further yield reduction due to degeneration (Gildemacher *et al*. 2007). Thus limiting the number of field multiplication cycles to two or three through seed certification and strict field hygiene has to be followed if health tubers from quality mother plants are to be realised (Geldermann *et al*. 2012). Seed certification minimizes the chances of disease and pest spread by strict field inspection and laboratory tests (GOK, 2012)

2.3.1 Physical and Physiological qualities of potato tuber

Tuber quality characteristics such as tuber colour, tuber size, eye depth, tuber shape and texture are often key factors in variety acceptability by consumers and processors (Mehta *et al*. 2011). Seed certification ensures only those tubers meeting field and laboratory standards are availed to the farmers for further seed multiplication or ware production. These should be tubers of correct size, shape, free from insect damage, physical defects (cracked and malformed shape, feathering/skinning, enlarged lenticels, brown center /

hollow heart and internal necrosis). The seed tubers should be at normal sprouted stage as this will ensure optimum use of other inputs as solar radiation, water and soil nutrients for maximum tuber yield. Seed tubers are classified into different sizes and packed in manageable units usually 50 kg for ease of handling and subsequent planting. Use of large tubers for planting give higher yields compared to small ones especially where soil and weather conditions are unfavourable or shorter growing season (Hossain *et al*. 2011). However, this depends on the physiological age of the tuber at planting. Seed tubers which are too old emerge earlier than those at normal stage, establish faster have small ground cover, mature earlier but results in low yields. The duration to breaking dormancy and the number of sprouts is varietal specific which the farmers need to know beforehand. In Kenya, seed potato is categorized into two sizes as 28-45 mm and 45-60 mm (GOK, 2012).

2.3.2 Chemical composition of the tuber

Potato tuber contains 75 % water and 13–37 % dry matter. Of the dry matter, 13–30 % is carbohydrates and 0.7–4.6 % protein. The protein is high in lysine but low in sulphur-containing amino acids. It also contains 0.02–0.96 % lipids, phosphorous, potassium and calcium (Ferris *et al.* 2001; Farahvash and Iranbakhsh, 2009). It has 17 % vitamin C, 11% riboflavin, 1.2 % niacin, B_1, B_2, phenolic substances and trace minerals (Anon, 2007).

The major component of the potato tuber is starch which constitute approximately 15–20 % by weight of fresh potato; equivalent to 65-80% of the dry weight of tubers (Bertoft and Blennow, 2009), and forms an important factor with regard to the texture of processed potato products (Thygesen *et al*. 2001). The amount of starch content in tubers varies with the variety, location of production, agricultural practices, maturity at harvest and subsequent storage history (Freitas *et al*. 2012; Dolores *et al*. 2009). Starch is a major functional unit of the potato having many applications in biomedical industry and in fermentation for the production of different bio-molecules (Shrikant and Singhal, 2009). Furthermore, starch is found as distinct granules of approximately 10–100 μm in diameter (Hoover, 2001) which are made up by two polysaccharides amylase and amylopectin. The composition of starch is about 21 % amylose and 75 % amylopectin. Normally, amylopectin constitutes 70–80 % by weight (Yusuph *et al*. 2003) regardless of the size of the granules (Noda *et al*. 2005) and is the major component in starches with approximately 4–6% of the linkages are of the β-(1, 6) - type, making it extensively branched. The glucopyranosyl residues are connected through α-(1, 4)-linkages forming chains through β-(1, 6)-branches and at the reducing end-side are linked to similar other chains. These physicochemical properties of potato starch are believed to be influenced by amylose and amylopectin content as well as molecular weight, chain length and its distribution together with phosphorus content (Jane and Chen, 1992).

2.3.3 Processing quality

The potato tuber composition determines the purpose for use. Characteristics such as dry matter content, reducing sugar, discolouration after peeling and/ or cooking, susceptibility to black spot are of considerable importance in potatoes for processing (Freitas *et al*. 2012). Each target market thus, sets specific quality requirements. For example, fresh market considers appearance and cooking quality as of preference by consumers and it depends on the variety, growing conditions, fertilization application and stage of maturity at harvest. Fresh market favour tubers which are consistent in shape and size with good skins that are free of any disease or blemish. Dry matter (DM) above 18-20 % is more susceptible to bruising and may disintegrate when boiled during cooking (Kirkman, 2007). On the other hand processing potatoes need to be evenly shaped and of a standard size and quality. For French fries and crisps, high dry matter content is necessary to achieve a high product yield and low oil content (Gould, 1999). Processing industry specifically requires potatoes with a 20-25 % DM with low reducing sugars. In the UK, potato processing companies consider DM content as a critical component of efficiency. An increase of 0.005 in specific gravity (SG) yields an extra one kilogram of chips per 100 kg finished product (Gould, 1999). Generally, the base factory deliveries are not acceptable if DM is less than 19.5 % (SG = 1.077), for French Fries and 20 % DM (SG = 1.079) for crisps. The upper limits do not apply, though penalties may be incurred for > 25 % DM (SG = 1.103) for French fry making (Kirkman, 2007). In the case of potatoes destined for starch production, varieties with greater than 23 % starch content are required. In fact, the starch quality influences the final paste properties, especially its viscosity.

2.4 Effect of site and post-harvest storage on potato quality

2.4.1 Chemical composition

The quality of potato tubers and products depend mainly on dry matter content and its chemical composition (Burlingame *et al.* 2009). Experiments by Hamouz *et al.* (2005) on the dry matter of tubers at various elevations showed that the variation between tubers grown at lower and higher altitudes was minimal on a three-year average (0.2 %). In the same study, in the one year the results were reverse as DM content at lower altitudes was lower by 1.3%) which were contradictory as they showed higher DM values in lower altitudes by 1.7% compared to those from higher altitudes. However, they attributed to weather conditions at the end of vegetative period. Investigation by Bisognin *et al.* (2008) established that potato tubers grown in spring had higher dry matter content and shorter dormancy than tubers grown in autumn. Other studies by Frančáková *et al*. (2011) found that dry matter content ranged from 20.68% to 25.12% which concurred with those of Kirkman (2007) who found that dry matter was strongly inherited characteristic varietal specific. Dry matter content of the same variety may vary considerably from season to season in the same locality due to differences in the time of planting, soil moisture and temperature (Bentini et *al*. 2006). In fact, Hamouz *et al*. (2005) concluded that temperature probably has the greatest effects. At high temperatures, respiration rates are higher than photosynthesis resulting in faster burning of solids than are formed, hence decreases in dry matter content.

During storage, the chemical composition, mainly carbohydrate, changes to fructose and glucose as dormancy breaking progresses (Burlingame *et al.* 2009). The rate of tuber carbohydrate breakdown depends on the variety and physiological age of tubers at harvesting stage as well as storage condition and duration (Vreugdenhil *et al.* 2007**)**. Bojňanská and Frančáková, (2008) found that mature tubers stored at temperatures of 10 to 20 ^{o}C, had most of their carbohydrates in form of starch. At the same study, dry matter and starch content in tubers decreased after three months of storage but, the dry matter content was still above 20% in spite of variation within varieties. Indeed, the potato starch content is largely determined by soil and climatic conditions which vary during the growing seasons in different years (Burlingame *et al.* 2009).

2.4.2 Specific gravity of potato tuber

The selection of potatoes on the basis of dry matter content or solids is very important to most processors. Yields of French Fries and potato crisps are directly related to dry matter content (Thygesen *et al*. 2001). Dry matter determination can be time consuming but, there is a very high correlation between dry matter and specific gravity (Tesfaye *et al*. (2013). Specific gravity (SG) reckoner readings, has been developed to serve as a yardstick by which quality is assessed. Normally specific gravity readings vary from about 1.055 to 1.095 which correlates with 16.5 % dry matter to 24 % dry matter. However, when potatoes are stored they lose dry matter content and specific gravity. Studies by Freitas *et al*. (2012) recorded a significant decreasing trend in the specific gravity and dry matter contents of the potato tubers stored for 180 days at 12 ^{o}C. This could be attributed to the gradual respiratory biochemical starch breakdown to sugars that is used up to maintain life of the tuber with concurrent production of carbon dioxide and water vapour (Bisognin *et al*. 2008).

2.4.3 Quality changes in potato varieties during storage

Variety, tuber maturity, storage temperature and relative humidity affect tuber weight in storage (Brandt and Olsen, 2007). The loss of water from the tubers during storage causes drastic reduction in weight and quality of potatoes especially at high temperature and on bruised tubers. Mohammad and Housmad (2010) in their studies on effects of temperature on potato respiration and weight loss showed that high temperature promotes tuber deterioration faster than cold condition. Exit of such water is through wounds and sprouts than the skin at a ratio of 1:300:100 (skin: wound: sprout, respectively). Brandt and Olsen, (2007) and Walingo *et al*. (2004) found that weight loss is greater during the early part of the storage season mainly due to higher tuber respiration rates which was approximately 1.5 % in weight at higher storage temperatures during wound healing, transpiration and damage particularly by pests in the tropics. Evaporation depends on the ventilation rate and relative humidity (Small and Pahl, 2003). Rate of respiration is a varietal characteristic and is higher for smaller tubers than large ones (Hunter, 1986). This occurs when oxygen from the surrounding is absorbed and used in biochemical breakdown of carbohydrates in the tuber to water, heat and carbon dioxide. It is influenced by maturity of the tuber, sugar content and bruises during harvesting. Studies by Beukema and Van der Zaag (1990) showed that freshly harvested immature tubers can produce up to 400 kj/kg /hr at 20 ^{o} C in the first two weeks before they stabilize. However, some varieties are more prone than others (Brandt *et al.* 2010**).** In the first one month of storage, tubers can lose 0.3 % of the dry matter content and gain 0.15% weight due to water produced during respiration. If respiration was the only source of net weight loss, a tuber with 22 % DM would after one month have DM of 21.1 % and six months later, 20.4 %. Water loss is also occurring during storage thus DM need not therefore decrease. Studies by Gachango *et al*. (2008) on tuber storage, found that those kept in direct light had the highest mean weight loss, followed by those under diffused light. Dutch Robjin had the lowest mean weight loss (4.49 %) after 12 weeks of storage. In terms of the number of sprouted tubers, Dutch Robjin had the least (85.83 %) by the 4th week of storage while Asante and Tigoni had over 95 % of sprouted tubers. Asante and Tigoni lost more weight compared to Dutch Robjin. Both Asante and Tigoni have smooth light skin and low dry matter, while Dutch Robjin is rather rough skinned and has high dry matter content (Gachango *et al*. 2008). In a good storage environment dry matter levels will remain fairly constant (Tesfaye *et al*. (2013). Thus, it is imperative to know the purpose of the storage, duration, maturity of tubers and handling methods as storage life of tubers depends on storage temperature, the variety and quality of the tuber. Of the factors determining the amount of reducing sugars in storage and hence suitability for processing, variety is the most important followed by maturity. Tuber maturity is very important for sugar content at the beginning of storage period and variation in that content during storage determines potato quality for processing.

2.4.4 Determination of major potato tuber solids

According to Norgia *et al.* (2008), there are chemical methods for determining the composition of potato tubers. However, there is a faster way of determining, which relies on estimating DM indirectly, from specific gravity measurements, using empirical conversion factors (Gould, 1995). The Specific gravity is calculated, from the potatoes being weighed first in air and in water and recording. Then the following equation is computed:

Specific gravity = (weight in air) ÷ [(weight in air) - (weight in water)]

It had been established earlier by Talburt and Smith, (1959) that the specific gravity of potatoes and other plant tissues is closely related to dry matter (correlation coefficient 0.9371), and can be determined using the following formula:

% Dry Matter = (24.182 ± 0.035) + (211.04 ± 3.33) (SG –1.0988); where 24.182 ± 0.035, 211.04 ± 3.33 and 1.0988 are constants.

Ten (10) kg potato tubers are weighed in air and in water. Percent dry matter is determined according to Gould (1995)

For starch content estimate, the same was done using specific gravity method as provided by Norgia *et al.* (2008),

Starch content estimate (%) =17.546+199.07(SG-1.0988) where

17.546+199.07 and 1.0988 are constants.

The storage was thereafter computed for dry matter and starch content.

CHAPTER THREE

MATERIALS AND METHODS

3.1 General Description of the Experimental Sites

The first site for the study was Kitale in the North Rift of Kenya, Trans Nzoia County. The County is predominantly agricultural and receives high rainfall in the months of April and tails off in July- August with short rains falling from September to early November. Rainfall is generally reliable in most parts of the county; however, to the north, rainfall is low and erratic. The area experience frequent clear skies with cloud cover during rainy seasons. However, as the rains is over sunshine prevails and occasional hailstones in June and late September. Night temperatures are moderate while day temperature averages 25 ^{o} C.

Soils are silt- loam interspersed with clay loam. The area has deep friable and easily drainable with good water holding capacity. The terrain is gentle slope with limited water logging.

The other two sites namely: Kapcherop and Kibigos are in Elgeyo Marakwet County. Kapcherop site is on leeward site of Cherang'any Hills. The area has deep fertile loam to clay loam soil; fairly well drained. The terrain is rugged and steep. These areas have two rainy seasons; the long rains start late March and reaches the peak in July ending around August. The short rains, often not reliable, fall from late September to early November. Kapcherop experiences cold nights (less than 10 ^{o} C) in July; day time temperature rarely exceeds 22 ^{o} C. During rainy seasons, the area is prone to hailstones in June-July as well as in September. Although temperatures are low, the area does not experience frost but is over cast and foggy during rainy seasons.

Kibigos is on the enclave of the tip of Cherang'any Hills on the leeward site. The soils are black clayey and of mountainous nature, easily workable, well drained with good moisture retention. Erosion is a major threat to bare soils unless covered by vegetation. Both night and day time temperatures are lower than at Kapcherop. During the rainy season the area experiences serious day time overcast with high relative humidity, a prevalent condition for potato leaf diseases especially late blight. Bacterial wilt is rampant but mostly exhibit latent state due to prevailing cool conditions (Fig. 1).

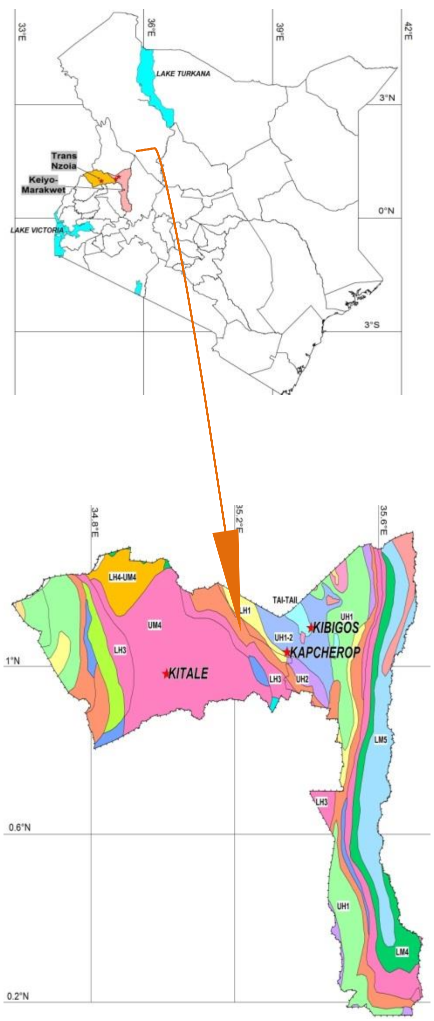


Figure 1: Map of Kenya and an extract indicating Kitale, Kapcherop and Kibigos experimentation sites (red stars)

3.2 Objective 1: Effect of variety on seed yield and yield attributes of potato at Kitale site

3.2.1 Geographical location and Characteristics of Kitale site

The first experiment was conducted at Kenya Plant Health Inspectorate Service farm; Kitale in Trans-Nzoia County at an altitude of 1901 metres above sea level (*masl*). The site is situated at 0.98 ^{o} North of the Equator and 35.01 ^{o} East of the Greenwich Meridian. The farm is in Upper Midland 4 (UM 4 Maize-Sunflower Zone), with gentle undulating to undulating slopes between 2 and 8 %. The site has well drained soils which are moderately deep, dark, reddish brown to dark brown, friable and slightly smeary clay, with acid humic topsoil moderate to high fertility ando - humic Nitisols and humic Andosols (Jaetzold *et al*. 2011). It has two rainy seasons; the long and short rains falling in September to mid-October. The long rains which start in April, has high precipitation which comes in torrents mainly in the afternoons with occasional thunderstorms and hailstones towards July. On the other hand, the short rains fall in late September and continue to October before tailing off towards November with isolated incidences of strong winds. Throughout the year, the area has clear skies with few overcast days. The average annual rainfall is between 1,050 – 1,200 mm per annum (mm p.a) and annual mean temperature ranges from 17.4-19.6 ^{o}C (Jaetzold *et al*. 2011).

3.2.2 Seed Preparation

Initial available breeders' seed tubers were sourced from the National Potato Research Centre, Tigoni during the long rains season of 2011. The well sprouted tubers had been graded (46-60 mm) and bagged in nets each weighing 14 kg. Eight varieties namely:

Asante; Dutch Robjin; Kenya Baraka; Kenya Karibu; Kenya Sifa; Tigoni1; Roslin Tana; and Pimpernel were used in the study. Varieties Asante; Kenya Sifa; Kenya Karibu; Dutch Robjin and Pimpernnel are red skinned varieties while Kenya Baraka; Tigoni 1 and Roslin Tana are white skinned (Table 2).

Table 2: Characteristics of Varieties used in the Trials

Variety	**Skin colour**	**Parentage**	**Year released**	**Origin**	**Owner**	**Maturity (days)**	**% DM**	**Yield potential (t ha^{-1})**
Asante	red	378493.15 X 15bk	1998	CIP	KARI	110-120	20-24	40
Tigoni 1	white	378493.15bk X Precoz	1998	CIP	KARI	100-110	20-22	40
Kenya Baraka	white	SDL3680e(18) X SDL3070(4)	1973	Scotland	KARI	120-130	high	35
Pimpernel	red	Bravo x Alpha	1970	Dutch	KARI	150	low	30
Dutch Robjin	red	Rode Star X Preferent	1945	Dutch	KARI	120-130	high	35
Roslin Tana	white	SDL882(5) X 1104e(2)	1974	Scotland	KARI	110-130	low	37
Kenya Sifa	red	unknown	2002	CIP	KARI	120-130	20.8	38
Kenya Karibu	red	CIP676064 (Cruza118) X CIP 800946 (AL-624)	2002	CIP	KARI	130-150	19.5	40

Sources: Kenya Potato Atlas and KARI Information brochures series, 2013

3.2.3 Experimental Design and Field Lay out

The land was ploughed to 30-40 cm using a disc plough and harrowed once. All the grass weeds were raked out and the plot levelled.

Three blocks measuring 21.75 m (inclusive of 0.5 m in between the plots) by 2.5 m were marked along the contour. Plots of 2.5 m were then measured in the blocks which resulted into 8 plots. Furrows were made at 0.75 m apart and a depth of 10 cm in each plot.

Diammonium phosphate fertilizer was applied at the rate of 36 gm. per furrow row of 2.5 m length (equivalent to 75 kg P_2O_5 and 29 kg N per hectare) and mixed with soil (MOA, 2005). The eight varieties were randomized in each plot and block by use of random numbers.

Tubers of each variety were planted at a spacing of 0.25 m in the furrow by orientating the rose end upwards. A total of 50 well sprouted tubers of each variety were planted per plot resulting in eight plots per block. Each plot had 5 rows of ten tubers. The tubers were covered with soil to leave a raised ridge on top. Two rows were planted around the experiment to serve as the guard rows.

The experimental design was Randomized Complete Block Design (RCBD) replicated three times.

3.2.4 Site management

Weed control was done manually with a hoe at 30 and 40 days after planting. During weeding, ridging was done by heaping top soil between the rows to cover lower parts of the stems thus ensuring that the potato plants had sufficient soil to avoid greening and tuber moth damage of the tubers. Control of leaf diseases was done by first spraying twice with Dithane M 45® (protective fungicide) followed once by Ridomil ® (curative) using a knapsack. A total of 5 sprays (two protective followed by one curative and back to protective) were done at 10- 14 day interval depending on the weather condition and disease severity. The heavy the rains and extended humidity, the shorter was the spraying intervals and *vice versa*.

3.2.5 Data Collection and analysis

At specific days during the plant growth, data was collected regarding plant emergence; stand count; leaf ground cover; foliage and tuber yield as follows:

3.2.5.1 Plant emergence

At 27 days after planting, data on number of emerged plants were taken. This was done again at 7 day interval till 56th day after planting. The data was converted to percentages by dividing each day's data by the initial 50 tubers planted per plot and multiplying by 100 and rounding to nearest whole number.

3.2.5.2 Determination of stand count

Stand count was done by counting the number of stems per metre square in the inner three rows at random from two different positions and averaging before recording. This was done, respectively at 42, 49, 56, 63 and 70 days after planting.

3.2.5.3 Leaf ground cover

Leaf ground cover was measured by using a metre square board split into 10 cm by 10 cm squares raised above plants at random within each plot (Fleisher *et al.* 2011). Counting of complete small squares covered by the leaves was done and portions partially covered were estimated to the nearest square. This was done at 42, 49 and 56 days after planting

3.2.5.4 Harvesting and tuber yield determination

At 75 days after planting (when the leaves had turned yellow), dehaulming was done and the foliage per plant from three inner rows were weighed and recorded (Sen, *et al*. 2010). Tubers were then left in the soil for three weeks to harden **(**Bussan, *et al*. 2007).

Harvesting was done by hoeing the plants from inner row below the ridge and lifting the soil gently thus exposing the tubers which were collected per plant. Repeated hoeing, lifting and working the soil ensured that all the tubers were recovered. This was done for all the three inner rows of each variety.

The tubers were then randomly counted and weighed per plant for ten plants. The total weight per plant for ten plants per variety and replicate was recorded. From the same ten plants, the tubers were graded by measuring tuber diameter using a standard gauge into chats (less than 28 mm), size I (28-45 mm), size II (46-60 mm) and ware (more than 60 mm). After sizing, two seed size (grade I and II) tubers were bagged and stored at ambient conditions till adequate sprouting had been achieved. These tubers were to for use as experimental materials for planting in the following season at Kitale, Kapcherop and Kibigos.

3.2.5.5 Determination of harvest index

Dehaulmed foliage per plant from three inner rows in 3.2.5.4 above were weighed and recorded. At harvest, each hill of the potato plant was harvested and weight taken accordingly. In order to determine the harvest index, weight of foliage of each hill was divided with respective tuber weight.

3.2.5.6 Data analysis

The statistical model of the analysis was:

$$Y_{ij} = \mu + \mathcal{R}i + \mathcal{V}j + \mathcal{E}ij$$

Where Y_{ij} is the tuber emergence at different dates, stems per square metre, seed tuber sizes, harvest index, tubers per plant and tuber yield (t/ha),

μ is the general mean,

$\mathcal{R}_i$ is the **i**th Block effects,

$\mathcal{V}_j$ is the **j**th variety effects and

ε_{ij} is the error term.

The generated data per plot were entered in the Excel and analyzed according to Sheffe's statistical procedure (Ott, 1988) using SAS 9.3 Software. Results on Analysis of Variance (ANOVA), Coefficients of Variations (C.V. %) and standard error (S.E) were obtained. Means were separated using Sheffe's method.

3.3 Effect of site and the selected varieties on seed potato production in Kitale, Kapcherop and Kibigos areas

3.3.1 Description of Experimental sites

In the second season, besides Kitale, two additional sites namely Kapcherop and Kibigos in Marakwet Sub-county of Elgeyo Marakwet County, approximately 36km and 58 km to the east of Kitale, were used in the study.

Kapcherop site lies 1.04^{o} N and 35.35^{o} E at an altitude of 2387metres above sea level. The area receives 1,200-1,700 mm of rain per annum and has a mean annual temperature of 15.0 ^{o}C. Kibigos, on the other hand lies 1.09 ^{0} N and 35.41 ^{0} E at altitude of 2886 metres above sea level and receive 1,050-1,250 mm rains annually with annual mean temperature of 12.4 ^{o} C. Both sites are situated on Cherang'any Hills which have an undulating plateau about 2,200 m high, with some ridges as higher as 3,365 metres above sea level, mainly on the upper limit of the agriculturally usable Upper Highland Zones. The Cherang'any Hills experience occasional frost nights that may affect seed potatoes, hence the microclimate must be considered when planting. The annual precipitation falls from April to November and may extend to early December with occasional short dry spells in early June and also mid-October. In the months of July and late August, these sites experience day time overcast skies with cool nights and high humidity. According to Jaetzold *et al*. (2011), the soils are of the mountainous to uplands (MU2), well drained, moderately deep, and reddish brown to brown, friable. Cases of stony sandy clay loam, with acid humic *Cambisols*; humic *Nitisols*, dystric *Regosols* and rock outcrops is common. The terrain at both sites is rather steep on the lee ward site of Cherang'any Hills.

3.3.2 Field Lay out, Experimental Design and Statistical Analysis

3.3.2.1 Field lay out and Experimental design

At all the sites, three blocks measuring 8.75 m (inclusive of 0.5 m in between the plots) by 2.5 m along the contour were demarcated. Plots of 1.25 m were then measured in the blocks which resulted in six plots per block. Furrows were then made at 0.75 m apart and to a depth of 10 cm in each plot, after thorough land preparation was done. 25g Diammonium phosphate fertilizer was equally spread along 1.25 m length of the furrows (rate of 27kg N and 75kg P_20_5 per hectare) and mixed with soil. Randomization of the potato varieties were done using random numbers to assign them to plots in the block and replicated three times. Tubers of each variety were planted at a spacing of 0.25 m resulting in five tubers in each furrow and 25 tubers per plot planted with the rose end facing upwards. The tubers were covered by soil to leave a raised ridge on top. Two rows were planted around the experiment as guard rows. The experimental design used was Randomized Complete Block Design with three replications.

3.3.3 Sites management

3.3.3.1 Weed and disease control

Weeds were manually controlled by a hoe at 30 and 40 days after planting each time raising the soils (Lung'aho *et al*., 2006) until the canopy closed. Control of leaf diseases were done by first spraying with Dithane M 45® (protective fungicide) followed by Ridomil® (curative). A total of 6 sprays were done at 7-10 day interval depending on the weather conditions and late blight severity. In overcast days with high rainfall and humidity compounded by cold nights, spraying was done after seven days and when weather was sunny with no rains, it was sprayed at ten days interval.

3.3.4 Data collection and analysis

Data collection was carried out at specific times during plant growth. Parameters considered and data analyses are given in the following sections.

3.3.4.1 Plant emergence

On the 14th day after planting emerged plants were counted in each plot. This was continued every 14 day interval till 42 day after planting.

3.3.4.2 Plant stand count

Plant stand count was done at 56 days after planting. The total number of stems per square metre was counted at random from the inner three rows.

3.3.4.3 Tuber harvesting ,weighing and seed grading

Dehaulming was done at 75 days after planting. Tubers were left in the soil for three weeks to harden and to reduce damage during harvesting.

Harvesting was done by lifting the tubers from the three inner rows. Several repeats by turning the soil and picking exposed tubers ensured complete collection of tubers in each plot. They were then counted per plant and recorded accordingly. This was followed by sorting to remove rotten tubers and only the good ones were sized using standard gauge into chatts (less than 28 mm), size I (28-45 mm), size II (46-60 mm) and ware (> 60mm) (GOK, 2012) and total tuber weight was recorded. Those tubers in seed size grade 28-60 mm were weighed and recorded per plot. The per cent by weight of tubers in seed size category was done by taking the respective weight of tuber in seed size category and dividing by the total tuber weight and multiplying by 100.

3.3.4.4 Data analysis

The statistical model used for the analysis was:

$$Y_{ijk} = \mu + S_i + V_j + S_iV_j + \varepsilon_{ijk}$$

Where $\boldsymbol{Y_{ijk}}$ is the emergence at difference dates, tuber weight and stems per plant,

$\boldsymbol{\mu}$ is the general mean,

$\boldsymbol{S_i}$ is the ith site effect,

$\boldsymbol{V_j}$ is the jth variety effect,

$\boldsymbol{S_iV_j}$ is interaction effects between the ith site and jth variety, and

$\boldsymbol{\varepsilon_{ijk}}$ is the error term.

The data for Kitale, Kapcherop and Kibigos on per cent tuber emergence, mean number of stems per plant, mean numbers of tubers of each size grade and total tuber weight per plot were entered in the Excel and analysed according to Sheffe's statistical procedure using SAS 9.3 Software (SAS, 2011). The Analysis of Variance (ANOVA), Coefficients of Variations (C.V %) and standard error (S.E) were tabulated. Means were separated using Sheffe's method.

Objective 3: Effect of site, storage environment and variety on seed potato quality

3.3.5 Field lay out and Experimental Design

A timber frame was made and the bottom part covered with wire mesh before splitting in to six equal sizes of 1.0 m length by 0.5 m wide and 0.15 m deep to form trays. Two of these trays represent a replicate, thus six of them were made per site. Then three store conditions were created by use of poles. One was to mimic dark environment where all the sites were covered with a dark 1000 mm black polythene sheet around and to the ground surface while the top was covered by iron sheets. The other structure which was to store tubers in diffused light environment, all the sides were made of 15 cm wide timber. The space between one timber and the next was approximately 2.5 cm. The last structure which served as the open environment, all the sites remained open while the roof was covered with iron sheets. At each site, all the trays' timber work was nailed on to three cross frames and the trays were suspended at 1.5 m above the ground.

Ten kilogram seed sized (28-60 mm) potato tubers of each of the 6 varieties (Asante; Tigoni 1; Kenya Karibu; Kenya Baraka; Dutch Robjin and Roslin Tana) were randomly weighed and loaded on to the trays of each storage environments. The experimental design used was Completely Randomized Design replicated two times in each storage environment.

In order to monitor the daily environmental changes during the storage period, a data logger (HOBO® data logger) was installed in between the diffused light structure at each site to monitor temperature and relative humidity. It was put on immediately after loading the trays.

3.3.6 Data collection

Data on tuber weight was done by weighing the ten kg seed potato tubers from each tray air and again when immersed in water. The same tubers were then re- loaded into its tray. This was followed again for the second, third, fourth and fifth times for all the environments at the three sites. The data was collected as follows:

Kitale: 0, 30, 49, 86 and 116 days of storage;

Kapcherop: 0, 31, 48, 95 and 119 days of storage and

Kibigos: 0, 29, 45, 82 and 116 days of storage.

The data was tabulated and averaged, resulting in days for tabulation as follows: 0, 30, 48, 88 and 117 days of storage, respectively. These days of storage were then used in the analysis.

3.3.7 Statistical model for analysis

The statistical model used in the analysis was:

$$Y_{ijkl} = \mu + S_i + E_j + V_k + S_iE_j + S_iV_k + E_jV_k + S_iE_jV_k + \varepsilon_{ijkl}$$

Where Y_{ijkl} is the tuber weight, dry matter and starch content,

μ is overall mean,

S_i is the ith site effect,

E_j is the jth environment effect,

V_k is the kth variety effect,

S_iE_j is the ith site and jth environment interaction effects,

S_iV_k is the ith site and k^{th} variety interaction effects,

E_jV_k is the j^{th} environment and k^{th} variety interaction effects,

$S_iE_jV_k$ are the ith site, j^{th} environment and k^{th} variety interaction effects and

ε_{ijkl} is the error term.

3.3.8 Data analysis

All the collected data were entered in the Excel sheets as follows:

a) Weight of tubers (kg),

b) Per cent estimates of dry matter and

c) Starch content over time during storage.

The data was analysed according to Sheffe's statistical procedure using SAS 9.3 Software. The results of Analysis of Variance (ANOVA), Coefficients of Variations (C.V %), standard error (S.E) were used in reporting the findings. Means were separated according to Sheffe's procedure.

CHAPTER FOUR

RESULTS

4.1 The effect of variety on seed tuber yield and yield attributes of potatoes

The results of tuber yield and tuber distributions of the eight potato varieties are as follow:

4.1.1 Effect of variety on plant emergence over time

At 27 days after planting the percent plant emergence was similar for Dutch Robjin, Kenya Karibu, Kenya Sifa, Tigoni 1 and Roslin Tana but significantly different ($p \leq 0.05$) between Asante and Kenya Baraka. At this time, Pimpernel variety had not emerged. At 35 DAP, Asante, Dutch Robjin, Kenya Karibu, Kenya Sifa, Tigoni and Roslin Tana were similar in percent plant emergence but significantly differed ($p \leq 0.05$) (Table 3) from Kenya Baraka and Pimpernel. From 42 DAP onwards; all varieties other than Pimpernel had fully emerged (Table 3).

Table 3 : Plant emergence (%) of various potato varieties over time

	(Days after planting			
Variety	**27**	**35**	**42**	**56**
Asante	69bc	89a	97a	99a
Dutch Robjin	95a	95a	99a	100a
Kenya Baraka	56c	56c	89a	89a
Kenya Karibu	90ab	90a	99a	99a
Kenya Sifa	89ab	89a	97a	97a
Pimpernel	0d	0d	9b	24b
Roslin Tana	70ab	7 0a	89a	89a
Tigoni 1	94ab	94a	96a	100a
C.V. %	29	12	7	7
S.E.	5.8	2.7	1.8	1.9
SCD	25.7	12.0	15.4	16.3

*: Values with the same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffes's test.

4.1.2 Varietal effects on plant stand (stems/m^2)

Asante, Dutch Robjin, Kenya Karibu, Roslin Tana and Tigoni 1 had similar stand count per metre square but significantly differed ($p \leq 0.05$) from Kenya Sifa, Kenya Baraka and Pimpernel at 42 DAP(Table 4). At 49,56, 63 and 70 DAP, Asante, Dutch Robjin, Kenya Karibu and Tigoni 1 remained statistically similar ($p \leq 0.05$) in respect to plant emergence but differed from Kenya Baraka, Kenya Sifa and Roslin Tana. Pimpernel had the least stem density at 49, 56, 63 and 70 DAP (Table 4).

Table 4 : Plant stand of the varieties at various days after planting

	Stem density/m^2				
Variety	**42 DAP**	**49 DAP**	**56 DAP**	**63 DAP**	**70 DAP**
Asante	30ab	43a	44a	44a	44a
Dutch Robjin	33ab	43a	43a	43a	43a
Kenya Baraka	20c	25b	29c	30d	30c
Kenya Karibu	34a	39ab	39ab	39abc	39ab
Kenya Sifa	27b	30b	33bc	33cd	34bc
Pimpernel	2d	6c	9d	10e	10d
Roslin Tana	29ab	33b	35bc	35bcd	35bc
Tigoni 1	33ab	39ab	40ab	41ab	41ab
C.V. %	21	21	18	18	17
S.E.	3.1	4.0	3.5	3.5	3.3
SCD	6.7	8.5	7.6	7.4	7.7

* Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe's test

4.1.3 Ground cover (%)

Asante, Dutch Robjin and Tigoni 1 were statistically similar ($p \leq 0.05$) in respect to ground cover (over 65 %) at 42 DAP, while the least was Pimpernel followed by Kenya

Baraka, Roslin Tana, Kenya Sifa and Kenya Karibu (Table 5). Seven days later, Asante, Dutch Robjin, Kenya Karibu and Tigoni 1 were statistically similar ($p \leq 0.05$) but deferred from Kenya Sifa and Roslin Tana. Pimpernel and Kenya Baraka had the least ground cover (less than 40%) at 49DAP. However, at 56 DAP, all varieties other than Kenya Barak and Pimpernel had completely covered the ground (Table 5).

Table 5: Ground cover (%) of various potato varieties over time

	Ground cover (%)		
Variety	**42 DAP**	**49 DAP**	**56 DAP**
Asante	73a	100a	100a
Dutch Robjin	64ab	95a	100a
Kenya Baraka	18d	38c	92b
Kenya Karibu	60b	89a	100a
Kenya Sifa	44c	65b	100a
Pimpernel	1e	3d	25c
Roslin Tana	30cd	73b	100a
Tigoni 1	67ab	98a	100a
C.V. %	22	18	6
S.E.	5. 7	7.1	3.0
SCD	12.2	15.3	6.4

*Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe's test.

4.1.4 Varietal effects on tuber size distribution per plant and harvest index

All the varieties had similar number of tubers in chat category ($p \leq 0.05$) (Table 6). Roslin Tana, Tigoni1, Dutch Robjin and Asante had statistically similar ($p \leq 0.05$) but differed from Kenya Karibu, Kenya Baraka, Kenya Sifa, Pimpernel and Kenya Sifa on number of seed tubers per plant in size I (28-45mm) However, in size II (46-60 mm) category, Tigoni 1 was significantly different from the rest of the varieties ($p \leq 0.05$).

Pimpernel did not have any tuber in seed size II category and was comparable to Kenya Baraka. In the ware category (≥60mm), Asante and Kenya Karibu were similar ($p \leq 0.05$) on the number of tubers but significantly differed from Dutch Robjin, Kenya Sifa, pimpernel, Kenya Sifa and Tigoni 1 as well as Roslin Tana ($p \leq 0.05$). When varieties were compared in respect to total number of tubers per plant, Tigoni 1 had the highest (11), followed by Asante (8), Kenya Karibu (8), Dutch Robjin (6) and Roslin Tana (5). Pimpernel had the least (2). Tigoni 1 had the highest number of tubers in the seed size grade (8) followed by Dutch Robjin (5), Asante and Kenya Karibu (4) and the least was Pimpernel (1).

Asante, Dutch Robjin, Roslin Tana and Kenya Sifa were statistically similar ($p \leq 0.05$) (Table 6) with respect to harvest index (HI) but differed from Tigoni 1, Kenya Baraka, and Kenya Karibu. Asante, Dutch Robjin, Kenya Sifa and Roslin Tana had the highest harvest indices while the least was pimpernel (Table 6).

Table 6: Number of tubers per plant of different sizes (mm) and harvest index of varieties grown at Kitale

Variety	<28 mm (Chatts)	28-45 mm (Size I)	46-60 mm (Size II)	>60mm (Ware)	HI
Asante	1a	2ab	2c	3a	0.83a
Dutch Robjin	1a	3a	2c	0d	0.87a
Kenya Baraka	0a	1b	1d	1c	0.68c
Kenya Karibu	1a	1b	3b	3a	0.66c
Kenya Sifa	0a	1b	2c	2b	0.84a
Pimpernel	1a	1b	0e	0d	0.61d
Roslin Tana	0a	2ab	2c	1c	0.86a
Tigoni 1	1a	3a	5a	2b	0.79b
C.V %	95	72	24	45	4
S.E	3.7	6.8	3.0	3.8	0.021
SCD	1.01	1.29	0.76	0.79	0.04

* Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe's test.
** HI: Harvest index

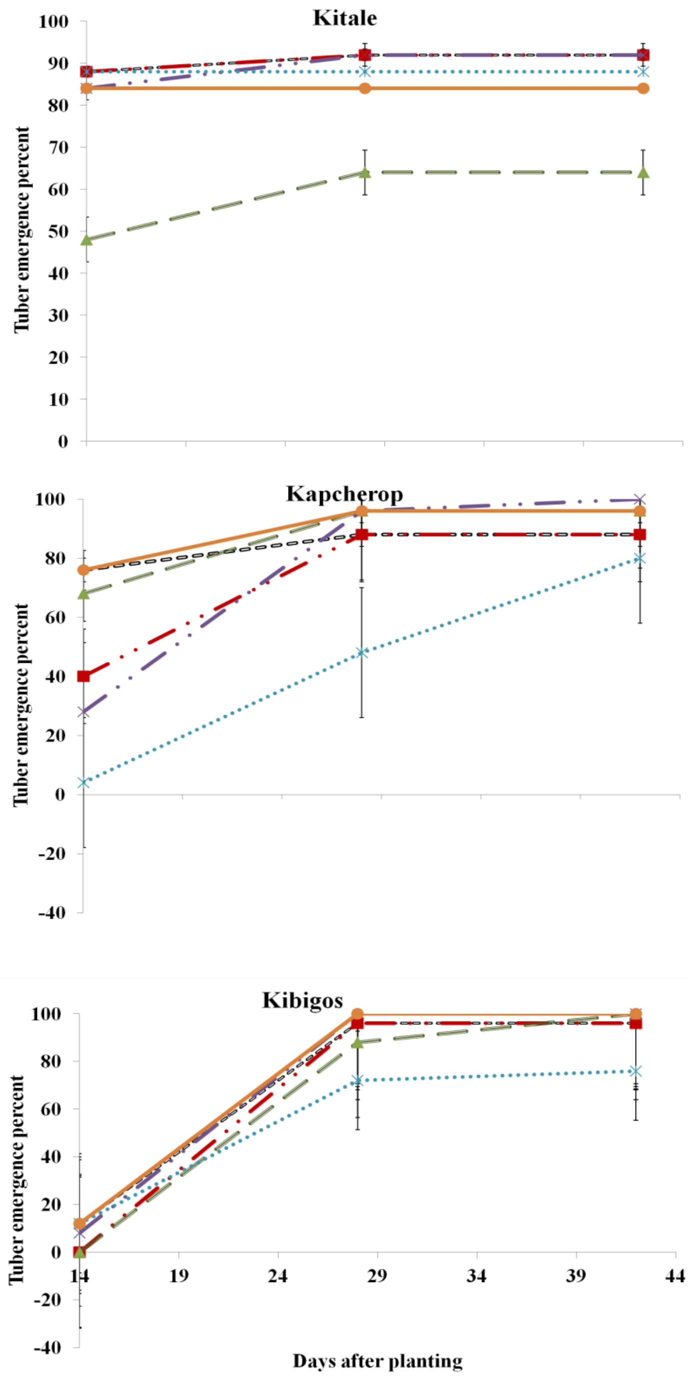
4.2 Performance of potato varieties at the various experimental sites

The results of the potato varieties planted at various sites were as follows:

4.2.1 Site and variety interaction effects on plant emergence

At 14 DAP, other than Kenya Baraka, all other varieties had plant emergence to over 85 % at Kitale while at Kapcherop only Asante and Tigoni 1 had attained over 70 % emergence; the other varieties were below (70%), (Figure 2). However, at this time, those planted in Kibigos had hardly passed 15% plant emergence with Dutch Rojin and Kenya Baraka having not emerged at all. Fourteen days later all these varieties at Kibigos had surpassed Kitale and Kapcherop in per cent plant emergence and by 42 DAP all had reached over 95 % other than Roslin Tana (Figure 2).

In Kibigos site all varieties emerged very slowly. In fact Dutch Robjin had reached over 80% emergence at Kitale, 40% at Kapcherop while at Kibigos it had not emerged. At 28 DAP, only Kenya Baraka and Roslin Tana had emerged to about 40 and 60%, respectively. Two weeks later, it was only Roslin Tana at Kapcherop and Kibigos as well as Kenya Baraka at Kitale which lagged behind the rest of the varieties in respect of this parameter (Figure 2).



Asante, Dutch Robjin, Kenya Baraka, Kenya Karibu, Roslin Tana Tigoni1

Figure 2: Site and variety interaction on plant emergence over time

4.2.2 Effect of sites on seed potato emergence

In the first 14 days after planting, Kitale site had the highest (80 %) plant emergence for all the varieties (Table 7). This was followed by Kapcherop at 48 % while Kibigos had the least (8 %). However, at 28 DAP; site had no significant difference ($p \leq 0.05$) on plant emergence. At 42 DAP, Kibigos and Kapcherop had the highest plant emergence for all the varieties while Kitale had the least (86 %) (Table7).

Table 7: Influence of site on seed potato emergence (%)

	Days after planting		
Site	**14**	**28**	**42**
Kitale	81a	85a	86b
Kapcherop	48b	85a	92a
Kibigos	8c	92a	95a
C.V. %	21	9	10
S.E.	0.6	0.5	0.6
SCD	17.17	7.35	5.76

* Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe's test.

4.2.3 Comparison of number of stems/plant, tuber yield/ha and proportion of tubers in seed size category

Dutch Robjin was significantly diferent ($p \leq 0.05$) from the rest of varieties in the number of stems/ plant while Asante, Tigoni 1, Kenya Karibu, Roslin Tana and were statistically similar ($p \leq 0.05$) but the least was Kenya Baraka (Table 8).

In terms of tuber yield per unit area, Asante, Kenya Karibu and Roslin Tana were statistically similar ($p \leq 0.05$) but differed from Dutch Robjin, Kenya Baraka and Tigoni

1. Consequently, when the percent proportion of tubers in seed size grades (28 -60 mm) were compared, Dutch Robjin, Kenya Karibu and Tigoni 1 were statistically similar ($p \leq 0.05$). This was also true for Asante and Kenya Baraka while Roslin Tana had the least. When all the varieites were compared, the variety that had both high tuber yield and seed size category was Kenya Karibu (Table 8).

Table 8: Influence of variety on the stems/ plant, tuber yield (t/ha) and per cent seed tuber

Variety	Stems/plant	Tuber yield (t/ha)	Seed grade (%) (Size I and II)
Asante	5b	22ab	63bc
Dutch Robjin	8a	16bc	80a
Kenya Baraka	4c	12c	60bc
Kenya Karibu	6b	27a	71ab
Roslin Tana	5b	28a	52c
Tigoni 1	6b	18bc	70ab
C.V %	13	18	14
S.E	0.74	3.7	9.4
SCD	1.23	6.17	15.77

* Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe'stest.

4.2.4 Effects of site and variety on tuber yield

At Kitale, Kenya Karibu was significantly different ($p \leq 0.05$) from the other varieties (Table 9). At the same site Roslin Tana, was significantly different ($p \leq 0.05$) from Asante, Dutch Robjin and Tigoni 1 while Kenya Baraka was the least. At Kapcherop on the other hand, Roslin Tana out performed all the varieties followed by Kenya Karibu and the least was Kenya Baraka. At Kibigos, still Roslin Tana and Kenya Karibu were not significantly different ($p \leq 0.05$) and the lowest tuber yielder was Kenya Baraka. In fact when all varieties were compared, Kenya Karibu had excellent performance across all the sites (Table 9).

Table 9: Interactions between the site and variety on tuber yield (t/ha)

	Tuber yield(t/ha)		
Variety	**Kitale**	**Kapcherop**	**Kibigos**
Asante	21c	22c	22bc
Dutch Robjin	17c	22c	11d
Kenya Baraka	10d	17d	8e
Kenya Karibu	28a	27ab	27ab
Roslin Tana	23b	28a	32a
Tigoni 1	15c	23bc	16cd
C.V. %	18	18	18
S.E.	1.2	1.2	1.2
SCD	2.17	4.13	6.77

* Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe's test.

4.2.5 Comparison of seed tubers per variety and seed size category across the sites

At Kitale site all varieties had over 70 % of tubers in seed sizes category compared to Kapcherop with less that 70 % with Kibigos in between. At Kitale, varieties Dutch Robjin, Asante, Kenya Karibu and Tigoni 1 attained over 80% while the rest were below 75%. At Kapcherop, only Dutch Robjin and Kenya Karibu reached 60% with Kenya Baraka only 40 %. Even at Kibigos, Dutch Robjin and Tigoni 1 averaged above 75% with the former reaching over 80%. Most varieties had the highest percentage in seed sizes category at Kitale site followed by Kibigos and Kapcherop in descending order, respectively. Kenya Karibu, Dutch Robjin, Asante and Tigoni 1 were similar in Kitale but significantly differed ($p \leq 0.05$) from Roslin Tana and Kenya Baraka. This was the same as in Kibigos and Kapcherop for Dutch Robjin and Tigoni 1. The varieties that had the highest per cent seed size category across all the sites were Dutch Robjin and Tigoni 1. The varieties with the lowest tubers in seed size category were Roslin Tana and Kenya Baraka at Kapcherop and Kibigos. Besides, Kitale had the highest tuber yield in seed category while Kapcherop had the least (Table 10).

Table 10: Proportion of tuber yield in seed size category (%) at the experimental sites

	Percent of tubers in seed size grade		
Variety	**Kitale**	**Kapcherop**	**Kibigos**
Asante	82ab	44bc	64b
Dutch Robjin	89a	66a	85a
Kenya Baraka	74b	39c	66b
Kenya Karibu	86ab	61a	66b
Roslin Tana	69b	43bc	50c
Tigoni 1	80ab	54ab	75ab
C.V. %	14	14	14
S.E.	3.2	3.2	3.2
SCD	13.32	12.18	12.18

* Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe's test.

4.3 Seed potato tuber quality changes over time at various sites and store environments

When tubers were stored *in situ* at various environments resulted in changes in their qualities as follows:

4.3.1 Effect of site on seed tuber weight during storage

After 30 DOS tuber weight at all the sites were significantly different ($p \leq 0.05$) and the trend was consistent at 48, 88 and 117 days of storage (Table 11). The highest loss in tuber weight occurred in the first 30 DOS at all the three sites. Those at Kibigos retained most of their weight while those at Kitale lost most weight. The same trend continued to the end of storage period where those at Kitale lost 48% while those at Kapcherop lost 16 % while those at Kibigos lost 10% weight (Table 11).

Table 11: Influence of site on changes in seed tuber weight (kg) over time during storage

Site	**Days of storage**				
	0	30	48	88	117
Kitale	10	7.3c	7.5c	5.8c	5.2c
Kapcherop	10	8.8b	8.5b	8.9b	8.4b
Kibigos	10	9.6a	9.1a	9.3a	9.0a
C.V. %	-	2	5	10	15
S.E.	-	0.03	0.1	0.1	0.2
SCD	0	0.16	0.26	0.26	0.38

* Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe's test.

4.3.2 Effect of storage environments on seed tuber weight (kg)

After 30 DOS tuber weights were statistically similar in open and diffuse but significantly different ($p \leq 0.05$) from dark environments (Table 12). Irrespective of which store environment, weight loss took place in the first 30 DOS. Beyond 30 DOS, seed tubers stored in the diffuse, open and dark environments were statistically similar as at 48DOS and remained having statistically similar weights to the end of experimentation at 117 DOS ($p \leq 0.05$) (Table 12).

Table 12: Effect of storage environment on seed tuber weight (kg) during storage

Environment	Days of storage				
	0	30	48	88	117
Dark	10	8.9a	8.2a	7.9a	7.2a
Diffuse	10	8.5b	8.5a	7.9a	7.6a
Open	10	8.6b	8.4a	8.0a	7.7a
C.V. %	-	2	5	10	15
S.E.	-	0.84	0.86	1.46	1.67
SCD	0	0.25	0.34	0.60	0.68

* Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe's test.

4.3.3 Effect of site and storage environment on seed tuber weight

Weight loss was highest in the first 30 DOS at all the storage environments but thereafter, the loss declined as storage duration progressed. Tubers stored in Kitale lost weight much faster than those stored at Kapcherop and Kibigos, irrespective of which store environments they were kept in. When individual storage environment and site were compared, it shows that those at Kitale continued losing faster weight compared to those stored at Kapcherop and Kibigos, irrespective of store environments. At Kibigos tubers stored better at open and diffuse environments compared to dark while at Kapcherop it was in diffuse and dark environments. At the end of the trial, weight of tubers stored at Kibigos retained more weight followed by those stored Kapcherop and the least at Kitale (Fig. 3). This is further exhibited by the regression equation on the graphs for Kapcherop and Kibigos having fairly similar slopes while Kitale one assumes rapid tuber weight loss in all the store environments (Fig. 3)

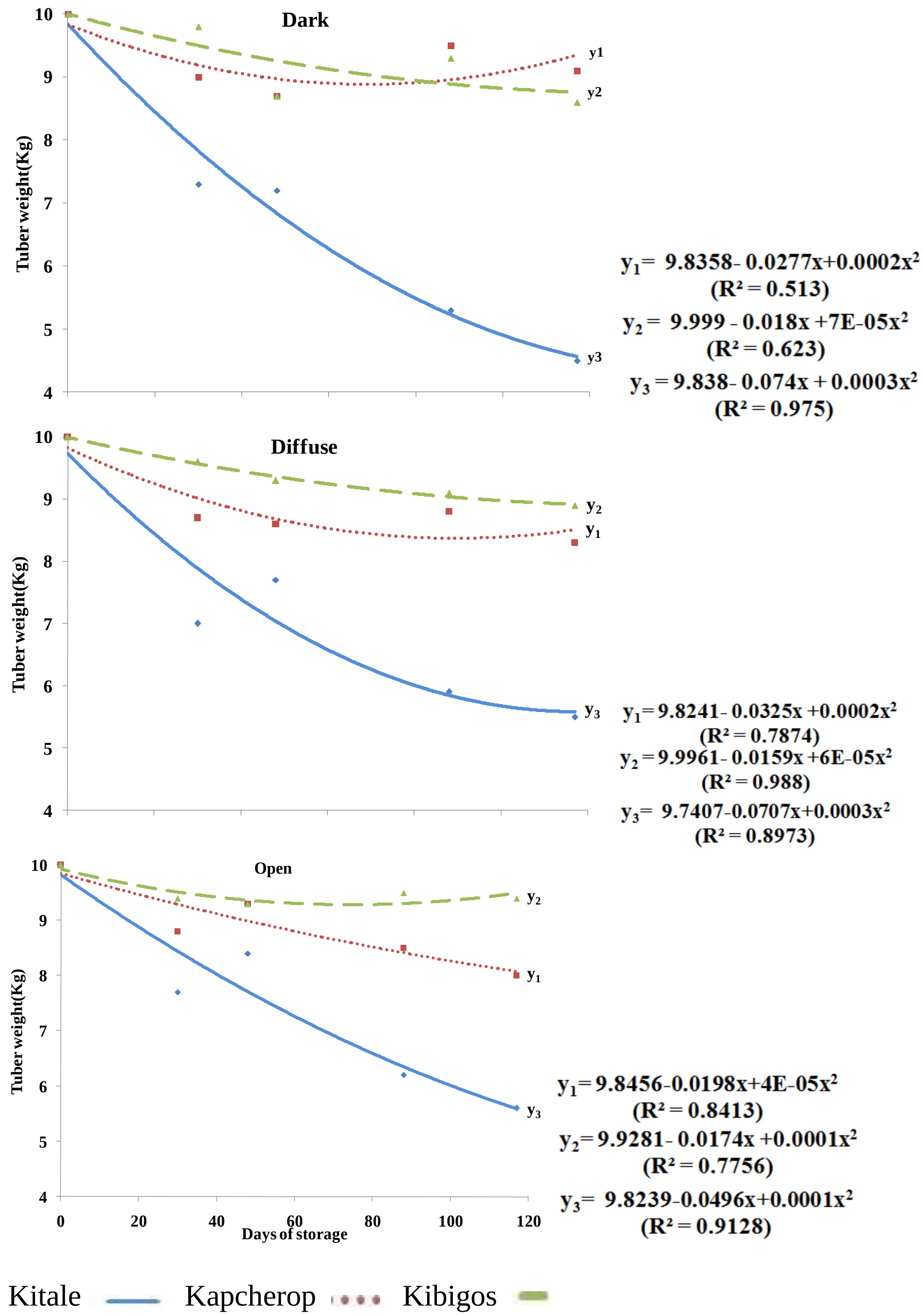


Figure 3: Effect of site and store environment interactions on tuber weight during storage over time

4.3.4 Site and varietal effects on seed tuber weight during storage

Seed potatoes stored at Kitale proportionately lost weight linearly at higher rate compared to Kapcherop and Kibigos. Varieties behaved differently at Kitale and Kibigos compared to Kapcherop in respect to weight loss. When trend is considered, tubers stored at Kapcherop initially decreased at increased loss in weight before assuming curvilinear slope while at Kibigos loss in weight was slow and less curvilinear (Fig.4). The regression equations depict better storage at Kapcherop and Kibigos compared to Kitale beyond 117 DOS

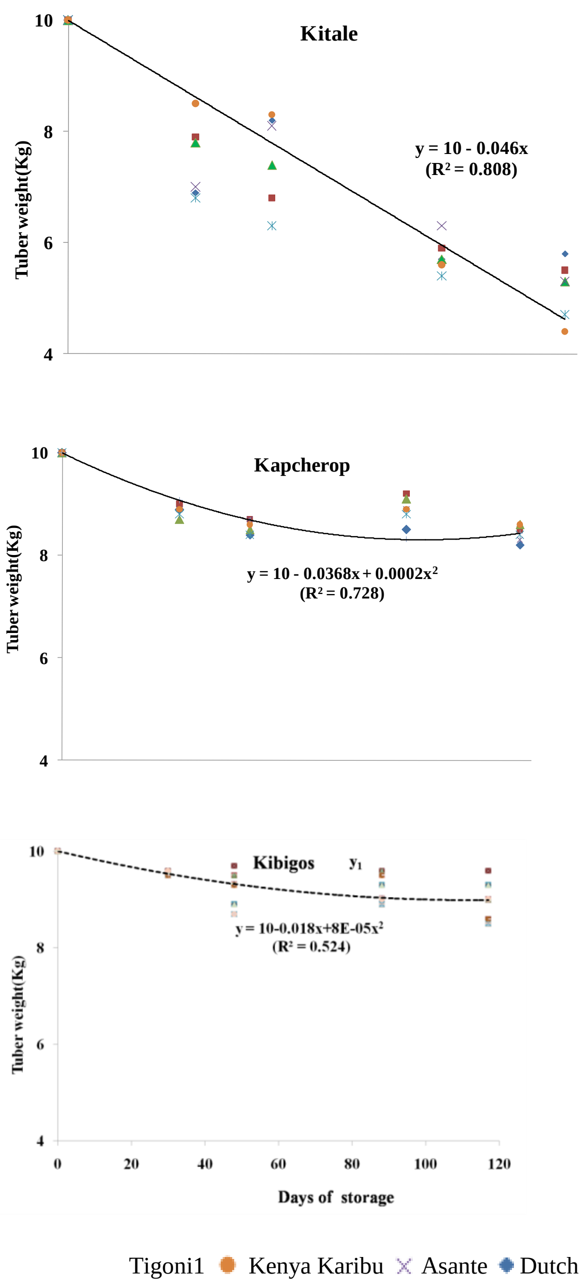


Figure 4: Relationship between site and variety interaction on seed tuber weight during storage

4.3.5 Effect of site on seed tuber dry matter content over time

At the start of storage, tubers at the various sites were significantly different ($p \leq 0.05$) in percent dry matter content (Table 13). Those produced at Kapcherop had highest dry matter content compared to those at Kitale and Kibigos. However, at 30 DOS, percent dry matter content of tubers at Kitale and Kapcherop were statistically similar ($p \leq 0.05$) but differed from those at Kibigos. At 48 DOS tubers stored at Kitale and Kapcherop were statistically superior with regard to dry matter content compared to those at Kibigos and remained so up to 88 DOS. After 88 DOS, effect of site was insignificant ($p \leq 0.05$) (Table 13).

Table 13: Effect of site on seed tuber dry matter content (%) over time

Site	**Days of storage**				
	0	**30**	**48**	**88**	**117**
Kitale	19.4b	16.8b	15.6a	14.1a	12.6a
Kapcherop	19.7a	16.8b	16.0a	13.8a	12.5a
Kibigos	18.9c	17.8a	15.0b	13.3b	12.7a
C.V. %	2	3	4	8	13
S.E.	0.06	0.10	0.11	0.18	0.27
SCD	0.22	0.39	0.40	0.48	0.65

* Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe's test.

4.3.6 Storage environment effects on tuber dry matter content (%)

At the start of storage, all seed tubers were statistically similar ($p \leq 0.05$) in dry matter content. At 48 DOS the dry matter content still in the seed tubers varied from one store environment to the other and continued to 48 DOS. From 88 DOS onwards to completion of the experimentation, there was no significant difference ($p \leq 0.05$) with respect to per cent dry matter content. Tubers stored in the open environment retained much dry matter content compared to the other environments up to 88 DOS. However, storage beyond this period, dry matter content was statistically similar ($p \leq 0.05$) (Table 14).

Table 14: Effects of storage environment on seed tuber dry matter content (%)

	Days of storage				
Environment	**0**	**30**	**48**	**88**	**117**
Dark	19.3a	16.4c	14.7c	13.9a	12.9a
Diffuse	19.4a	17.2b	15.8b	13.6a	12.7a
Open	19.3a	17.8a	16.2a	13.7a	12.3a
C.V. %	2	3	4	8	13
S.E.	0.60	0.93	0.89	1.21	1.57
SCD	0.24	0.38	0.37	0.49	0.63

* Values with same letter along each column are not statistically different at $p \leq 0.05$ according to Sheffe's test

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4.3.7 Changes in seed tuber dry matter content of potato varieties on storage

In the first 30 DOS there was an accelerated loss of dry matter content at the start and as the storage period advances, the loss became gradual. Dutch Robjin had the highest dry matter content and differed from the rest of the varieties at the start of the experiment while, Asante had the least dry matter content from the start of storage and proportionately remained so to the end of storage (Fig.5)

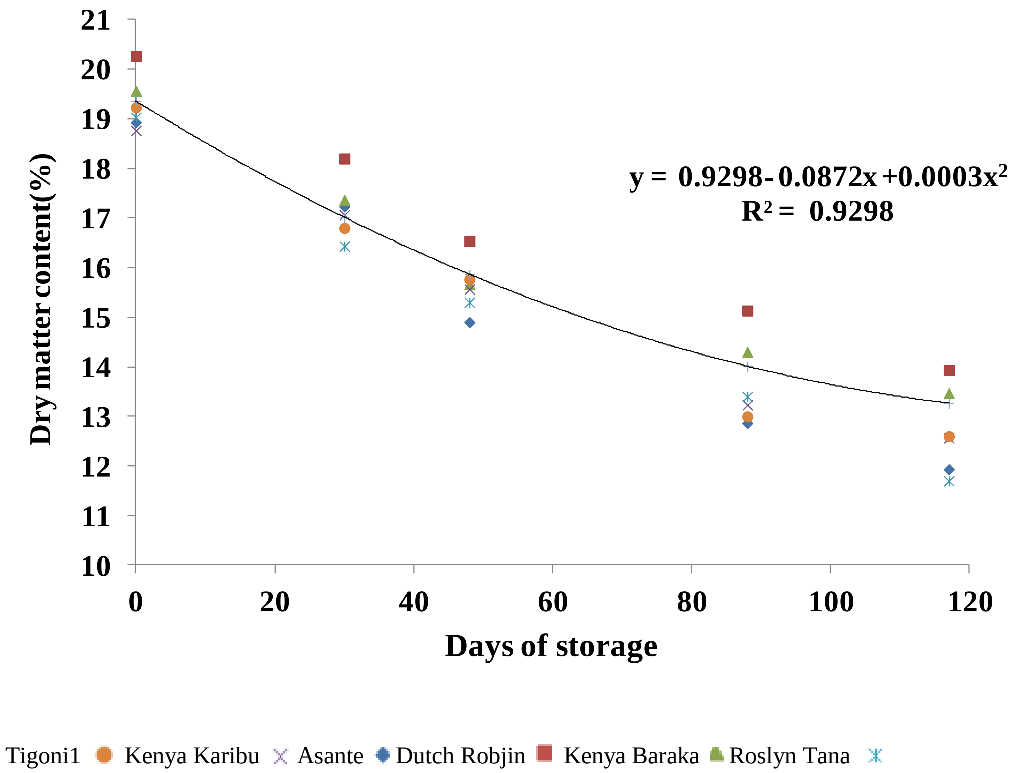


Figure 5: Relationship between potato dry matter content (%) and variety over time

4.3.8 Site and storage environment effects on seed tuber dry matter content

The per cent dry matter content of tubers decreased rapidly in the initial 30 DOS, irrespective of store environment or site. The trend showed a curvilinear decrease of dry matter content with increase in storage time in the dark and diffuse light environments while in the open, the decrease was linear. Those tubers stored in the open environment lost more dry matter content compared to those in the diffuse and dark environment. Overall the store environments and sites, tubers store in the open environment lost dry matter content compared to those in dark and in diffuse (Fig.6). This is supported by the regression equations of Kapcherop and Kibigos, which slopes are similar compared to that of Kitale. Tubers retain most dry matter in the dark store environment than in the diffuse and open, respectively (Fig.6)

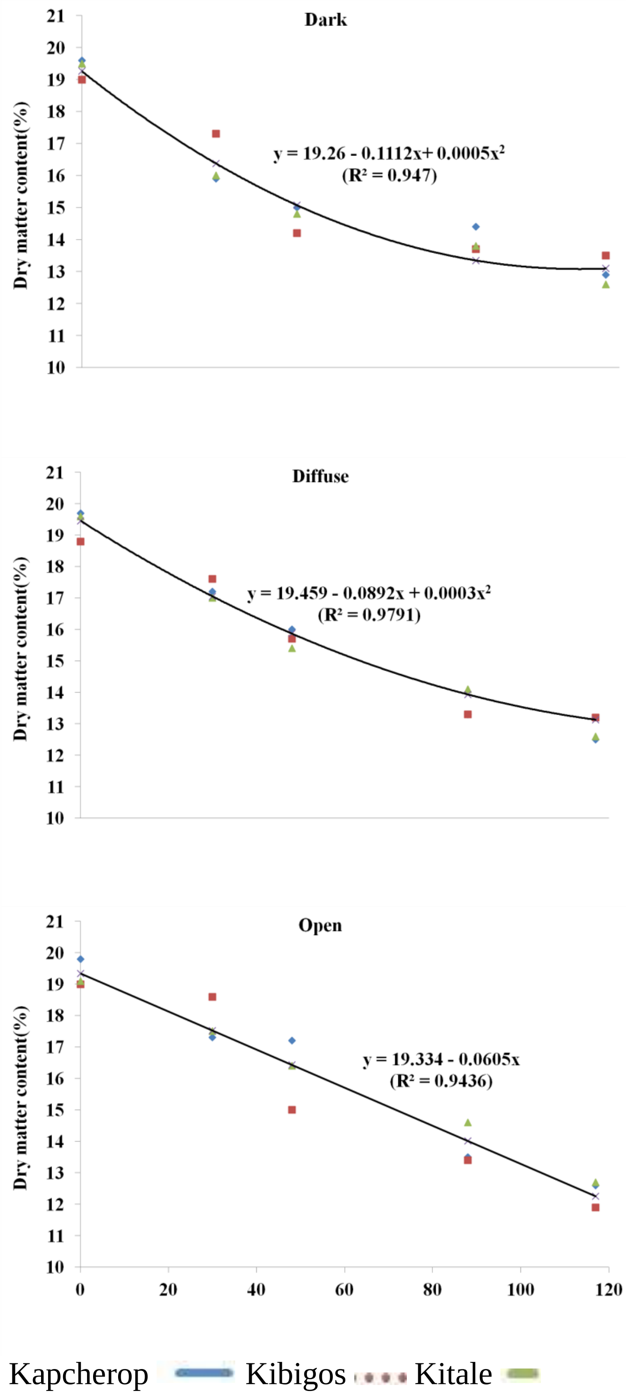


Figure 6: Relationship between site and store environments on dry matter content (%) over time

4.3.9 Effect of site and variety on seed tuber dry matter content

From the start of storage, there is an accelerated loss in dry matter content by all the varieties in the first 30 DOS, irrespective of sites. When sites are considered, tubers stored at Kitale and Kapcherop lost dry matter content more gradual compared to Kibigos. At Kibigos, Dutch Robjin retained high dry matter compared to the rest of varieties. The per cent dry matter content decreased linearly at Kibigos while in Kitale and Kapcherop it was gradually over time of storage (Fig. 7). From the graphs, Kitale and Kapcherop, tubers can be stored longer than 117 DOS compared to Kibigos (Fig. 7).

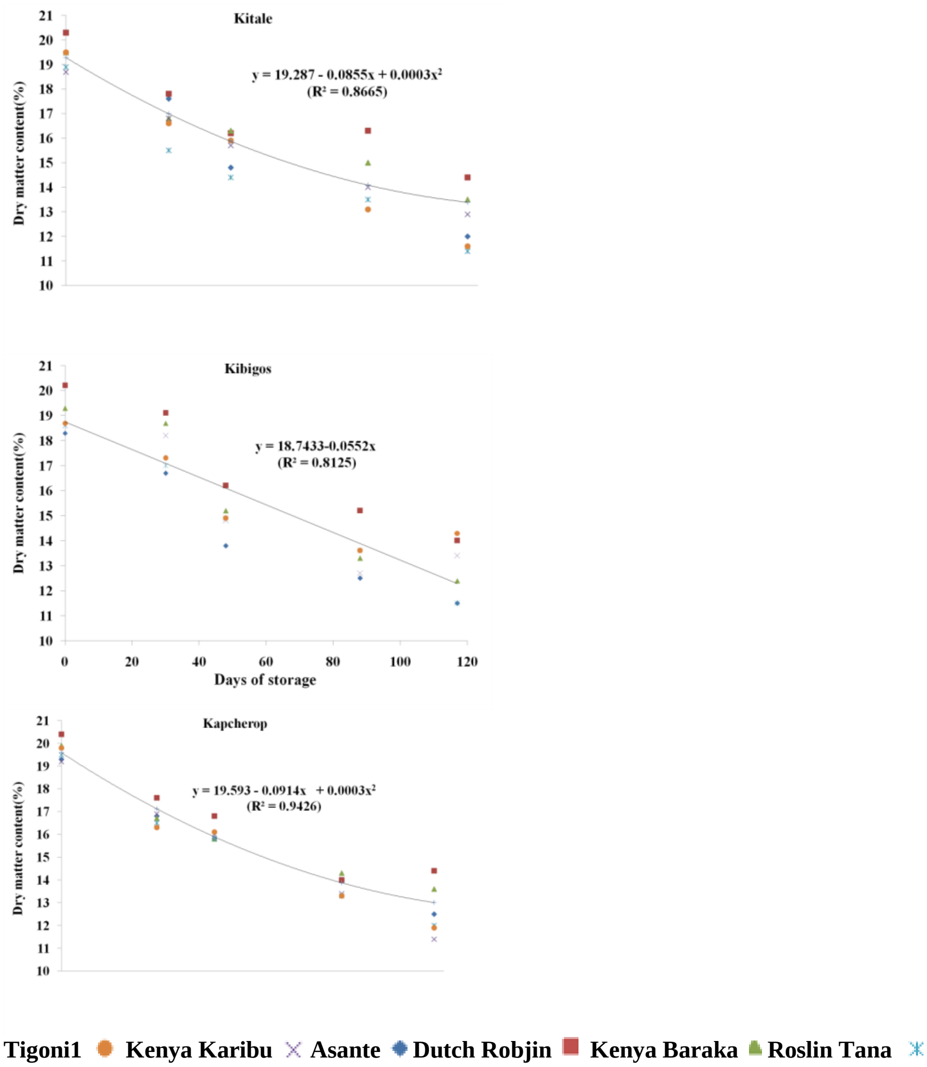


Figure 7: Effect of site and variety interaction on dry matter content (%) over time

4.3.10 Effect of variety and storage environment on seed tuber dry matter content over time

In the first 30 DOS, dry matter content loss of the tubers stored at all the environments was more rapid, irrespective of variety. However, as storage continued, the loss in dry matter was gradual in the dark and diffuse environments while in the open, the loss was linearly to the end of experimentation. In fact, loss in dry matter content was highest by in the tubers stored in the open compared to the ones stored in dark or diffused environments. In terms of varieties, Dutch Robjin had the highest dry matter throughout the experimentation in consideration to the other varieties (Fig. 8). Potato tubers retain more dry matter for a longer time in dark and diffuse environment in comparison with open, as displayed by the regression analysis (Fig. 8).

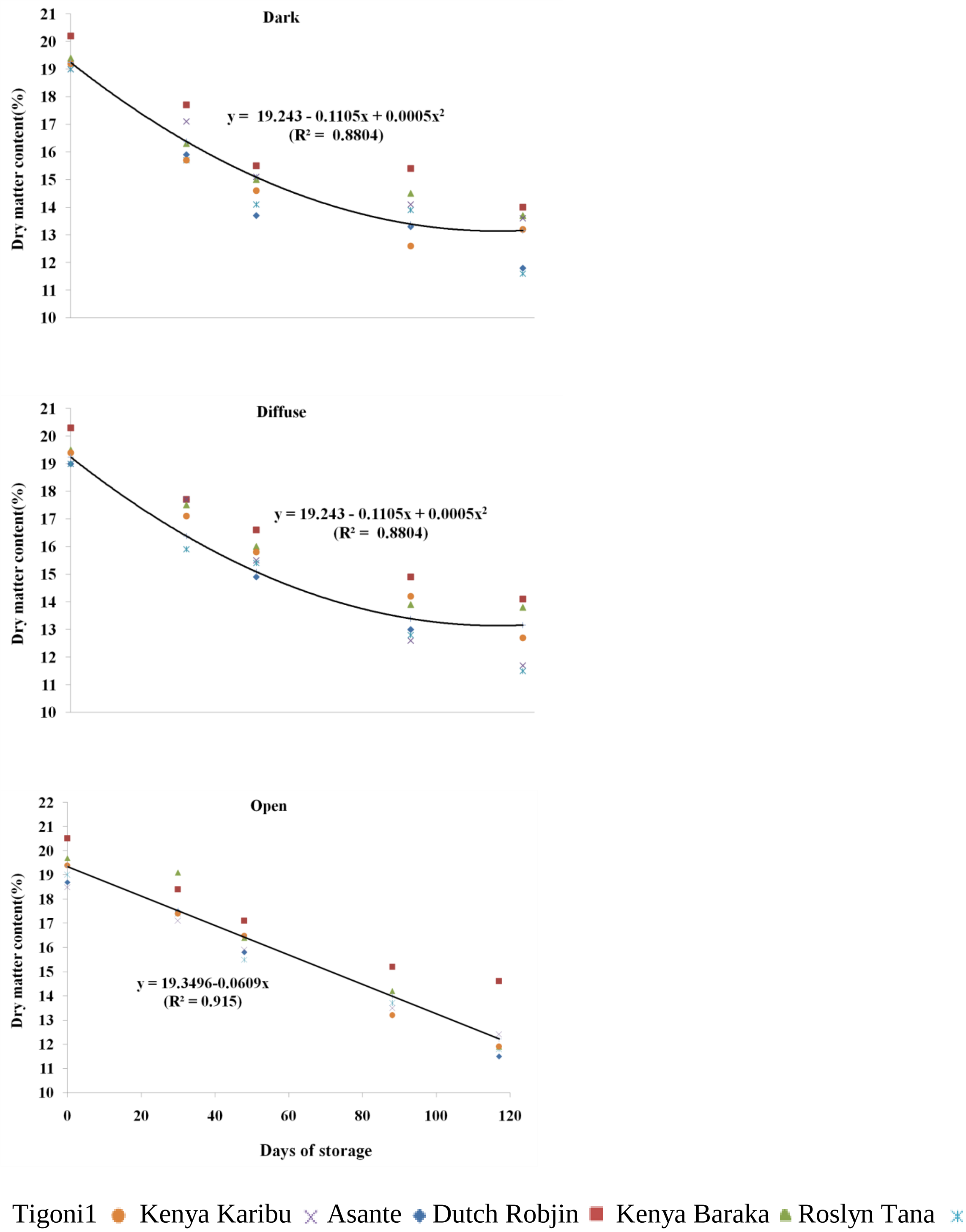
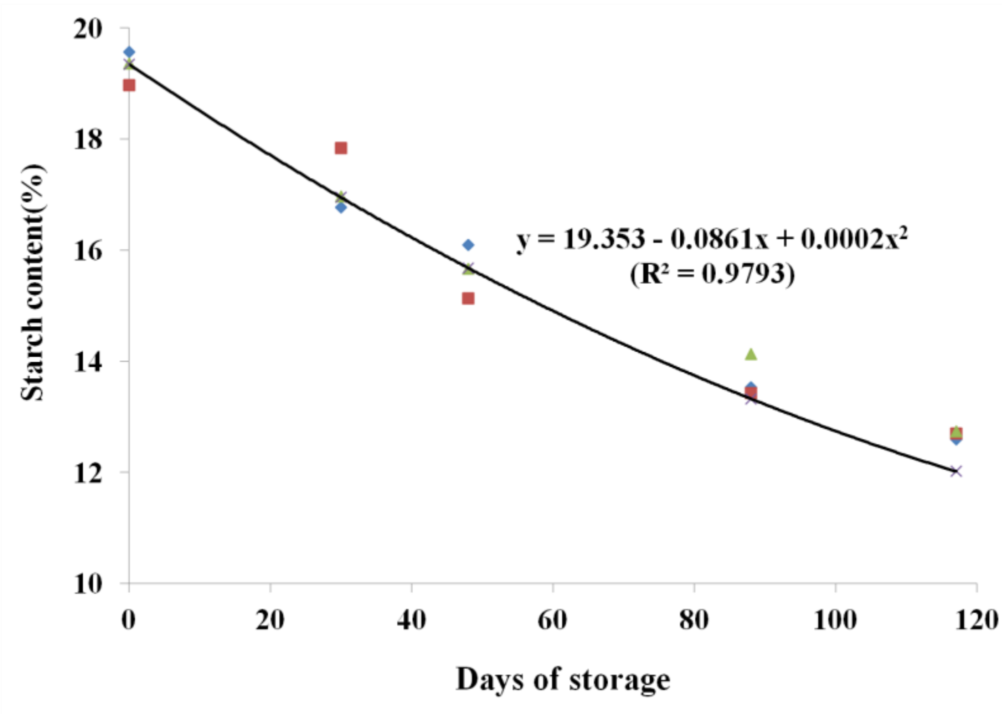


Figure 8: Relationship between variety and store environment on dry matter content (%) over time

4.3.11 Effect of site on seed tuber starch content (%)

Starch content at the start for the varieties was higher for seed tubers produced and stored at Kapcherop compared to those at Kitale and Kibigos but was below 20 %. In the first one month of storage, the loss in starch content was rapid as expressed by the sharp gradient before it gradually slowed down and this continued to the 117 DOS, irrespective of site (Fig.9).



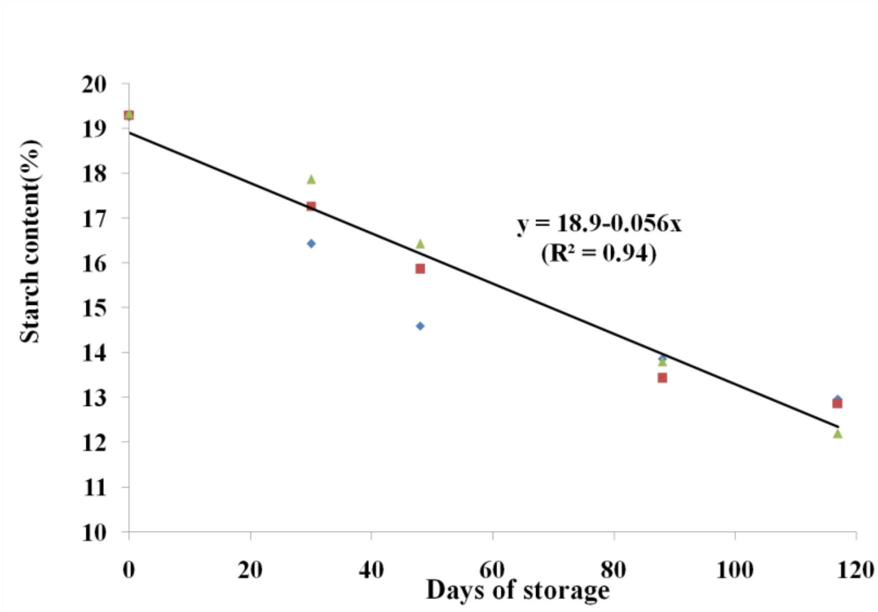
Kapcherop ◆ Kibigos ■ and Kitale ▲

Figure 9: Effect of site on starch content (%) over time

4.3.12 Effect of storage environment on seed tuber starch content

At the start of the experiment, tubers at the storage environments had similar per cent starch content but the loss was rapid in the first 30 DOS in all the store environments.

Progression in starch content loss remained rather constant throughout storage period in all the store environments, as depicted by the regression equation (Fig. 10).

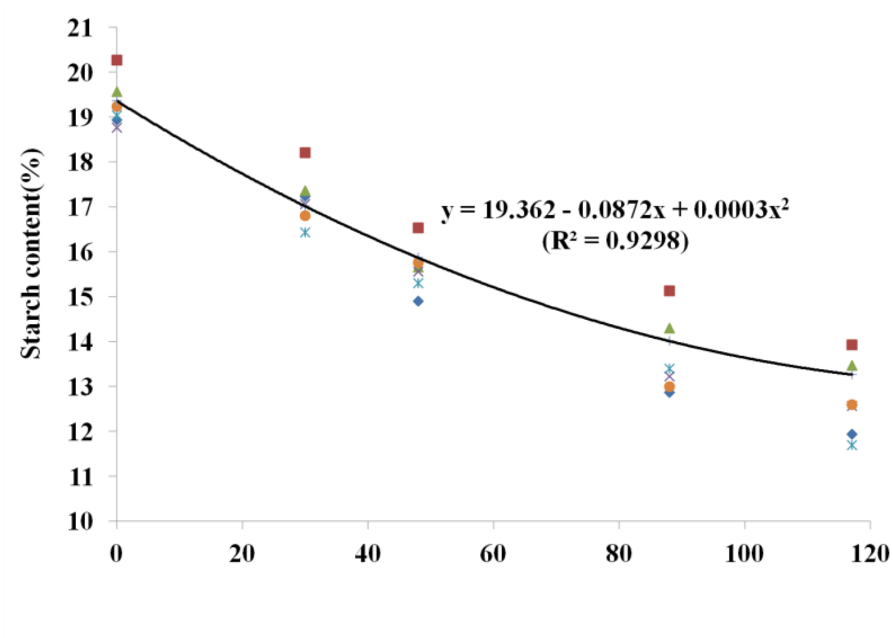


Dark ◆ Diffuse ■ Open ▲

Figure 10: Effect of store environment on starch content (%) over

4.3.13 Effect of variety on starch content during storage

There was accelerated starch content loss in the initial four weeks of storage, notwithstanding which variety was under consideration. Dutch Robjin had the highest starch content at the start of storage while the rest were below 20%. After 30 DOS, the rate of starch loss was gradual to the end of the experimentation (Fig.11).

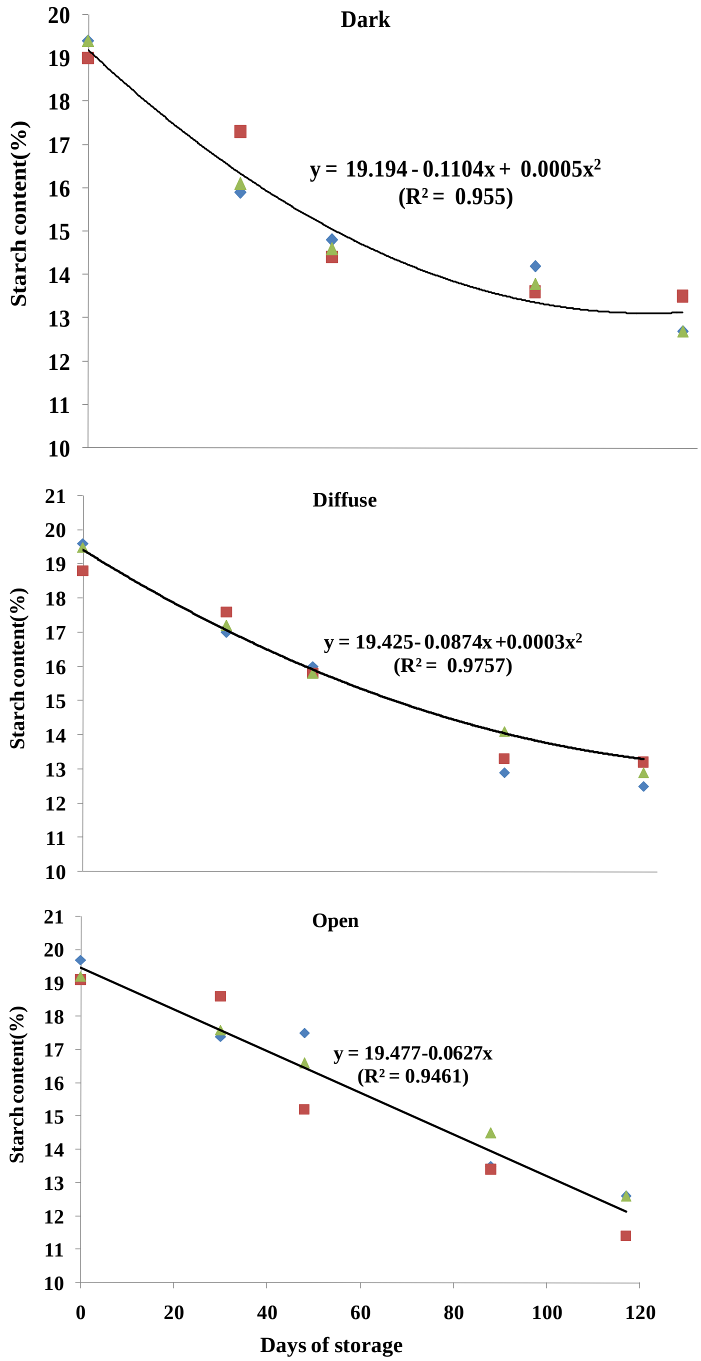


Tigoni1 ● Kenya Karibu × Asante ◆ Dutch Robjin ■ Kenya Baraka ▲ Roslin Tana ✱

Figure 11: Effect of variety on starch content (%) over time

4.3.14 Effect of site and storage environment on seed tuber starch content (%)

In the first 30 DOS, starch content decreased at an increasing rate and continued to 48 DOS at all the store environments. Thereafter, the decrease was gradual in dark and diffuse environments but linearly in the open environment (Fig. 12). As expressed by the regression equations, tubers stored in the dark and diffuse environment retain starch content better than in the open. Of the two store environments, tubers store better in dark than diffuse (Fig. 12)

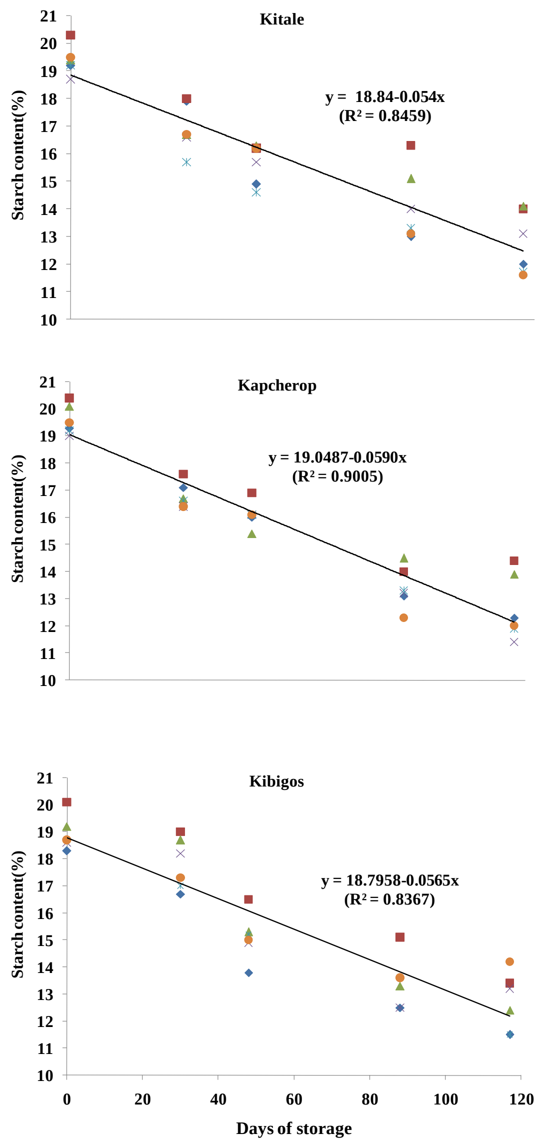


Kapcherop ◆ Kibigos ■ and Kitale ▲

Figure 12: Relationship between site and store environment interaction on starch content (%) over time.

4.3.15 Effect of site and variety on seed tuber starch content (%)

In the first 30DOS of storage, the starch content loss was linear, irrespective of varieties and sites. From 48 DOS till the end of the experimentation at 117 DOS, starch loss similar at all the sites as shown by the similar equation (Fig. 13).

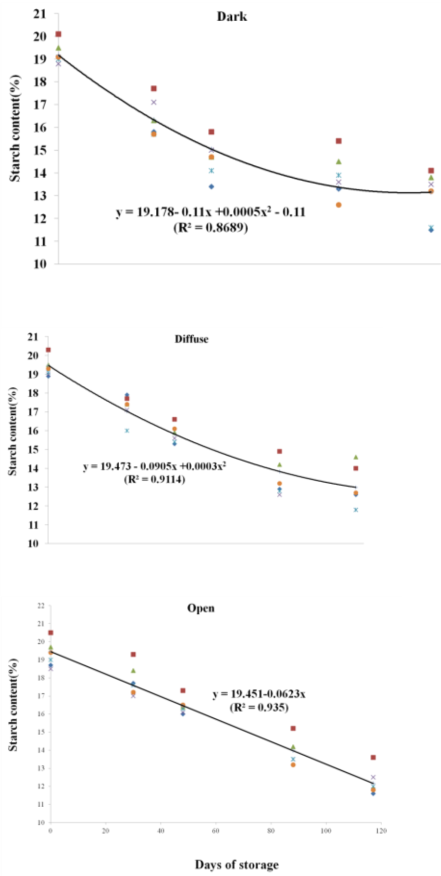


Tigoni1 ● Kenya Karibu × Asante ◆ Dutch Robjin ■ Kenya Baraka ▲ Roslin Tana ✳

Figure 13: Relationship between site and variety interaction on starch content (%) over time.

4.3.16 Effect of variety and store environment on seed tuber starch content (%)

In the first 30 days of storage the starch content loss was rapid in the dark and diffuse environments compared open. In terms of rate of loss of starch content, it increased at decreasing rates in the diffuse environment but more curvilinear in dark whereas more or less constant in the open store environment. This is indicated by the regression equation for the diffuse and dark, respectively. When varieties were considered, Dutch Robjin remained the variety with the highest starch content (Fig. 14).



Tigoni1 ● Kenya Karibu × Asante ◆ Dutch Robjin ■ Kenya Baraka ▲ Roslin Tana ⁎

Figure 14: Relationship between variety and environment interaction on starch content (%) over time.

CHAPTER FIVE

DISCUSSION

5.1 Evaluation of potato varieties in Kenya's North Rift Region

5.1.1 Potato emergence and establishment at Kitale

Plant emergence and crop establishment, despite from same source and of similar tuber size and at physiological state, varied at the initial stages to 27 days after planting. Mean number of plant emergence at Kitale of varieties; Asante, Dutch Robjin, Kenya Karibu, Kenya Sifa, Tigoni 1 and Roslin Tana were higher than for Kenya Baraka and Pimpernel. Tubers of Pimpernel had not emerged even after 35 days since planted when the rest of varieties had attained over 70% other than Kenya Baraka (56%). This differed from the findings of Masarirambi *et al.* (2012) but similar to what findings by Struik (2007). It suggests that Pimpernel tubers are of late maturity class of a cultivar hence delays in emergence rate compared to the other varieties which by the 42 DAP had similar number of plants per plot.

At 42 days after planting, Kenya Karibu had the highest stems per unit square metre (34) Dutch Robjin (33), Tigoni 1 (33) followed by Asante, Roslin Tana, Kenya Baraka and Kenya Sifa. At this time, Pimpernel had a mean value of 2 stem/m^2; suggesting that the tubers were physiologically young. This is in agreement with the findings by Beukema and Van der Zaag (1990) when they compared several Dutch varieties and later, Struik and Wiersema, (1999) who stated that the number of main stems per tuber planted is mainly determined by the seed size, the physiological age and their pre-treatment. Beyond 56 days after planting there is no significant changes in the stem density per unit area and even to the foliage turning stage at 70 DAP when the latter group of varieties when computed to number of stems/ha resulted to over 350,000 stems while, Kenya Sifa and Pimpernel reached 330,000 and 10,000 stems/ha, respectively. This study concurs with Alvin *et al*. (2007), who recommended that the stem density for seed crop be over 300,000 stems per hectare for optimum crop stand and high tuber yields.

In terms of ground cover, some varieties had achieved over 70%; almost plant closure while others like Pimpernel were still far of (1%), at 42 DAP. In fact varieties such as Asante, Dutch Robjin and Tigoni 1 had attained over 64 % when the other varieties were below 50%. The former were the first to reach over 90% ground cover, fourteen days later and at 56DAP when all varieties had almost covered the ground other than Pimpernel. Independent studies by Struik and Wiersema (1999) akin to this experimentation on potato canopy and gross assimilate indicate that the rapid ground cover and leaf duration has much influence on the ultimate tuber yield.

5.1.2 Potato seed tuber distribution and yield of the various varieties

Tigoni 1 and Dutch Robjin had the highest number of tubers per plant in seed size category at 8 and 6, respectively while Pimpernel had only one. However, Pimpernel had highest number of tubers in the chats category. Asante and Kenya Karibu had the highest number of tubers in the ware category (> 60mm). When variety productivity was evaluated, Asante and Tigoni 1 had the highest tuber yield at an equivalent of at 97 and 86 tonnes per hectare, respectively which suggest photosynthetic efficiencies from the rapid row closure and high harvest index gave rise to faster bulking rate. When tuber emergence, ground cover and number of stem per square metre are considered, it shows a direct relationship between the tuber size distributions. Gale *et al*. (2003) stated that tuber bulking period for both yield and quality varies according to variety. Alvin *et al*. (2010)

while studying tuberization, found that the final marketable tuber yield and size distribution of potato tubers were defined by the degree of stolon branching, the duration of the stolon tip swelling period, the ability of the small growing tubers to reach a marketable size and tuber resorption. On the other hand Firman *et al*. (2004) showed that proportion of tubers within the optimum size range could be increased by extending or reducing the period between tuber initiations of seed crop and planting dates of the resulting seeds, respectively.

Harvest index showed that Dutch Robjin, Roslin Tana and Kenya Sifa were much better than Asante, Kenya Karibu, Kenya Baraka and Pimpernel, in that order. All varieties attained value of 0.8, other than Pimpernel (0.6). Vos and Haverkort (2007) stated that potato high harvest index of about0.75, compared with approximately 0.5 for cereals, contributes high water efficiency in areas of low moisture duration. Studies by Stelf and Juzl, (2002) on the relationship between leaf area index and tuber yield found that the number of tubers per plant is a varietal character requiring high level of management. The proportion of tuber weight per plant to total plant weight (harvest index) rarely varied with varieties.

When ground cover rate, stem density, harvest index and seed tuber per plant were compared, all the varieties which had the highest in these parameters produced the highest tubers per unit area whereas those having the fastest ground cover rate but lowest in all the rest were lowest tuber yield.

5.2 Evaluation of potato varieties for seed production in the North Rift Region of Kenya

5.2.1 Potato emergence and plant establishment

All potato varieties emerged faster at Kitale (1901 m) and Kapcherop (2387 m) but slowly in Kibigos (2886m) at 14 DAP. Although emergence was slowest in Kibigos in the first 14 days after planting, two weeks later, emergence had attained the highest per cent compared to Kitate and Kapcherop. This could have been associated with warmer conditions at Kitale compared to cooler conditions at the other sites resulting in tuber breaking dormancy early and advance sprouting, as some were at branching physiological age by the time of planting while at normal sprouted other sites, repsectively. The rapid emergence later at Kibigos and to attain the highest plants stand could have been that tubers were more vigorous while those at Kitale had lost some vigour. In terms of varieties, Kenya Baraka trailed behind the varieties in Kitale and so was Roslin Tana in Kapcherop and Kibigos. This could be due to varietal characteristics which lends credence to Allen *et al.* (1991) on tuber emergence. However, when all the sites were compared this factor was not significant for all the varieties evaluated.

When mean stem densities were compared for varieties at the various sites, Dutch Robjin and Tigoni 1 had the highest number of stems per plant and the least was Kenya Baraka while the rest were in between. When site by site comparison was done, Kitale site had all varieties having the highest stems per plant. This concurs with the findings by Alvin *et al*. (2010) that stem density largely determines the plant population per unit area. Similar findings had been found by Firmann *et al*. (1991) when he stated that after potato plant emergence; main stems arising from the seed tuber assume independent existence from the plant resulting in a collection of competing stems

5.2.2 Potato seed productivity at the various sites

Potato productivity at the various sites showed that Kapcherop had the highest tuber yield followed by Kibigos and Kitale. In terms of varieties, other than Tigoni 1 and Dutch Robjin, the rest did well at all the sites. It suggests that for tuber yield *perse*, Kapcherop would be considered first compared to the other sites. When varieties were considered, Kenya Karibu and Roslin Tana had the highest yield at an equivalent of 28 and 27 t/ha compared to Dutch Robjin and Tigoni 1 at 16 and 18 t/ha, respectively. These findings agree with those earlier. Studies done in Kenya by Lung'aho *et al*. (2006), recorded 29.79 t /ha for variety Kenya Karibu. However, when tuber yield was separated in to various size components, Kitale site had 79.89 % of tubers in seed size compared to 51.20 % for Kapcherop and 67.48 % for Kibigos. In this respect, Kitale was the most suitable site for seed production followed by Kibigos and Kapcherop This could have been due to photosynthates net yield (daily Photosynthesis- respiration), initial physiological stage of the tubers planted at Kitale (already at advance compared to those at other sites - normal or apical dominance) or the net photosynthates (photosynthesis less respiration) which could be lower at Kitale due to higher solar radiation and high temperatures. Dutch Robjin, Kenya Karibu and Tigoni 1 had high stem density which may have competed resulting in small but may tubers.

5.3 The influence of storage at production sites on potato tuber quality

5.3.1 Potato tuber weight changes during storage

During the first 30 days of storage, the weight loss was more rapid compared with later storage period, irrespective of site or store environment. When site by site comparison was done, tubers stored at Kitale lost most weight when in dark and diffuse and less in the open. In Kapcherop and Kibigos tubers retained high tuber weight. The weight loss declined as storage period progressed and by the 117 DOS, those stored in Kitale irrespective of store environments lost most weight compared to the other two sites. This suggests the effect of temperature and relative humidity differences. The high temperature and low relative humidity at Kitale could have contributed to most tubers losing weight during storage while at Kibigos, being cooler with high relative humidity stored tubers better than Kapcherop. As to which store environment was better for tuber storage, it is Kibigos in open and dark. The findings are in agreement with those of Jenny (2012) who found out that some varieties are prone to weight loss than others. However, this study differs from Gachango *et al*. (2008) which found that tubers stored at Tigoni, (2100 m) in the direct light had the highest mean weight loss. Site of production has a lot of influence tuber water content which is over 75 % and contributes to its perishability (Farashvash and Iranbakhsh, 2009). In fact apart from evaporation through the lenticels of the tubers, respiration is the other major physiological process which has it continues after potato tuber detaches from the parent plant, causes tuber weight loss (Fennie *et al*. 2003).

5.3.2 Potato dry matter and starch content

All varieties lost dry matter and starch content, irrespective of the site or store environments. Dutch Robjin had the highest dry matter content and even at the end of storage period was superior while Kenya Karibu had the least dry matter content a long with Roslin Tana. Kenya Karibu is a late maturing variety which suggest, that tubers at the time of harvesting and storage they could have been younger and with high simple sugar content.

Starch of the potatoes stored varied according to varieties. Dutch Robjin had the highest content and the least was Asante. Tubers at Kitale retained high content due to loss of water faster than in the cooler areas with high relative humidity. The storage environments and sites appear not to have influenced the rate of loss in starch content. Like the DM, there was rapid starch content decrease in the first 30 days before it gradually stabilizes with time of form.

Results of this study compare well with those by Francakova *et al*. (2011) who reported that dry matter content varied from 20.68 to 25.12 %. Dry matter content of the varieties did not differ with altitude and concurs with those of Hamouz *et al*. (2005) where locality had no significant effect on dry matter content of tubers significantly. Dry matter content is attributed to variety and maturity with early maturing varieties having the highest dry matter content (Geremew *et al*. 2007) and may be influenced by factors such as water up take and temperature (Simongo *et al*. 2011). As earlier stated, dry matter content depends on variety, soil fertility, growing condition and maturity. In fact the DM content of most varieties selected for commercial use range from about 18 to 26% (Burton, 1989b). DM is an important aspect of tuber quality and is affected mostly by environmental factors during growth of the crop and development of the tuber, including intercepted solar radiation, soil temperatures, and available soil moisture and growth conditions.

Similar to dry matter, starch significantly reduced from as high as 19% to 12% irrespective of variety, storage environments or sites. This agrees with findings by Jenny (2010) in Denmark who reported loss in weight of starch content in the tubers after three months of storage. Fernie *et al*. (2003) found that a sprouting tuber obtain energy from the mother tuber most of which is derived from starch degradation. The findings also concurs with those by Jukneiviciene *et al*. (2011) who stated that tubers stored at higher temperature consume nutrients more actively and show earlier sprouting compared to those stored at low temperature.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. Potato varieties had the highest tubers in seed size grade at Kitale and the least at Kapcherop.
2. Kenya Karibu and Roslin Tana out yielded all the other varieties at the three sites
3. Dutch Robjin, Kenya Karibu and Tigoni 1 had the highest tubers in seed sizes category across the three sites
4. Potatoes grown at around 1,900 metres above sea level break dormancy earlier than those at higher elevation, produce more stems and small tubers
5. Although plant emergence is slow at higher altitudes they reach a better stand establishment and higher tuber yield compared to those grown at lower elevation.
6. Potato tubers lose weight faster in the first 30 days of storage in ambient conditions irrespective of altitude
7. Potato tubers retain weight better at higher than at lower altitudes
8. Dry matter and starch contents do not vary considerably with the site of production

6.2 Recommendations

1. Before introducing commercial potato production, variety performance evaluation should be done to identify suitable varieties for the region.
2. Store tubers in open environment at high elevation than at lower elevation.
3. Famers at higher altitudes should pay more attention to haulm killing dates in regulating seed tuber size of potatoes than those at lower elevations.

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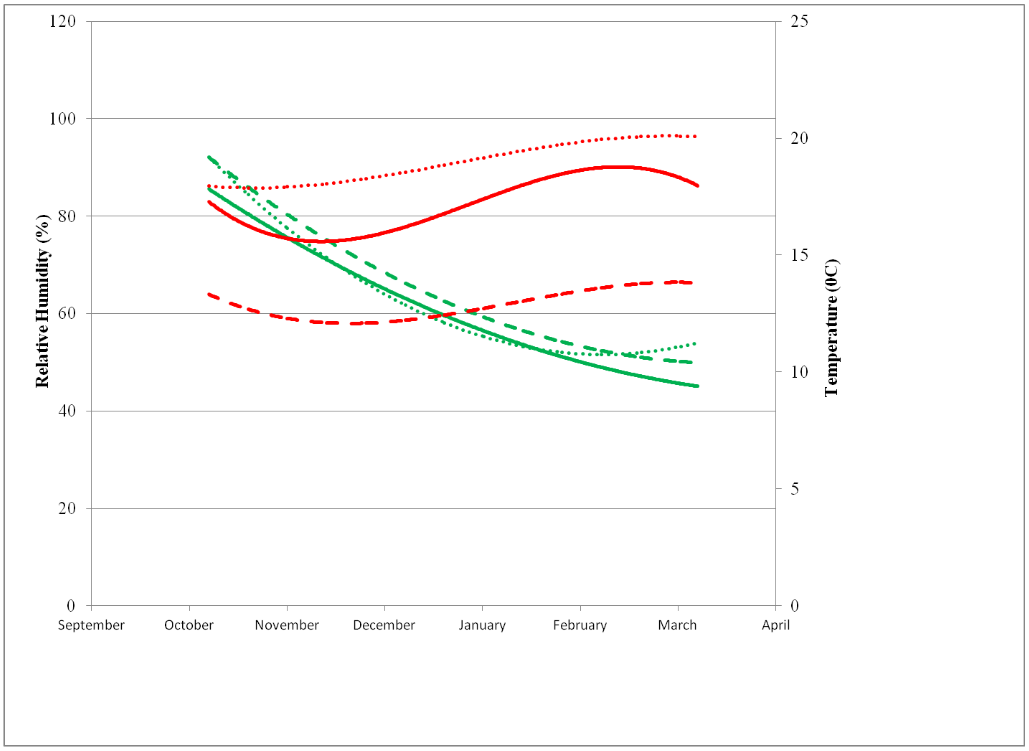
APPENDICES

Appendix I: Temperature and Relative Humidity during storage



Kapcherop (^{0}C) Kibigos (^{0}C) Kitale (^{0}C)

Kapcherop (%) Kibigos (%) Kitale (%)

Appendix II: Specific Gravity determination procedure

Specific gravity was determined by weighing of 10kg seed size potato tubers both in air and after their immersion in water. The specific weight was calculated with following relation:

SG= Wa/Wa-Ww) where:

Wa= weight of potatoes in air,

Ww = weight of potatoes immersed in water and

SG = specific gravity in gm

This method has been developed and use by Talburt and Smith as early as 1959 and recently by Vasanthan an Colab 1999 as quoted by NORGIA et al. 2008

For determination of the total starch content are used the following relation was used:

(Talburt and Smith, 1959; Vasanthan and colab, 1999):

amd = 17546 + 199.07 (gsp – 1,0988)

where:

gsp = specific gravity; similar to SG above,

amd = starch content of vegetal material,

DM is not usual and most methods estimate DM indirectly, from specific gravity measurements, using empirical conversion factors (Talburt and Smith (1959).

The dry matter content is calculated, from the potatoes' weight in air and weight in water, using the following equation:

% Dry Matter = $(24.182 \pm 0.035) + (211.04 \pm 3.33)(SG - 1.0988)$ where:

24.182 ± 0.035, 211.04 ± 3.33 and 1.0988 are constants. This method is widely used by British Potato Council to evaluate potatoes for processing.

Appendix III: ANOVA on Effect of variety on emergence, stems/m2, tuber size distribution, harvest index, number of tubers/ plant and tuber yield (t/ha) at Kitale

a) Plant emergence (%)

27 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	149.333	74.667	0.73	0.5000
Variety	7	5291.333	755.90	7.38	0.0008**
Error	14	1434.667	102.476		
Corrected Total	23	6875.333			

35 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	22.583	11.292	0.50	0.6151
Variety	7	5418.292	774.042	34.50	<.0001**
Error	14	314.083	22.43		
Corrected Total	23	5754.958			

42 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	42.583	21.292	2.29	0.1378
Variety	7	4965.167	709.310	76.34	<.0001**
Error	14	130.083	9.292		
Corrected Total	23	5137.833			

56 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	19.750	9.875	0.96	0.4073
Variety	7	3510.000	501.429	48.67	<.0001**
Error	14	144.250	10.304		
Corrected Total	23	3674.000			

b) Stems per square metre

42 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	2250.083	1125.042	38.55	<.0001**
Variety	7	2424.667	346.381	11.87	<.0001**
Error	14	408.583	29.18		
Corrected Total	23	5083.333			

49 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	1134.083	567.042	11.91	0.0010**
Variety	7	3168.292	452.613	9.51	0.0002**
Error	14	666.583	47.613		
Corrected Total	23	4968.958			

56 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	936.583	468.292	12.56	0.0008**
Variety	7	2702.667	386.095	10.35	0.0001**
Error	14	522.083	37.292		
Corrected Total	23	4161.333			

63 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	876.083	438.042	12.03	0.0009**
Variety	7	2605.958	372.280	10.22	0.0001**
Error	14	509.917	36.423		
Corrected Total	23	3991.958			

70 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	868.000	434.000	13.08	0.0006**
Variety	7	2496.958	356.708	10.75	0.0001**
Error	14	464.667	33.191		
Corrected Total	23	3829.625			

c) Ground cover rate (%)

42 days after planting

Source	DF	SS	M S	F Value	Pr > F
Rep	2	3172.75	1586.38	16.34	0.0002**
Variety	7	14233.63	2033.38	20.94	<.0001**
Error	14	1359.25	97.09		
Corrected Total	23	18765.63			

49 days after planting

Source	DF	SS	M S	F Value	Pr > F
REP	2	797.25	398.63	2.62	0.1078
VARIETY	7	24713.96	3530.57	23.23	<.0001
Error	14	2127.42	151.96		
Corrected Total	23	27638.63			

56 days after planting

Source	DF	SS	MS	F Value	Pr > F
Rep	2	89.58	44.79	1.66	0.2249
Variety	7	14479.17	2068.45	76.80	<.0001**
Error	14	377.08	26.94		
Corrected Total	23	14945.83			

d) Seed tuber grade (tubers/plant)

Less than 28mm

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	1.583	0.792	0.02	0.9813
Variety	7	343.958	49.137	1.17	0.3769
Error	14	586.417	41.887		
Corrected Total	23	931.958			

Between 28-45mm

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	2977.000	1488.500	10.84	0.0014**
Variety	7	2576.958	368.137	2.68	0.0551

Source	DF	SS	MSS	F Value	Pr > F
Error	14	1921.667	137.262		
Corrected Total	23	7475.625			

Between 45-60mm

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	57.583	28.792	1.10	0.3587*
Variety	7	3651.292	521.613	20.00	<.0001**
Error	14	365.083	26.077		
Corrected Total	23	4073.958			

Over 60mm

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	52.333	26.167	0.60	0.5632
Variety	7	1894.667	270.667	6.19	0.0019**
Error	14	612.333	43.738		
Corrected Total	23	2559.333			

e) Harvest index

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	0.008	0.004	4.91	0.0258*
Variety	7	0.162	0.023	28.30	<.0001**
Error	13	0.011	0.001		
Corrected Total	22	0.180			

f) Tubers per Plant

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	37.987	18.994	9.76	0.0026**
Variety	7	149.901	21.415	11.01	0.0001**
Error	13	25.286	1.945		
Corrected Total	22	213.174			

g) Tuber yield (t/ha)

Source	DF	SS	MSS	F Value	Pr > F
Rep	2	1185.673	592.836	8.29	0.0048**
Variety	7	14636.930	2090.990	29.25	<.0001**
Error	13	929.193	71.476		
Corrected Total	22	16751.796			

Appendix IV: ANOVA on Effect of treatments on emergence, stems/plant, tuber yield (t/ha) and per cent seed grade

a) Plant emergence (%)

14 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
Site	2	3000.44	1500.22	272.03	<0.0001***
Rep (Site)	6	84.56	14.09	2.56	0.0405*
Variety	5	284.89	56.98	10.33	<0.0001***
Site*Variety	10	802.00	80.20	14.54	<0.0001***
Error	30	165.44	5.52		
Corrected Total	53	4337.33			

28 Days after planting

Source	DF	SS	M SS	F Value	Pr > F
Site	2	32.48	16.24	4.18	0.0250*
Rep (Site)	6	86.78	14.46	3.72	0.0069**
Variety	5	294.32	58.86	15.15	<.0001***
Site*Variety	10	268.63	26.86	6.91	<.0001***
Error	30	116.56	3.89		
Corrected Total	53	798.76			

42 Days after planting

Source	DF	SS	MSS	F Value	Pr > F
SITE	2	49.93	24.96	4.63	0.0177*
Rep (Site)	6	95.00	15.83	2.94	0.0224*
Variety	5	86.15	17.23	3.20	0.0197*
Site*Variety	10	124.52	12.45	2.31	0.0373*
Error	30	161.67	5.39		
Corrected Total	53	517.26			

b) Stems per plant

Source	DF	SS	MSS	F Value	Pr > F
Site	2	12.93	6.46	11.87	0.0002***
Rep (Site)	6	3.00	0.50	0.92	0.4956
Variety	5	57.20	11.44	21.01	<.0001***
Site*Variety	10	8.63	0.86	1.59	0.1592
Error	30	16.33	0.54		
Corrected Total	53	98.09			

c) Tuber yield (t/ha)

Source	DF	SS	MSS	F Value	Pr > F
Site	2	193.74	96.87	7.11	0.0030***
Rep (Site)	6	76.08	12.68	0.93	0.4876
Variety	5	1804.08	360.82	26.48	<.0001***
Site*Variety	10	347.09	34.71	2.55	0.0233*
Error	30	408.82	13.63		
Corrected Total	53	2829.81			

d) Per cent tubers in seed grade (%)

Source	DF	SS	MSS	F Value	Pr > F
Site	2	7452.93	3726.47	41.75	<.0001***
Rep (Site)	6	804.93	134.16	1.50	0.2110
Variety	5	3723.46	744.70	8.34	<.0001***
Site*Variety	10	800.80	80.08	0.90	0.5471
Error	30	2677.67	89.26		
Corrected Total	53	15459.79			

Appendix V: ANOVA on Effect of storage treatments on tuber weight (kg) dry matter and starch contents (%)

a) Tuber weight (kg)

30 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	94.12	47.06	2543.74	<.0001***
Rep (Site)	3	0.07	0.02	1.17	0.3301
Environment	2	0.96	0.48	25.86	<.0001***
Site*Environ	4	2.83	0.71	38.18	<.0001***
Variety	5	4.58	0.92	49.56	<.0001***
Site*Variety	10	9.61	0.96	51.97	<.0001***
Environ*Variety	10	1.32	0.13	7.12	<.0001***
Site*Environ*Variety	20	2.93	0.15	7.91	<.0001***
Error	50	0.93	0.02		
Corrected Total	106	117.66			

48 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	47.54	23.77	144.53	<.0001***
Rep (Site)	3	0.34	0.11	0.69	0.5613
Environ	2	1.96	0.98	5.97	0.0047**
Site*Environ	4	3.08	0.77	4.68	0.0027**
Variety	5	8.41	1.68	10.23	<.0001***
Site*Variety	10	17.70	1.77	10.76	<.0001***
Environ*Variety	10	7.78	0.78	4.73	<.0001***
Site*Environ*Variety	20	17.02	0.85	5.17	<.0001***
Error	50	8.22	0.16		
Corrected Total	106	112.86			

88 days of storage

Source	DF	SS	MS S	F Value	Pr > F
Site	2	268.08	134.04	235.26	<.000***1
Rep (Site)	3	1.69	0.57	0.99	0.4047*
Environ	2	0.28	0.14	0.24	0.7860
Site*Environ	4	11.09	2.77	4.86	0.0022**
Variety	5	3.30	0.66	1.16	0.3425
Site*Variety	10	4.00	0.40	0.70	0.7181
Environ*Variety	10	5.69	0.57	1.00	0.4579
Site*Environ*Variety	20	7.56	0.38	0.66	0.8416
Error	50	28.49	0.57		
Corrected Total	106	328.47			

117 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	304.59	152.30	128.58	<.0001***
Rep (Site)	3	5.96	1.99	1.68	0.1840
Environ	2	1.69	0.84	0.71	0.4958
Site*Environ	4	20.00	5.00	4.22	0.0051**
Variety	5	7.49	1.49	1.27	0.2936
Site*Variety	10	6.49	0.65	0.55	0.8472
Environ*Variety	10	14.97	1.50	1.26	0.2763
Site*Environ*Variety	20	24.65	1.23	1.04	0.4369
Error	50	59.22	1.18		
Corrected Total	106	442.97			

b) Dry matter content (%)

0 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	9.15	4.58	30.88	<.0001***
Rep (Site)	3	917.57	305.86	2064.82	<.0001***
Environ	2	0.07	0.03	0.22	0.8014
Site*Environ	4	1.31	0.33	2.21	0.0822
Variety	5	23.66	4.73	31.95	<.0001***
Site*Variety	10	3.69	0.37	2.49	0.0177*
Environ*Variety	10	2.96	0.30	2.00	0.0559
Site*Environ*Variety	20	3.83	0.19	1.29	0.2312
Error	46	6.81	0.15		
Corrected Total	102	1029.77			

30 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	21.68	10.84	32.17	<.0001***
Rep (Site)	3	868.79	289.60	859.40	<.0001***
Environ	2	33.89	16.95	50.29	<.0001***
Site*Environ	4	2.89	0.72	2.14	0.0905
Variety	5	32.02	6.41	19.01	<.0001***
Site*Variety	10	17.33	1.73	5.14	<.0001***
Environ*Variety	10	15.25	1.52	4.52	0.0002***
Site*Environ*Variety	20	20.12	1.01	2.98	0.0011***
Error	46	15.50	0.34		
Corrected Total	102	1096.74			

48 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	19.74	9.87	24.30	<.0001***
Rep (Site)	3	805.73	268.58	661.00	<.0001***
Environ	2	41.54	20.77	51.11	<.0001***
Site*Environ	4	13.11	3.28	8.06	<.0001***
VARIETY	5	26.44	5.29	13.01	<.0001***
Site*Variety	10	10.48	1.05	2.58	0.0143*
Environ*Variety	10	3.27	0.33	0.80	0.6253
Site*Environ*Variety	20	23.34	1.17	2.87	0.0016**
Error	46	18.69	0.41		
Corrected Total	102	1014.19			

88 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	7.37	3.69	3.08	0.0557
Rep (Site)	3	880.39	293.46	244.91	<.0001***
Environ	2	2.68	1.34	1.12	0.3355
Site*Environ	4	9.03	2.26	1.88	0.1294
Variety	5	48.25	9.65	8.05	<.0001***
Site*Variety	10	27.73	2.77	2.31	0.0266*
Environ*Variety	10	17.65	1.77	1.47	0.1804
Site*Environ*Variety	20	40.18	2.01	1.68	0.0744
Error	46	55.12	1.20		
Corrected Total	102	1146.11			

117 days of storage

Source	DF	SS	MSS	F Val	Pr > F
Site	2	1.23	0.62	0.23	0.7970
Rep (Site)	3	954.76	318.25	117.76	<.0001***
Environ	2	6.66	3.33	1.23	0.3011
Site*Environ	4	10.41	2.60	0.96	0.4369
Variety	5	67.91	13.58	5.03	0.0009***
Site*Variety	10	47.18	4.72	1.75	0.0989
Environ*Variety	10	26.64	2.66	0.99	0.4690
Site*Environ*Variety	20	74.31	3.72	1.37	0.1842
Error	46	124.31	2.70		
Corrected Total	102	1370.29			

c) Starch content estimate (%)

0 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	7.40	3.70	20.05	<.0001***
Rep (Site)	3	1039.03	346.34	1876.16	<.0001***
Environ	2	0.05	0.02	0.12	0.8848
Site*Environ	4	1.59	0.340	2.15	0.0884
Variety	5	28.00	5.60	30.32	<.0001***
Site*Variety	10	2.90	0.29	1.57	0.1423
Environ*Variety	10	2.15	0.22	1.17	0.3353
Site*Environ*Variety	20	5.24	0.26	1.42	0.1569
Error	51	9.41	0.18		
Corrected Total	107	1095.76			

30 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	22.99	11.49	21.02	<.0001***
Rep (Site)	3	932.31	310.77	568.41	<.0001***
Environ	2	39.10	19.55	35.76	<.0001***
Site*Environ	4	2.54	0.64	1.16	0.3385
Variety	5	32.84	6.57	12.01	<.0001***
Site*Variety	10	24.35	2.44	4.45	0.0002***
Environ*Variety	10	21.18	2.12	3.87	0.0006***
Site*Environ*Variety	20	33.74	1.69	3.09	0.0006***
Error	51	27.88	0.55		
Corrected Total	107	1136.93			

48 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	17.88	8.94	14.77	<.0001***
Rep (Site)	3	911.1	303.73	501.55	<.0001***
Environ	2	62.33	31.17	51.46	<.0001***
Site*Environ	4	17.36	4.34	7.17	0.0001***
Variety	5	27.80	5.56	9.18	<.0001***
Site*Variety	10	19.09	1.91	3.15	0.0033**
Environ*Variety	10	5.29	0.53	0.87	0.5634
Site*Environ*Variety	20	24.21	1.21	2.00	0.0241*
Error	51	30.88	0.61		
Corrected Total	107	1116.04			

88 days of storage

Source	DF	SS	MSS	F Value	Pr > F
Site	2	9.53	4.76	6.97	0.0021**
Rep(Site)	3	833.74	277.91	406.85	<.0001***
Environ	2	4.08	2.04	2.99	0.0592
Site*Environ	4	9.97	2.49	3.65	0.0109*
Variety	5	63.38	12.68	18.56	<.0001***
Site*Variety	10	34.92	3.49	5.11	<.0001***
Environ*Variety	10	6.21	0.62	0.91	0.5321
Site*Environ*Variety	20	44.45	2.22	3.25	0.0003***
Error	51	34.84	0.68		
Corrected Total	107	1041.12			

117 days of storage

Source	DF	SS	Mean SS	F Value	Pr > F
Site	2	0.25	0.12	0.05	0.9532
Rep(Site)	3	720.33	240.11	92.70	<.0001***
Environ	2	11.21	5.60	2.16	0.1254
Site*Environ	4	19.51	4.88	1.88	0.1277
Variety	5	64.34	12.87	4.97	0.0009***
Site*Variety	10	52.22	5.22	2.02	0.0508
Environ*Variety	10	33.10	3.31	1.28	0.2678
Site*Environ*Variety	20	65.38	3.27	1.26	0.2472
Error	51	132.10	2.59		
Corrected Total	107	1098.43			