

**EFFECTS OF PLANT GROWTH REGULATORS, LIGHT AND NATURAL
MATERIALS ON DORMANCY, GROWTH AND YIELD OF POTATO
(*Solanum tuberosum* L.) IN KENYA**

‘MALEKHOOA SUZAN MOLETSANE

**A Thesis Submitted to Graduate School in Partial fulfilment of the Requirements for
the Master of Science Degree in Agronomy of Egerton University**


EGERTON UNIVERSITY

OCTOBER, 2021

DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and it has not been submitted or presented for examination in any other institution for the award of any degree or diploma.

Signature: 


Date: 4th October 2021.....

Malekhoa Suzan Moletsane

KM121/14579/18

Recommendation

This thesis has been submitted for examination with our approval as university supervisors

Signature: 

Date: 17th October 2021.....

Prof. Paul Kimurto (Ph.D)

Department of Crops, Horticulture and soils,
Egerton University.

Signature : 

Date: 17th October 2021.....

Dr. Maurice E. Oyoo (Ph.D)

Department of Crops, Horticulture and Soils,
Egerton University.

COPYRIGHT

©2020 'Malekhooa Suzan Moletsane.

All Rights Reserved. No part of this thesis may be reproduced, stored in any retrieval system, or transmitted in any form or by any means without prior written permission from the author or Egerton University

DEDICATION

This work is dedicated to my family for encouraging me during the entire period of my study. I also dedicate this work to Prof. Nancy Mungai and Prof. Patience Mshenga for offering parental guidance during my stay here in Kenya.

ACKNOWLEDGMENTS

I thank The Almighty God for his mercy, love and support throughout this challenging work. I sincerely thank Egerton University for providing a conducive learning environment and resources used in this work. I also thank KALRO Molo for providing study sites for conducting my studies. I appreciate TAGDev through RUFORUM for offering me scholarship for this study. I would also like to acknowledge my supervisors Prof. Paul Kimurto and Dr. Maurice Oyoo for their professional advice love, interest and dedication in making this research successful. I would also like to thank Prof. Joshua Ogweno for his initial contribution to this work. I would again like to thank my lecturers at National University of Lesotho, Prof. K.J.B. Keregero, Dr. Adenkule Abiola and Poloko Mosebi for the motivation and encouragement during my academic journey. Finally, I indebtly appreciate the efforts of Messrs James Ngelezi and Peter Caleb for their technical assistance in the laboratory and Ms Lillian Jeptanui and Ms Virginia Wanjiku of Crops, Horticulture and Soils department, Egerton University for their support during the entire period of this research project.

ABSTRACT

In Kenya, potato is grown throughout the year in the major growing areas. However, potato farmers face an acute challenge of seeds associated with dormancy of 2-3 months after harvesting, causing untimely availability of well-sprouted and disease-free seed potato tubers at planting. The study was conducted to determine the effects of different chitting methods on enhancing pre-sprouting and breaking seed dormancy of different commercial potato varieties (Shangi, Dutch Robijn and Kenya Karibu) in Kenya. Two experiments were conducted. First experiment was conducted under greenhouse conditions and three plant growth regulators (PGRs) (Gibberellins (GA3), 6-Bezylaminopurine and Zeatin) and natural materials (grass, banana leaves, and soil) were evaluated. The three plant growth regulators were sprayed at the concentration of 1mg L^{-1} while natural materials were applied in thin layers that filters direct Photo Synthetically Active Radiation light. In the second experiment, three light exposure regimes (8, 12, and 16 hours) were studied under lighthouse. Natural room light conditions was the control treatment. Both experiments were laid in complete randomized design (CRD). Sprouted mini-tuber seed sets were thereafter planted at Egerton University and Kenya Agricultural and Livestock Research Organization, Molo, in a split plot in RCBD where varieties were main plots and PGRs and natural materials were sub plots. The results showed that there were significant differences ($p \leq 0.05$) amongst the pre-sprouting PGRs, natural materials and light exposures on pre-sprouting time, growth and yield of tubers. Natural materials were the most effective compared to PGRs and control treatment. Natural materials and PGRs increased large size potatoes by 261% and 103% respectively as compared to control treatment. Natural materials increased thickness and length of sprouts the most, by 174% and 159% respectively. Light exposure treatments reduced sprouting time from 44 to 21 days. Light regimes also significantly increased the sprout thickness by 31-43 % and sprout length by 15-39%. Light exposure of 16 hours had the highest percent of plant germination. The best light regime was 16 hours exposure which increased tuber weight by 25%. According to the findings, Farmers in Kenya can use banana leaves and dry grass as they were the best treatments on enhancing pre-sprouting and increasing tuber yields; 16 hours of light exposure is the best in increasing tuber yields under Shangi and Kenya Karibu varieties.

TABLE OF CONTENTS

DECLARATION AND RECOMMANDATION	ii
COPYRIGHT	iii
DEDICATION	iv
ACKNOWLEDGMENTS	v
ABSTRACT	vi
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF APPENDICES	xiii
LIST OF ABBREVIATIONS	xiv
CHAPTER ONE	1
INTRODUCTION	1
1.1 Background Information	1
1.2 Statement of the Problem.....	3
1.3 Objectives	4
1.3.1 Main Objective.....	4
1.3.2 Specific Objectives	4
1.4 Hypotheses.....	4
1.5 Justification of the study	4
CHAPTER TWO	6
LITERATURE REVIEW	6
2.1 Potato production	6
2.2 Potato Production areas and trend.....	6
2.3 Mode of propagation in potato.....	7
2.5 Potato Production in Kenya	8
2.6 Constraints to Potato Production	10
2.7 Seed Production Systems in Kenya	10
2.8 Classes of Seed Potato in Kenya.....	11
2.9 Formal Sources of Seed Potato in Kenya	11
2.10 Roles of Plant Growth Regulators in Potato Production	11
2.11 Use of natural materials in breaking tuber dormancy	12

2.12	Sprouting Management Strategies in Seed Potato Production	13
2.13	Potato Tuber Dormancy and Sprouting	14
2.14	Effects of Storage Temperature and Light on Pre-sprouting Regimes on Seed Quality and Tuber Health.....	16
2.15	Structural changes and sprouting behaviour in potato	16

CHAPTER THREE **18**

EFFECTS OF PLANT GROWTH REGULATORS AND NATURAL MATERIALS ON DORMANCY, GROWTH AND YIELD OF POTATO (*Solanum tuberosum* L.) IN

KENYA **18**

Abstract	18
----------------	----

3.1	Introduction.....	19
-----	-------------------	----

3.2	Materials and Methods.....	20
-----	----------------------------	----

3.2.1	Description of the study sites	20
-------	--------------------------------------	----

3.2.2	Potato germplasm.....	21
-------	-----------------------	----

3.2.3	Experimental procedure	21
-------	------------------------------	----

3.2.4	Field experiment	22
-------	------------------------	----

3.4	Results.....	23
-----	--------------	----

3.4.1	Response of seed tubers to Plant growth regulators (PGRs) and natural materials under greenhouse conditions	23
-------	---	----

3.4.2	Influence of plant growth regulators and natural materials on growth parameters under field conditions	26
-------	--	----

3.4.3	Correlation between sprout, growth and yield parameters for greenhouse and field trials	36
-------	---	----

3.5	Discussion	38
-----	------------------	----

3.6	Conclusion	40
-----	------------------	----

CHAPTER FOUR..... **42**

EFFECTS OF DIFFERENT LIGHT EXPOSURE REGIMES ON PRE-SPROUTING AND YIELD PERFORMANCE ON POTATO (*Solanum tuberosum* L.) SEED IN

KENYA **42**

Abstract	42
----------------	----

4.1	Introduction.....	42
-----	-------------------	----

4.2	Materials and Methods.....	44
4.2.1	Site description.....	44
4.2.2	Germplasm evaluated.....	45
4.2.3	Experimental procedure	45
4.2.4	Evaluation of pre-sprouted potato seed under field conditions.	45
4.3	Data analysis	46
4.4	Results.....	47
4.4.1	Effects of different light exposures on potato seeds under light-house	47
4.4.2	Growth and yield performance of pre-sprouted potato seeds under field conditions	48
4.4.3	Pearson correlation between sprout, growth and yield parameters for light house and field trails	54
4.4.4	Regression analysis	57
4.5	Discussion	59
4.6	Conclusion	62
	CHAPTER FIVE	63
	GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS	63
5.1	General discussion	63
5.2	Conclusions.....	64
5.3	Recommendations.....	65
	REFERENCES.....	66
	APPENDICES	75
Appendix 1:	Analysis of variance for number of sprouts and sprout quality under greenhouse, Egerton site	75
Appendix 2:	Analysis of variance for three potato varieties on germination (stand count) at Molo and Egerton sites	76
Appendix 3:	Analysis of variance for three potato varieties on plant height and number of stems at Molo and Egerton sites	77
Appendix 4:	Analysis of variance for tuber yield.....	77
Appendix 5:	Analysis of variance for number of sprouts and sprout quality under light house.	78

Appendix 6: ANOVA for three potato varieties on germinated plants (stand count) at Molo and Egerton sites	78
Appendix 7: ANOVA for three potato varieties on plant height and number of stems	79
Appendix 8: ANOVA for tuber yield in Molo and Egerton sites	79
Appendix 9: National commission for science-technology and innovation research license	81
Appendix 10: Published article on the effect of different light exposure regimes on pre-sprouting and yield performance on potato tuber (<i>Solanum tuberosum</i> L.) seed in Central Rift, Kenya	82

LIST OF TABLES

Table 3.1:	Varieties evaluated in the current study and some of their attributes	21
Table 3.2:	Effects of plant growth regulators and natural materials on number of sprouts and sprout quality under greenhouse	25
Table 3.3:	Number of sprouts and sprout quality of three potato varieties.....	26
Table 3.4:	Effects of plant growth regulators and natural materials on germinated plants (stand count) at different weeks after planting in Molo and Egerton sites	29
Table 3.5:	Mean comparisons of three potato varieties on germinated plants (stand count) at different weeks after planting in Molo and Egerton sites.	30
Table 3.6:	Effects of plant growth regulators and natural materials on plant height and number of stems at different weeks after planting.....	33
Table 3.7:	Means of three potato varieties on plant height and number of stems at different weeks after planting.	34
Table 3.8:	Effects of plant growth regulators and natural materials on tuber yield.....	35
Table 3.9:	Mean comparisons for tuber yield of three potato varieties	36
Table 3.10:	Combined Pearson correlation coefficient with probability value on sprout, growth and yield parameters.....	37
Table 4.1:	Effects of light exposures treatments on number of sprouts and sprout quality under light house.....	48
Table 4.2:	Mean separation for site, variety and treatment on stand count at different weeks after planting in Molo and Egerton sites.....	50
Table 4.3:	Effects of light exposures on plant height and number of stems at different weeks after plant emergence in Molo and Egerton sites.....	53
Table 4.4:	Mean effects of light exposures on tuber yield at Molo and Egerton sites.....	54
Table 4.5:	Combined Pearson correlation coefficient with probability value on sprout, growth and yield parameters	56

LIST OF FIGURES

Figure 2.1: Potato production in Kenya (FAOSTAT, 2020).....	9
Figure 2.2: Sprouted potatoes in the current study.....	13
Figure 3.1: Effect of selected interactions between varieties and treatments (soil, banana leaves and grass, GA3, BAP and Zeatin) on germinated plants. Number of plants 2, 3, 4 and 5: weeks after planting. A: Dutch Robijn, B: Kenya Karibu, C: Shangi variety	28
Figure 3.2: The interaction effects between varieties and treatments (soil, banana leaves, grass, GA3, BAP and Zeatin) on potato plant height. Plant height 3, 4 and 5: weeks after planting. A: Dutch Robijn, B: Kenya Karibu, C: Shangi variety	31
Figure 4.1: Means of number of plants for pre-sprouted potato seed for three varieties under three light exposures and control	49
Figure 4.2: Effect of interactions between potato varieties and light exposure treatments (8, 12 and 16 hours) and control (seeds placed under natural room light conditions) on plant height. Plant height 3, 4 and 5: weeks after planting.	51
Figure 4.3: Relationship between time and number of sprouts. NSP1, number of sprouts at week 1, week 2, week 3 and 4 of the pre-sprouting period	57
Figure 4.4: Relationship between time and sprout quality. TH4, thickness of the main sprout at week 4 of the pre-sprouting period. L4, length of the main sprout at week 4 of the pre-sprouting period.....	58
Figure 4.5: Relationship between time and plant heights. Weeks after plant emergence	58
Figure 4.6: Relationship between time and tuber yield. NT, number of tubers, size of tubers, small, medium, large.....	59

LIST OF APPENDICES

Appendix 1: Analysis of variance for number of sprouts and sprout quality under greenhouse, Egerton site	75
Appendix 2: Analysis of variance for three potato varieties on germination (stand count) at Molo and Egerton sites	76
Appendix 3: Analysis of variance for three potato varieties on plant height and number of stems at Molo and Egerton sites	77
Appendix 4: Analysis of variance for tuber yield.....	77
Appendix 5: Analysis of variance for number of sprouts and sprout quality under light house.	78
Appendix 6: ANOVA for three potato varieties on germinated plants (stand count) at Molo and Egerton sites	78
Appendix 7: ANOVA for three potato varieties on plant height and number of stems	79
Appendix 8: ANOVA for tuber yield in Molo and Egerton sites.....	79
Appendix 9: National commission for science-technology and innovation research license	81
Appendix 10: Published article on the effect of different light exposure regimes on pre-sprouting and yield performance on potato tuber (<i>Solanum tuberosum</i> L.) seed in Central Rift, Kenya	82

LIST OF ABBREVIATIONS

ADC:	Agricultural Development Cooperation
AGRA:	Alliance for a Green Revolution in Africa
ANOVA:	Analysis of Variance
CIP:	International Potato Center
Cm:	Centimeter
CRD:	Complete Randomized Design
DAE:	Days After Emergence
DM:	Dry Matter
DMRT:	Duncan multiple range test
FAO:	Food and Agriculture Organization
FAOSTAT:	Food and Agriculture Organization Corporate Statistical Database
GA ₃ :	Gibberellic Acid
Ha:	Hectare
GIZ-PSDA:	Deutsche Gesellschaft für International Zusammenarbeit and Promotion of Private Sector Development in Agriculture
KALRO:	Kenya Agricultural and Livestock Research Organization
KEPHIS:	Kenya Plant Health Inspectorate Services
LSD:	Least Significant Difference
PAR:	Photo-synthetically Active Radiation
PGRs:	Plant Growth Regulators
Mm:	Millimeter
NCPK:	National potato council of Kenya
RCBD:	Randomized Complete Block Design
SAS:	Statistical Analysis System

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Globally, potato (*Solanum tuberosum L.*) is produced in over 100 countries and consumed by over a billion people (Devaux *et al.*, 2014; Haverkort & Struik, 2015). Global production is about 370 million metric tons, mainly in Europe and Asia, with an annual share of 28.96% and 51.24%, followed by America 12.17% and Africa with 7.16%, respectively (FAOSTAT, 2019). Presently, more than half of the global potato production come from developing countries (CIP, 2019). In Africa, potato is produced in the fertile highlands of East, Central, West, and Southern Africa by about six million smallholder farmers (Tessema *et al.*, 2018). These areas have a temperate climate with cool low growing seasons, temperature regimes, and generally adequate rains, which are ideal conditions for growing potato. However, rising populations and growing cities are shrinking landholdings, thus, reducing economies of scale. Since the early 1960s, the growth in the potato production area has rapidly overtaken all other food crops in developing countries (CIP, 2019).

In Kenya, potato is grown throughout the year in about 217315 hectares of land in highland areas of Rift valley (Bomet, Elgeyo-Marakwet, Nakuru, Narok, Nyandarua, Uasin Gishu, West Pokot, Trans-Nzoia), Central (Kiambu, Meru, Nyeri), and Western (Bungoma) (FAOSTAT, 2018). Potato production has increased in recent years, mainly due to population growth and diversification of food crops away from staple cereals, mainly maize. Nutritionally, potatoes provide an excellent source of nutrients and vitamins as it contains high potassium, high calcium, protein (contains 9 out of 10 essential amino acids), phosphorous, vitamins K and C as well as a good source of dietary antioxidants, which may play a part in preventing diseases related to aging, and a source of dietary fiber (Fantaw *et al.*, 2019).

The National breeding program and International Potato Centre (CIP) in Kenya have under taken concerted efforts in developing several potato varieties which are now commercially available for growing in different areas which include Uneka, Kenya Karibu, Dutch Robjin, Kenya Mavuno, Rudolph, Shangi, Sherekea, Tigoni, Ambition, Arizona and Arnova among others. These varieties are adapted to varied agro-ecological zones and have diverse agronomic traits and market preferences for different multi-uses. Some of the attributes considered in ranking a potato cultivar by farmers were high yield potential, late potato blight (*Phytophthora infestans*) resistance, taste, maturity period, market demand, bacterial wilt resistance, size of the tuber, and drought tolerance (Muthoni *et al.*, 2013).

The National Breeding Program led by KALRO and CIP further initiated breeding for several abiotic and biotic constraints. However, the potato sector is still affected by numerous problems resulting in diminished yields affecting an estimated 800,000 potato farmers (AGRA, 2019; CIP, 2018), who mostly depend on uncertified local seeds. The dependence on uncertified seeds results in low yields that average 7.3t ha⁻¹ as compared to attainable yields of 25-35t ha⁻¹ and the global average of 17.4t ha⁻¹ (CIP, 2018; FAOSTAT, 2018). Specifically, major constraints include; lack of proper pest and disease management (late potato blight, Fusarium wilt, nematodes and viruses), clean seeds, timely availability of well-sprouted seed potato tubers, clear policies on the packaging and a disorganized marketing system (Riungu, 2011). A good-quality seed has a significant potential of increasing on-farm productivity due to enhanced vigour. Thus, planting a high-quality seed is the foundation for profitable production and early marketing of the produce, contributing to 30% of the total production (Ellis, 1992 & Halmer, 2003). In addition, high-quality seeds are genetically and physically pure, vigorous, and free from insect pests and pathogens (Ellis, 1992), which guarantees and ensures uniform field establishment and increased production (Ventura *et al.*, 2012). According to Doijode (2006), availability, quality, and cost of seeds influence the global production and ultimately food security.

In the Kenyan highlands, potato is a major cash crop to many small-scale farmers (Muthoni *et al.*, 2013). However, since most of the potatoes are used for home consumption, farmers prefer cultivars that are tasty, high yielding, and resistant to late blight. Some of the tuber quality characteristics such as skin colour, tuber size, tuber shape, and time to maturity (early maturity) are often key factors in cultivar acceptability based on local consumer preferences and criteria for potato processing (McArthur, 1989). In major potato growing areas, the use of poor-quality unchitted seeds often accelerates the spread of seed-borne diseases such as bacterial wilt, which affects 77% of potato farms in the country (Kaguongo *et al.*, 2010; Muthoni *et al.*, 2013). Besides, demand for potato seed is high, and pre-sprouted seed tubers are often required before planting occurs all year-round. However, this is limited by lack of pre-sprouted potato seed due to limited technologies, lack of chitting, and proper storage facilities in most growing areas of Kenya. This situation is exacerbated further by lack of proper seed system since the informal seed systems (farmers organized and managed without legal documentation to guarantee quality standards) constitute for 75-90% and these seed systems remain the dominant source of seed for most potato smallholder farmers.

As a physiological requirement to convert fresh tubers to seed, potato tubers must undergo between two to three months of dormancy after harvesting, which is a big

impediment to availing high-quality disease-free seed for timely planting (Muchiri *et al.*, 2015). This long period of dormancy should be broken to achieve the timely availability of well-sprouted seed potato tubers at the onset of rains. This is a critical cultural practice for attaining high yields and increased intensification up to 3-4 cropping seasons per year instead of 1-2, leading to increased incomes. In most areas, this intensification is not achieved due to an inadequate supply of pre-sprouted potato seed. Breaking dormancy will also lead to obtaining good quality sprouted seed, which leads to efficient seed germination, rapid and uniform seedling emergence, and early seedling establishment as it produces a deep root system before the upper layers of soil dry out, harden, or reach supra-optimal temperatures, thus escaping the most susceptible stages of the life cycle of crop plants leading to successful establishment and final yield.

Pre-sprouting of potato seed tubers is achieved by the use of several strategies, which include use of plant growth regulators (PGRs), natural products (soil, grass, plant residues among other products) and light (green-sprouting), which accelerate physiological aging that enhances bud opening, vigour, growth, yield and maturity leading to an increased number of growing seasons and overall yield (Reust, 1986). Despite the importance of potato seed there is limited information on the application of plant growth regulators, natural products and light in enhancing the timely availability of pre-sprouted seed for wide potato varieties in Kenya (Andrade-Piedra *et al.*, 2016). This study determined the effects of pre-sprouting plant growth regulators (PGRs), natural materials and light exposures on dormancy of selected potato varieties, seed quality and tuber health under the green house and light house, growth and yield under field conditions, with a goal to improving timely availability of pre-sprouted potato seed for cropping cycles and increased yield.

1.2 Statement of the Problem

Potato is grown throughout the year in major growing areas of Kenya, and it requires large quantities of seed. The major challenge to farmers has been the timely availability of seed associated with physiological dormancy. To convert fresh tubers to seed, potato tubers require the tubers to undergo two to three months of dormancy after harvesting. This is a big impediment to availing high-quality disease-free seed for timely planting as compared to other crops like maize, beans, which have a dormancy period of 7-30 days. Furthermore, in many areas, potato is grown during short rains season after harvesting long rains season crops like maize and wheat. Hence, it is important to use potato seed tubers with a high growth vigour and a short growth cycle. However, farmers have limited access to such quality of

tubers. Although this can be enhanced by pre-sprouting technologies that advance the physiological age of the seed tubers, there is limited information on the use of plant growth regulators, light exposures and natural materials that can be used especially by small scale farmers which are cost-effective and economical to break the dormancy of current potato varieties, provide high quality and timely planting material for increasing yields and incomes. Also, the responses of current high yielding potato varieties to pre-sprouting treatments is not well documented in Kenya. As a remedial measure, farmers use the natural methods of natural light exposure of seed in storage without any form of pre-sprouting, resulting in the growth of sprouts that are thin, white and unhealthy which are broken during transportation or planting, leading to poor emergence and/or the delays in planting resulting in low potato yields.

1.3 Objectives

1.3.1 Main Objective

To contribute to food and nutritional security through improving the timely availability of pre-sprouted potato seed for increased yields in Kenya.

1.3.2 Specific Objectives

- i) To determine the significant effects of pre-sprouting plant growth regulators (PGRs) and natural materials on potato dormancy, growth, and yield of selected potato varieties under the green house and field conditions.
- ii) To determine the significant effect of light exposure regimes on pre-sprouting potato, seed germination and yield performance in light house and field conditions.

1.4 Hypotheses

- i) The pre-sprouting plant growth regulators and natural materials have no significant effects on potato dormancy, growth, and yield of selected potato varieties in the greenhouse and field conditions.
- ii) The light exposure regimes has no significant effects on pre-sprouting potato, seed germination and yield performance in lighthouse and field conditions.

1.5 Justification of the study

Limited availability, low quality and low vigour diseased potato seeds can be improved using a variety of seed technologies that will thrive under smallholder cultivation

conditions and also improve the good-quality seed supplies in the local seed industry. Cost-effective ways of increasing the availability of potato seeds by manipulating their responses to physiological ageing to enhance vigour, growth, yield and maturity for increased growing seasons should be deployed in a more cost-effectively. These would alleviate the challenges often experienced in potato mainly poor sprouting, leading to the delay in planting and poor emergence resulting in low yields. Information on the recommendation on which daily hours of light to be used during pre-sprouting is lacking. Although using plant growth regulators to stimulate the pre-sprouting of potatoes while still in the storage systems for preserving and manipulating their responses to physiological ageing have been reported, there is limited information available for use by small-scale farmers in Kenya. Hence in this study, information on the possibility of improving the availability of quality seed through studies on pre-sprouting techniques mainly PGRs, light and local natural materials to enhance fast availability of seed, intensification for earlier harvests and higher early yields will be established and documented. The findings of this study has suggested cheap ways of increasing availability of quality and timely potato seeds for increasing yields and incomes for farmers in major growing areas of Kenya.

CHAPTER TWO

LITERATURE REVIEW

2.1 Potato production

Potato (*Solanum tuberosum* L.) is a herbaceous plant belonging to the Solanaceae family and is one of the major tuber crops grown in temperate regions in the world (Khanal & Uprety, 2014). It originated and first domesticated in the Andes Mountains of South America (CIP, 2019). More than 4,000 native potato varieties are found mostly in the Andes and have different sizes and shapes (CIP, 2019). More than a billion people in the world eat potato and consider it being the third most important food crop after rice and wheat in terms of human consumption (FAO, 2008). Potato global total production is approximately 370 million metric tons and there are over 180 wild potato species (CIP, 2019). Though they are too bitter to eat, their important biodiversity includes natural resistance to pests, diseases, and climatic conditions (Bhaskar *et al.*, 2016).

Potatoes are up to 7 times more efficient in using water than cereals and produce more food per unit of water than any other major crop (CIP, 2008). The yield obtained from potato can be two to four times the food quantity of grain crops in a one hectare and they can grow up to 4,700 meters above sea level from southern Chile to Greenland (CIP, 2019). The rate at which the growth of potato production area has increased has overtaken all other food crops in developing countries since the early 1960s. Therefore, potato is considered a fundamental food security element to millions of people across South America, Africa, Asia, and Central Asia. Presently, more than half of global potato production now comes from developing countries (CIP, 2018).

2.2 Potato Production areas and trend

The highest yields in potato production are obtained in the highlands areas, mainly in the cooler season. These regions mainly range from 1200 m to 3000 m above sea level. Under these regions, each potato seed can produce new plants that can produce 5 to 20 new tubers that will be genetic clones of the mother plant (CIP, 2019). The production levels of potatoes vary with these regions. However, in 2014, potato production levels in Europe and Asia regions were highest with annual share of 40.7% each. Recently, the Europe region production has declined to 28.96% while in Asia, the production increased to 51.24% (FAOSTAT, 2019). The World Potato Markets (2011), predictions showed that the demand for potato is likely grow by 2050 in the developing countries due to the world population growth from 7 billion to 9 billion. In the 2019, the world production increased at an average

annual rate of 1.6% and is expected to retain growth in the coming years. This change in output was observed on the harvested area and yield figures growth (World Potato Markets, 2011).

2.3 Mode of propagation in potato

Potato is vegetatively propagated, meaning that a new plant can be grown either from a seed tuber or piece of potato, called a “seed” at the seed rate ranging between 1.5 to 4.0 t ha⁻¹ (Asalfew, 2016). True seeds can also propagate potato, which has been found to arouse many farmers’ interests because of little transmission of diseases. In the highlands, traditional propagation of seed tubers can be implemented especially if climates are cool for the population insect vectors diseases to be kept low. During propagation, some factors like physiological quality should be considered because it affects the vigour of sprouts, stems, the growth and yield potential of the plant (Struik, 2007). Maintaining of good quality seed can lead to high attainment of profits (Wang, 2008). Maintenance of potato quality can be achieved through storing seed in a way that it would be less damaged by the climatic imbalance and pathogen. According to Johansen and Molteberg (2012), high-quality seed tubers are a prerequisite for producing healthy, vigorous potato plants and a high yield of good quality under varied environmental conditions. Storing seed tubers at proper storage conditions is also one way of maintaining seed quality. However, potato tubers are stored at different storage conditions depending on the purpose. Those which are to be used for seed purposes, are to be stored at 2°C to 4°C and those used in processing and consumption purposes are stored at 8-12°C (Khanal & Uprety, 2014).

Another important aspect that must be put into consideration is the handling of the seed potatoes and production methods from the time of harvesting up until and during planting. This is very important since it can affect the quality of the seed potatoes (Pinhero *et al.*, 2009). Well sprouted quality seed has a significant potential of increasing farm productivity due to enhanced vigour. Thus, planting a high-quality seed with vigorous sprouts can bring chances of early harvest, early marketing of the produce and more profitable production, contributing to 30% of the total production (Ellis, 1992; Halmer, 2003). One other important agronomic tool in achieving early harvest is to achieve early photosynthetically active leaf area (Eremeev *et al.*, 2008; Struik & Wiersiema, 1999). This could be achieved by exposing seed tubers to various methods of breaking tuber dormancy. In that way, seed tubers can be pre-sprouted. Pre-sprouting means preparing potatoes for planting by encouraging the production of sprouts before planting (CIP, 2018). For

adequate yields and quantities to be achieved in potato, pre-sprouting seeds should be considered, especially in those regions with cool and short growing seasons (Johansen *et al.*, 2012). Pre-sprouting encourages faster growth and heavier crops once the seed potatoes are planted.

2.4 Economic Importance of Potatoes

According to Chandrasekara (2016), potatoes can be grown in those agro-ecologies where other crops will fail and they have the highest yielding capacity in arable land. They produce more yields in a hectare than other crops and because of this reasons they are likely to play a major role in achieving the Sustainable Development Goal of zero hunger in Sub-Saharan Africa (Harahagazwe *et al.*, 2018). They are the largest contributor to human caloric consumption after the three cereals, rice, wheat and maize. According to Pandey (2008), global potato production was significantly increasing more than any other crop in developing countries in 2007 and by that time the global production had reached 325 million metric tons. Potato production tripled from 1994 through 2011 in Africa and figures increased from 8 to 24 million metric tons largely due to the increase of cropping area (Harahagazwe *et al.*, 2018). Also FAO data shows that the total production in Africa, which was only 4% of global supply, increased to 9% ten years later (FAO, 2008). Potato is one of the main commercial crops grown in many countries. In the Europe region, it was chosen as a driving engine for economic growth while in the developing countries farmers advance their economic development through increasing potato use (Salmensuu, 2021). Potato has a potential to boost incomes due to the diversification towards its preparations for consumption (CIP, 2008). It is found in different forms such as fresh, frozen and dried on the market (Islamova, 2020). Several studies have shown that potato production is highly profitable and it is one of the competitive crops that could provide cash money to farmers. In the study that was conducted by Mukul *et al.* (2013), potato was highly profitable than any other winter vegetables.

2.5 Potato Production in Kenya

Potato (*Solanum tuberosum* L.) in Kenya is amongst those crops contributing to food security and poverty alleviation since it creates employment and generates income for people (Riungu, 2011). It has a high potential for addressing food insecurity due to its high productivity and is considered the second most important food crop after maize (Kimani, 2016). In one hectare, it can yield two to four times the food quantity of grain crops and said to be among the leading sources of food calories (CIP, 2019). Potatoes are more efficient in

using water, and due to their high productivity, the potato sector is currently creating employment for about 2million Kenyans in a year (Mumia *et al.*, 2018).

In major potato regions of Kenya like Rift valley (Bomet, Elgeiyo-Marakwet, Nakuru, Narok, Nyandarua, Uasin Gishu, West Pokot, Trans-Nzoia), Central (Kiambu, Meru, Nyeri), and Western (Bungoma) a bimodal rainfall and the window of planting potatoes is two weeks. However, most potato varieties are dormant for longer than three weeks due to genetic background, tuber development, environmental, and management conditions during tuber growth and storage (Muchiri *et al.*, 2015). Therefore, terminating dormancy in freshly harvested potatoes would enable seeds to sprout adequately, which will enhance early planting and increase the productivity of potatoes (Shibairo *et al.*, 2006).

The production of potatoes in Kenya has been variable since 1939, with a general increase in area from 2400 hectares producing 16 000 metric tons. In 2015 close to 800 000 farmers were heavily engaged in potato production and due to limited use of high-quality seeds, the potato yields were low, with an average yield of approximately 10 tons per hectare (AGRA, 2019). However, 1.5 million tons of potato is produced each year, generating livelihood for millions of Kenyans (Kimani, 2016). Figure 2.1 below illustrates Kenya potato production, which has been declining since 2010 due to many constraints in potato production as discussed.

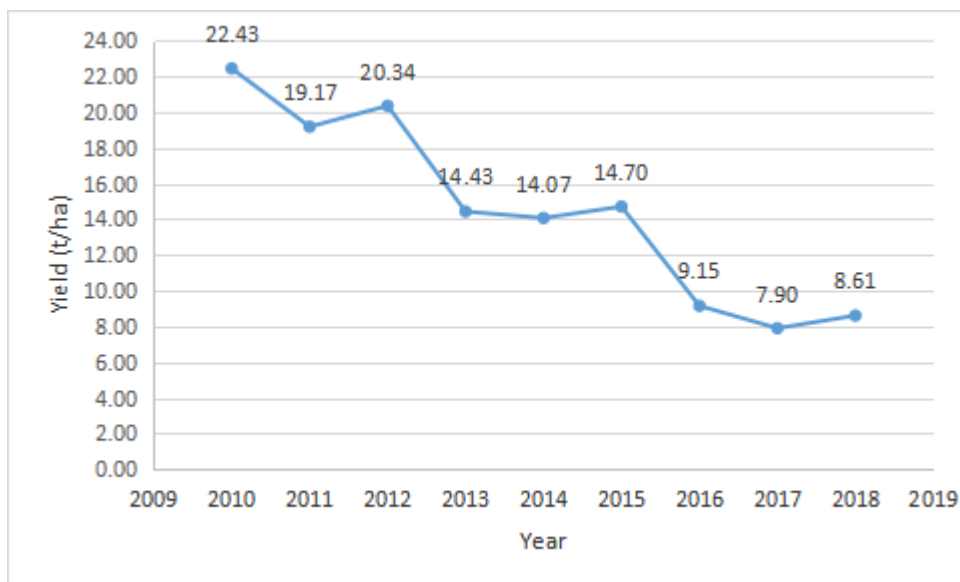


Figure 2.1: Potato production in Kenya (FAOSTAT, 2020)

2.6 Constraints to Potato Production

Many potato production constraints are associated with their biological characteristics, low multiplication rates of seed tubers, cost for maintaining seed quality through successive multiplications and susceptibility to soil and seed-borne insect pests and diseases. Lack of efficient seed systems especially in developing countries for regular multiplication and distribution of certified seeds (FAO, 2008). The environment can be among the factors that can lead to failure in potato production. Therefore consideration of the environment in potato sprouting is very important because sometimes potato tubers (*Solanum tuberosum* L.) cannot sprout even if the environmental conditions for growth are suitable as long as they have reached the harvesting time (Delaplace *et al.*, 2008). This state differs among cultivars and can be affected by both pre and postharvest environments (Carli *et al.*, 2010; Salgado de Oliveira *et al.*, 2012). Seed potato quality affects potato production and it can be measured by the ability of a seed to produce sprouts and daughter tubers (Daniels-Lake & Prange, 2007). Seed quality can temper with the physiological state of tubers (Caldiz *et al.*, 2001). There are other constraints affecting potato production which include the shortage of clean (disease-free) planting materials and spread of pests and diseases (GIZ-PSDA Kenya, 2011; Riungu, 2011). These problems have forced farmers in Kenya to plant seeds from informal sources such as farm-saved (self-supply) and local markets or neighbours. Kenya is currently producing less than 1% of the nationally certified seed demand. These constraints and farming practices differ with regions (Muthoni *et al.*, 2013).

2.7 Seed Production Systems in Kenya

Formal system undergoes seed certification by Kenya Plant Health Inspectorate Services (KEPHIS). This system follows written legal procedures that involve public and private organizations such as KALRO, ADC and other certified growers, while informal system involves the production of seed potato outside the formal seed certification system and include the selected seed, farm-saved seed and clean seed (Mumia *et al.*, 2018). These systems result in three different types of seed potatoes, which are certified seed, clean seed and farm, saved seed (Gildemacher, 2009). Certified seeds are used by less than 2% of potato farmers and the quality of seed is assured according to the law (Cap 326) by KEPHIS, while clean seed involves planting certified or basic seed potato and is used by about 4% of potato farmers, the quality is assured by extension officers and is produced using good agricultural practices.

The informal system is used mainly by farmers where the seed is not certified and thus using their seeds. Farm saved food involves planting seeds from unknown sources, which are normally produced by farmers with no input from other seed industry players of which 95% of potato farmers use this seed and it has no quality standards (Kimani, 2016). This leads to the use of poor quality seeds and often accelerates the spread of seed-borne diseases such as bacterial wilt (Muthoni, 2014). A strict rotation programme must be employed in potato production because some studies that were undertaken in Kenya have shown that about 77% of potato farms have been affected by bacterial wilt (Muthoni *et al.*, 2013). Since there is still no control method that is very effective in controlling bacterial wilt some few farmers has opt for crop rotation in Kenya (Riungu, 2011).

2.8 Classes of Seed Potato in Kenya

The seed multiplication system in Kenya is based on the Organization for Economic Corporation and Development system and has 8 classes of certified seed and one class of non-certified seed (Simon, 2017). These classes include Breeders seed, Pre- Basic seed, Basic seed, Certified 1, Certified 2 and Certified 3. Based on the tolerance on off-types during field inspection the Breeder seed class must have 0 tolerance (number of off-types per 100 plants), Pre-Basic must have 1 tolerance, Basic 2, Certified 1 must have 2, Certified 2 and 3 must have 3 tolerance (CAP 326 Seed & Plant Varieties Act, 2012). In the current study, the certified seeds from KALRO Tigoni were used.

2.9 Formal Sources of Seed Potato in Kenya

Formal seeds for potato production in Kenya are obtained from public institutions like KALRO, ADC, private seed companies like Kisima Farm Ltd, Agrico E.A. Ltd, Syngenta E.A Ltd and Suera Flowers and other registered individual seed growers. All seeds from these formal sources must undergo certification by KEPHIS (Kimani, 2016). The Kenya Agricultural and Livestock Research Organization's Tigoni Centre and Agricultural Development Cooperation are also source of basic seed class for Kenyan varieties.

2.10 Roles of Plant Growth Regulators in Potato Production

Plant growth regulators contribute to an early seed planting materials by inducing dormancy breaking of seed potatoes. Amongst the plant growth regulators, GA3 has been widely used in many countries for breaking tuber dormancy (Benkeblia *et al.*, 2008). In general, plant growth regulators played a primary role in the regulation of potato tuber endo-

dormancy and many other aspects of plant development (Hemberg, 1985; Rappaport & Wolf, 1969). They are considered to be the most important and efficient endogenous regulators of both tuber dormancy and sprouting. There is evidence that from the dynamics of endogenous hormones related to stages of dormancy and sprouting there is a possibility to change dormancy duration and sprouting by tuber treatment with hormonal preparation (Aksenova *et al.*, 2013).

There are five classes of hormones and these are categorized into plant growth promoters and plant inhibitors. The plant growth promoters promote cell division, cell enlargement, flowering, fruiting and seed formation and examples are auxins, gibberellins and cytokinins. These hormones play a crucial role in controlling potato tuberization (Vreugdenhil & Struik, 1989). The 6-Benzylaminopurines (6-BAP) and Zeatin used in the current study are the cytokinins. Cytokinins play crucial role in creating the sink during plant development and through regulating the expression of a gene involved in the partition of assimilates towards the stolons as observed in potato (Sonnewald & Sonnewald, 2014). It has been demonstrated that, cytokinins and gibberellins are required for the reactivation of meristematic activity and sprout growth (Hartmann *et al.*, 2011). Cytokines are nitrogen-containing compounds namely adenine. They are effective in stimulating shoot induction and maintaining chlorophyll degradation hence the 6-BAP could stimulate the dormant buds for new shoots (Amelia *et al.*, 2020).

In general, the cytokinins and gibberellins are required for bud break and sprout growth, respectively, while auxin plays a role in vascular development. Therefore, the dormant seed tubers can be induced to sprout by treatment with cytokinins and gibberellins (GA). According to Suttle (1998), in the experiment he conducted in the previous studies, he concluded that the application of cytokinins resulted in the termination of dormancy and enhanced sprouting of potato tuber. Gibberellins and cytokinins promote growth and regulate the termination of end dormancy (Muchiri, 2015).

2.11 Use of natural materials in breaking tuber dormancy

Materials producing ethylene might have a beneficial effect in breaking the dormancy. They were traditionally used for ripening banana fruits and tomatoes by producing ethylene. Covering increases humidity and carbon dioxide level of the storage atmosphere which may have an effect in pre-sprouting.

2.12 Sprouting Management Strategies in Seed Potato Production

It is very important to manage seed dormancy in potato production. Like in every crop, dormancy in potatoes will depend on genetic background, stage of tuber development, environmental and management conditions during tuber growth and storage. Physiologically, such tubers are in the stages for normal sprouting (Mani, 2014). Therefore, some introductory methods on pre-sprouting seeds could be of great importance to avoid long or thin sprouts that can break during planting. Pre-sprouting means preparing potatoes for planting by encouraging the production of sprouts before planting (CIP, 2018). It gives a plant an advantage of growing fast and makes heavier crops once the seed potatoes are planted. Determination of potato sprouting behavior during storage can help in understanding the physiological ageing process of seed potato tubers; this can help in developing better appropriate storage strategies prior to planting (Oliveira *et al.*, 2012). An example of pre-sprouted potato is shown in (Figure 2.2).



Figure 2.2: Sprouted potatoes in the current study.

This process can be regulated, especially when seed tubers are needed before natural sprouting occurs through chemical agents as one of pre-sprouting methods. The time the seeds take to break the dormancy also depends on the cultivar.

According to Suttle (2004), these endogenous hormones play an important role in regulating dormancy of potato tuber bud (eye). These hormones have also been observed to break dormancy and promote sprouting even in those potato seeds that have a longer dormancy period. There are several factors involved in dormancy breaking, such as time and age of the cultivar. Determining the physiological age could be important because breaking dormancy alone cannot guarantee good yield (Ittersum, 1992). The physiological age of a tuber is defined as the stage of development of a tuber, which is modified progressively by increasing chronological age, depending on growth history and storage conditions (Ittersum,

1992; Struik & Wiersema, 1999). Due to the physiological aspect, the sprouts that will develop after the dormancy breakage also have their physiological characteristics affecting seed performance (Mani, 2014).

The maintenance performance of seed starts in the storage where the storage conditions must be carefully understood because they are very important (Haverkort, 2015). To increase growth vigour of the sprouts and maintain growth vigour of the tuber, the idea of exposing seeds to light can be implemented (Johansen *et al.*, 2012). The recent field trials in northern and other short-season climates have shown that after pre-sprouting seeds both emergence and yield were faster than seeds are just storage (Eremeey *et al.*, 2008; Essah & Honeycutt, 2004). Another field trial by Haverkort *et al.* (2015) under longer season conditions underlined that both temperatures and light during the later stages of seed potato storage may be useful in manipulating tuber size distribution and yields of the desired size grades. These are very important aspects to have high growth vigour, which can be defined as fast emergence and establishment of a green plant. This can be beneficial regarding resistance against diseases and weeds and thereby improve both yield and quality.

According to Suttle (1998), in his previous studies he conducted, he concluded that the application of cytokinins resulted in the termination of dormancy and enhanced sprouting of potato tuber. Also, Hassani *et al.* (2014) noted that very low quantities of gibberellic acid at about 50 g/litre, and other chemicals like 25 ml/m³ carbon disulfide, 3% thio-urea were used on two potato cultivars and potato mini-tuber size to promote seed sprouting under greenhouse in at Institute of Seed and Plant Certification and Registration Research Karaj, Iran. The results further showed that the use of chemicals increased the number of sprouts, although most of these sprouts were observed in increased seed size tubers, which were linked to the availability of nutrients in tuber storage. In another related study, the application of gibberellic acid at low concentrations (5 and 10 mg/litre) promoted sprouting and productivity of seed tubers of potatoes. The tuber production in all the cultivars was increased by the application of gibberellic acid. GA3 enhanced earlier sprouting as compared to control, which sprouted very late and slow (Barani *et al.*, 2013).

2.13 Potato Tuber Dormancy and Sprouting

Potato varieties have different dormancy periods, which could be long dormancy, medium and short. Dormancy is regarded as a physiological state characterized by a period during which autonomous sprout growth does not occur, even under optimal sprouting conditions (Mani *et al.*, 2014). If dormancy duration is known, the selection of varieties for

both short and long-term storage would be easy. This could also provide information on how long the seed potatoes can be stored before they initiate sprout development. Innate dormancy also depends largely on the cultivar and environmental growing conditions like temperature, long photoperiod (18 hours) light, especially during tuberization and this can shorten dormancy (Van Ittersum, 1992). In addition these environmental factors (temperature, water supply and the photoperiod) during growth and storage regulate the sprouting behaviour (Sonnewald, 2001). Sprouting behavior of potatoes during storage helps in the understanding of the physiological ageing process of seed potato tubers and this can help in developing better appropriate storage strategies before planting (Oliveira *et al.*, 2012).

Several methods have been tested for breaking tuber dormancy, which include Light exposure. Exposing seed tubers to light in thin layers and increased temperatures before the estimated planting date would help in preventing sprout elongation of which the benefits would be short and strong sprouts, fast emergence, early tuber initiation, increased sprouts vigour and maximal and relatively mature yields (van der Zaag & van Loon, 1987). Light exposure secures short and robust sprouts for mechanical planting (Johansen & Molmann, 2017). Therefore pre-sprouting seed tubers in light have been considered very important in regions with cool and short growing seasons (Johansen *et al.*, 2012). Storage temperature and light among methods of pre- sprouting has been found to produce healthier crops, especially when they are exposed to a moderate temperature of 21-23 °C. Thus, the possibility of high sprouting capacity and growth vigour may be maintained for a long period under optimal storage conditions (Hartmans & van Loon 1987; Van Loon 1987). However, light requirements for seed germination may vary with temperature changes, although at the storage level, high temperature is considered the main factor that shortens the duration of dormancy, promoting sprouting activity (Wiltshire & Cobb, 1996).

Plant growth regulators and heat treatment can also be used to terminate dormancy. In heat treatment, tubers are kept in the dark-room at 18-25 °C until sprouting occurs. While in the cold shock plus heat treatment, harvested tubers are placed in 40 °C for 2 or more weeks and then held at 18-25 °C until sprouting occurs (Muthoni, 2014). The plant growth regulators that can be used in dormancy breaking and to stimulate sprout growth of seed potatoes include gibberellic acid, cytokines, and other chemicals like bromoethane (Barani *et al.*, 2013).

2.14 Effects of Storage Temperature and Light on Pre-sprouting Regimes on Seed Quality and Tuber Health

Seed potatoes are valuable because of seed potato quality, which is a determining factor in yield. The quality of seed potatoes is determined by their disease status, physiological stage, size and vigour (Caldiz, 2009). Production methods during the seed potato as well as the handling of the seed potatoes from the time of harvesting up until and during planting, affect the quality of the seed potatoes (Mehta & Ezekiel, 2006). Potato seeds can be chitted in storage using either diffused light structures or in cold rooms of about 4 °C for preservation (Beukema, 1990). Potato tubers are stored differently depending to the purpose; for seed purpose, are to be stored in 2°C and for processing, and consumption purposes are stored at 8-12 °C. These storage conditions helps to maintain the quality of the potatoes for processing (Mehta & Ezekiel, 2010).

The experiment conducted at KALRO Tigonu revealed that 8 seed potato varieties from both cold store (40 °C) and in the diffused light store were grown in the fields and all varieties achieved 100% emergence after 45 days of planting, although the emergence varied with varieties (Muthoni *et al.*, 2015). The tubers that were stored in the diffused light store emerged faster than those were from cold store. Those that were from the cold store were very cold and took long to adapt to the field conditions hence longer time to emergence and had long weak sprouts. During planting, the sprouts were just breaking down due to handling and this made them to re sprout again hence taking longer to emerge. In the stores varieties, management was according to the recommended practices for potato production in Kenya (KARI, 2008) in reference to Crissman *et al.* (1993). These varieties revealed that the production from diffused light stored tubers gave higher yield of 16.62 t ha⁻¹. The cold-stored tubers gave 14.56 t ha⁻¹ and most of the varieties yielded far below the expected levels possibly because most tubers had aged during storage (Muthoni *et al.*, 2015).

2.15 Structural changes and sprouting behaviour in potato

Since the amount of sugars present in potato tubers at the harvesting period vary in amounts, the supply of sucrose to meristem has to meet the energy demand of the developing sprout due to the connectivity of the meristem that is restored with the onset of sprout growth (Viola *et al.*, 2007). During the growth and sprouting transition of potato tubers, cellular metabolism shifts from a net synthesis of reserve compounds to net degradation (Hajirezaei *et al.*, 2003). It is during this process that starch and protein break-down outweighs their synthesis leading to the formation of soluble sugars and amino acids. During the sink

(growing) to source (sprouting) transition of potato tubers, cellular metabolism shifts from a net synthesis of reserve compounds to net degradation (Hajirezaei *et al.*, 2003). It is during this process that starch and protein breakdown outweighs their synthesis leading to the formation of soluble sugars and amino acids. During the transportation of sugars, sucrose is formed in parenchyma cells and transported via the phloem system towards the developing sprout. The sucrose will then be hydrolyzed and utilized to support the growth and development of the developing sprout. Due to increased sucrose demand in developing sprouts, soluble sugar levels decrease in storage parenchyma cells; hence the reduced sugar levels serve as a signal to trigger starch break-down to provide sufficient assimilates for sprout growth. After the growth and development of sprouts, the visible sprout growth precedes detectable starch degradation.

CHAPTER THREE
EFFECTS OF PLANT GROWTH REGULATORS AND NATURAL MATERIALS
ON DORMANCY, GROWTH AND YIELD OF POTATO (*Solanum tuberosum* L.) IN
KENYA

Abstract

Potato is amongst the highly grown and demanded crop in Kenya for food, industrial starch, and animal feed. Farmers however face a serious challenge of timely availability of well-sprouted seed potato tubers due to physiological seed dormancy period of 2-3 months, thereby reducing production cycles. This study was conducted to determine the effects of different chitting methods on enhancing pre-sprouting of different potato varieties in Kenya. Plant growth regulators (PGRs) (Gibberellins (GA₃), 6-Bezylaminopurine and Zeatin) and natural materials (grass, banana leaves and soil) were evaluated for their effects in breaking dormancy and stimulating growth of sprouts under greenhouse conditions in complete randomized design (CRD). The three plant growth regulators were sprayed at the concentration of 1mg L⁻¹ while natural materials were applied in thin layers that filters direct Photo Synthetically Active Radiation light. The evaluation of the pre-sprouted seed in the field was conducted at Egerton University and Kenya Agricultural and Livestock Research Organization (KALRO), Molo in a split plot in RCBD for two seasons. Data was taken on crop emergence, length, thickness, plant height, tubers per plant, tuber thickness and tuber yield. Data were subjected to general linear model to partition the variance component using SAS software version 9.13 and means separated using Least Significant Difference ($p \leq 0.05$). Results showed that there were significant ($p \leq 0.05$) main effects for pre-sprouting time, growth and yield of tubers. The interaction effects due to variety and treatment was also significant ($p \leq 0.05$) for sprout thickness. Natural materials produced most vigorous sprouts, increased crop emergence, plant height and superior tuber yield. Natural materials and PGRs increased tuber size for chitted potato seed by 261% and 103% respectively. Control treatments had significantly high frequency of small sized tubers than natural materials and PGRs, proving the importance of chitting in increasing tuber size and yields. Natural materials increased sprout quality (thickness and length) better than PGRs and control treatments. This study showed that small holder farmers could adopt the use of readily available soil, grass and banana leaves while large scale growers, with access to better facilities could use PGRs to break tuber dormancy for increased potato tuber yield.

3.1 Introduction

Potato (*Solanum tuberosum* L.) is one of the major tuber crops considered as the third most important food crop after rice and wheat in terms of human consumption (FAO, 2008). Its consumption is very high in the world since more than a billion people consume it (FAO, 2008). Potato is vegetatively propagated from seed tubers (Asalfew, 2016). In Kenya, potato is grown throughout the year in about 217315 hectares of land mainly in highland areas of Rift valley and Western (FAOSTAT, 2018). It is a major cash crop to many small-scale farmers (Muthoni *et al.*, 2013). The National Breeding Program and International Potato Centre (CIP) in Kenya have under taken a concerted effort in developing several potato varieties which are now commercially available for growing in different areas. These varieties are adapted to varied agro-ecological zones, have diverse agronomic traits and market preferences for different multi-uses. Some of the attributes considered in ranking a potato cultivar by farmers were high yield potential, late potato blight (*Phytophthora infestans*) resistance, taste, maturity period, market demand, bacterial wilt resistance, size of the tuber, and drought tolerance.

The National Breeding Program led by KALRO and CIP has initiated breeding for several abiotic and biotic constraints. However, the potato sector is still affected by numerous problems resulting in diminished yields affecting an estimated 800,000 potato farmers (AGRA, 2019; CIP, 2018), who mostly depend on uncertified local seeds. The dependence on uncertified seeds results in low yields that average 7.3t ha⁻¹ as compared to attainable yields of 25-35t ha⁻¹ and global average of 17.4 t ha⁻¹ (CIP, 2018; FAOSTAT, 2018). Other major problems affecting potato production in Kenya include timely availability of well-sprouted seed potato tubers (Riungu, 2011). As a physiological requirement, to convert fresh tubers to seed, potato tubers must undergo between two to three months of dormancy after harvesting which is a big impediment to availing high-quality disease-free seed for timely planting (Muchiri *et al.*, 2015). This long period of dormancy should be broken to achieve timely availability of well-sprouted seed potato tubers at the onset of rains. Furthermore, in many areas, potato is grown during short rain season after harvesting long rain season crops like maize and wheat. This implies that, it is great important to use potato seed tubers with a high growth vigour and a short growth cycle, which is currently major limitation to potato farmers. Limited availability, low quality and low vigour diseased potato seeds can be improved using a variety of seed technologies that will thrive under smallholder cultivation conditions and also improve the good-quality seed supplies in the local seed industry.

One of the most important physiological aspect of preparing potatoes for planting in potato production and which must be considered is the pre-sprouting. Pre-sprouting means preparing potatoes for planting by encouraging the production of sprouts before planting (CIP, 2018). For adequate yields and quantities to be achieved in potato, pre-sprouting seeds should be considered especially in those regions with cool and short growing seasons (Johansen *et al.*, 2012). Pre-sprouting encourages faster growth and heavier crops once the seed potatoes are planted. According to Chandrasekara (2016), potatoes can still be grown in those agro-ecologies where other crops will fail and because of this reason they are likely to play a major role in achieving the Sustainable Development Goal of Zero hunger in Sub Saharan Africa. (Harahagazwe *et al.*, 2018).

To have an early seed planting materials, introduction of growth regulators that induce dormancy breaking are important and GA3 has been widely used in many countries for breaking tuber dormancy (Benkeblia *et al.*, 2008). In general, PGHs have been playing a primary role in the regulation of potato tuber endo dormancy and many other aspects of plant development (Suttle, 2004). PGHs are considered to be the most important and efficient endogenous regulators of both tuber dormancy and sprouting. There is an evidence that from the dynamics of endogenous hormones related to stages of dormancy and sprouting there is a possibility to change dormancy duration and sprouting by tuber treatment with hormonal preparation (Aksenova *et al.*, 2013). In this process of dormancy breakage, the hormones suitable for this activity are cytokinins and gibberellins since they are required for bud break and sprout growth. There are other methods of breaking dormancy which among others include; magnetic field strengths, light exposure and physical and chemical pretreatments (Bahadir *et al.*, 2020; Yildiz *et al.*, 2017). This study determined the effects of pre-sprouting PGRs and natural materials on potato vigour, growth and yield of selected potato varieties under the green house and field conditions, with goal to improve timely availability of pre-sprouted potato seed for cropping cycles and increased yield.

3.2 Materials and Methods

3.2.1 Description of the study sites

The greenhouse experiment was conducted at Egerton University, while the field one was conducted in two sites, at Kenya Agricultural and Livestock Research Organization (KALRO), Molo and Egerton University. Egerton University lies on longitude 35° 35'E, latitude of 0° 23'S and an altitude of 2238 m above sea level. This site experiences a mean annual rainfall of 1200 mm and the average temperatures ranges between 10.2 and 22

(Jaetzold *et al.*, 2007). The Kenya Agricultural and Livestock Research Organization Molo lies on latitude of 0.2472°S, longitude of 35.7373° 'E and altitude 2480 m above sea level. This site experiences a mean annual rainfall of 1100 mm to 1500 mm and average temperature of 15° C to 25°C. (Jaetzold *et al.*, 2007).

3.2.2 Potato germplasm

Three potato genotypes with varying agronomic traits were used in this study for pre-sprouting, tuberization and yield (Table 3.1). The planting materials, Shangi, Dutch Robyjin and Kenya Karibu used as commercial varieties were sourced from KALRO Tigoni. Shangi has short pre-sprouting period and short maturation period, it is also a newly released variety. Dutch Robyjin is the oldest variety with long maturation of 3.5- 4.5 months and takes longer period to pre-sprout. Kenya Karibu has moderate chitting period and long maturity periods of 3.5 months (NPCK, 2019).

Table 3.1: Varieties evaluated in the current study and some of their attributes

Varieties	Year evaluated	Place evaluated	Maturity time	Potential yield	Dormancy duration under normal conditions
Shangi	2019-2020	Egerton University & Molo	≤3 months	30-40 t ha ⁻¹	4-6 weeks
Kenya Karibu	2019-2020	Egerton University & Molo	3-4 months	35-45 t ha ⁻¹	4-6 weeks
Dutch Robyjin	2019-2020	Egerton University & Molo	4-5 months	35-40 t ha ⁻¹	4-6 weeks

3.2.3 Experimental procedure

The greenhouse experiment was conducted at Field 7, Egerton University for two seasons (Sept-Dec-2019 and April-Aug 2020). Three PGRs and three natural materials were evaluated as pre-sprouting materials. The PGRs included Gibberellins (GA₃), 6-bezylaminopurine (BAP) and zeatin at the concentration of 1mg L⁻¹ (Kumlay, 2014). The three natural materials used were fresh banana leaves, dry grass and moist soil. The seed tubers from three varieties (Dutch Robyjin, Shangi, and Kenya Karibu) were laid in 2-3 layers in plastic trays sprayed with three plant growth regulators or covered by three natural

products. The natural materials were applied in thin layers that filters direct Photo Synthetically Active Radiation light as reported by Bushnell, (1929). The controls were the seed tubers placed in a tray neither sprayed with PGRs nor covered with natural materials.

The experiments were laid in complete randomized design (CRD) and a total of 63 trays were used, each tray carrying 20 seed tubers for each variety. At each pre-sprouting period, the temperature was maintained at ambient conditions similar to pre-sprouting storage facilities as Krystyna (2013) did in his experiment where the tubers were placed under conditions conducive to their physiological ageing from harvest to planting, in which the appropriate temperature (18 °C) was a most important condition. The pre-chitting process took 44 days, after which pre-sprouted seed was planted in two sites (Egerton Agro Science Park field station and KALRO-Molo). Data collected included number of sprouts which was physical counted at 7, 14, 21 and 28 days up to the pre-sprouting period of 4 to 6 weeks. The length of sprouts and thickness (mm) measured using electronic vernier caliper (stainless hardened MARS battery 1,55V) and colour of sprouts was determined using visual assessment.

3.2.4 Field experiment

The pre-spouted seeds were planted for evaluation in the field at KALRO Molo and Egerton's Agro-Science Park field station. The individual field plots had four rows, spaced at 0.75 m apart and 0.30 m between plants within the rows. Each experimental plot measured 3 m by 1.5 m. A standard fertilizer (NPK 17-17-17) was applied at rate of 300 kg ha⁻¹ to the furrows and incorporated into the soil prior to planting (aimed at giving 51 kg ha⁻¹ of N, P₂O₅ and K₂O), respectively. The experimental design used was split plot arrangement where the main factors were varieties and the sub factors were plant growth regulators.

All agronomic practices including weeding, spraying and earthing up were maintained. Weeding was done by uprooting immediately after plant emerged while earthing up was done at flowering stage. Early blight and late blight was controlled by Ridomil[®] gold MZ 68 WG (Metalaxyl-M 40 gkg⁻¹ + Mnacozeb 640 gkg⁻¹) at the rate of 50g/20L of water making one pump and alternated with Milor[®] 720 WP (Metalaxyl + Mancozeb 720 gkg⁻¹) at the rate of 50g/20L of water mostly when more rains were received. These chemicals were sprayed after every 7 days and 14 days when more and little rains were received respectively. Data on growth and yield and yield parameters were taken. These included tuber emergence recorded after 7, 14, 21, and 28 days after planting; number of stems (shoots) per plant was physically counted at 7, 14, 21, 28 and 35 days after emergency (DAE); plant height (cm)

measured using a ruler from the highest upper leaf base up to the tuber after complete emergence of all the varieties until at flowering stage; number of tubers per plant was counted physically after pulling out tubers (at harvesting time). The grades of tubers were done after harvesting and ranked in three classes; big size: >60 mm diameter-middle size: 30-60 mm diameter- small size: <30 mm diameter, different grades were weighed separately and values recorded were converted to $t\ ha^{-1}$. The total tuber yields (kg) was determined as mean weight of tubers per plot then converted to tons per hectare ($t\ ha^{-1}$).

3.3 Data analysis

Data were transformed using square root to meet normality assumption of ANOVA. ANOVA was performed using SAS version 9.13. Treatment means were compared using LSD test at $p \leq 0.05$. Pearson correlation analysis at 5% level of significance was done to determine the relationship between tuber yields, number of sprouts, length and thickness of sprouts, stand count, plant height, number of stems and grade of tubers.

Statistical model: $Y_{ijkl} = \mu + S_s + B_i + V_j + BV_{ij} + T_k + VT_{jk} + \epsilon_{ijks}$

Where:

Y_{ijks} = Observation

μ = Overall mean

S_s = Season

B_i = Block

V_j = Variety (Main plot)

BV_{ij} = Main plot error

T_k = subplots

VT_{jk} = Interaction between the treatments

ϵ_{ijks} = Random error component.

3.4 Results

3.4.1 Response of seed tubers to Plant growth regulators (PGRs) and natural materials under greenhouse conditions

Analysis of variance (ANOVA) showed that there were significant differences ($p \leq 0.05$) among the treatments and varieties (Appendix 1). Further, there was significant ($p \leq 0.05$) interaction between season* treatments for sprout length and variety* treatment for sprout thickness.

Combined data analysis revealed a significant difference ($p \leq 0.05$) amongst the treatments for number of sprouts on tubers, which varied with treatments (Table 3.2). The sprout quality (length and thickness of the sprouts) were significantly ($p \leq 0.05$) affected by pre-sprouting treatments which affected colour of the tubers during chitting. Purple colour was observed on seed sprouts treated with natural materials and green on seed sprouts treated with PGRs, showing that treatments resulted in production of flavonoid variants of the pre-sprouted seed tubers.

Seeds treated with grass, soil and banana leaves had thick and longest sprouts ranging from 3.86-4.71 mm thick and length of 5.49-6.73 mm compared to seeds treated with PGRs (GA3, Zeatin and BAP) and control with 2.59-2.97 mm and length of 3.44-3.69 mm; 1.59 and 2.39 mm respectively. The natural materials (soil, grass and banana leaves) increased sprout quality by 174% and 159% (means of $(4.49+4.71+3.86) - 2.26$ (control) compared to PGRs with 74% and 48 %. Seeds treated with banana leaves had good quality sprouts described by its thickness (4.71 mm) and length (6.73 mm) compared to seeds treated with GA3, with the length and thickness of 3.69 mm and 2.97 mm. Banana leaves treatment increased sprout quality by 196% (means of $4.71-1.59$) and 182% (means of $6.73-2.39$) compared to percent increase of 87% and 54% (means of $2.97 -1.59$) and (means of $3.69-2.39$) attained from GA3 treatment.

Table 3.2: Effects of plant growth regulators and natural materials on number of sprouts and sprout quality under greenhouse

Treatments	Number of sprouts				Sprout quality	
	Week 1	Week 2	Week 3	Week 4	Thickness (mm)	Length (mm)
Grass	2.06ab	3.11a	3.72ab	5.00a	4.49a	6.31a
BL	2.28a	3.00a	3.83a	5.33a	4.71a	6.73a
Soil	1.50bc	2.56ab	2.94c	3.89b	3.86b	5.49b
BAP	0.94cd	1.83c	2.56c	3.78b	2.76c	3.44c
GA3	1.44bc	2.06bc	3.11bc	3.78b	2.97c	3.69c
Zeatin	1.67ab	2.56ab	3.00c	3.50b	2.59c	3.49c
Control	0.33d	0.72d	1.22d	1.83c	1.59d	2.39d
Mean	1.46	2.26	2.91	3.87	3.28	3.51
LSD	0.67	0.69	0.68	0.93	0.49	0.64
P<0.05V	***	**	***	***	***	***
Season	ns	*	*	**	ns	ns

Key: Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$), BL: Banana leaves, GA3: Gibberellins, BAP 6-bezylaminopurine, different weeks: at pre-sprouting time, sprout quality: at week 4

The varieties showed significant difference ($p \leq 0.05$) for number of sprouts and sprout quality (thickness and length) (Table 3.3). During the 4th week of chitting, Dutch Robijn had the highest number of sprouts while Shangi and Kenya Karibu showed no significant differences (Table 3). The varietal difference was significant for thickness and length of the sprouts. Shangi had good quality sprouts (4.52 and 6.53 mm) compared to Kenya Karibu (3.41 and 4.39 mm) and Dutch Robijn (1.92 and 2.60 mm) respectively.

Table 3.3: Number of sprouts and sprout quality of three potato varieties

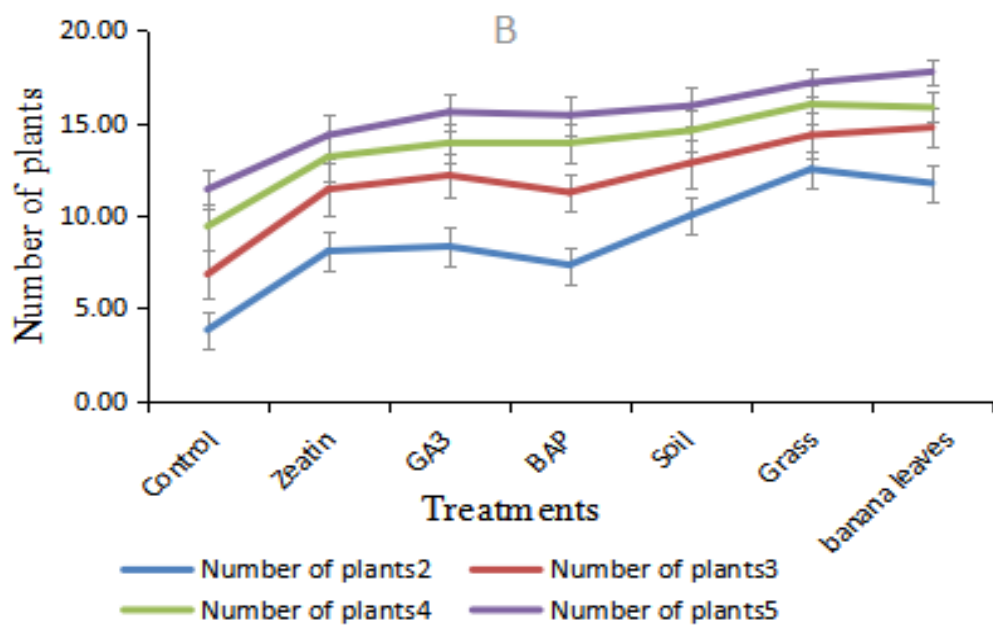
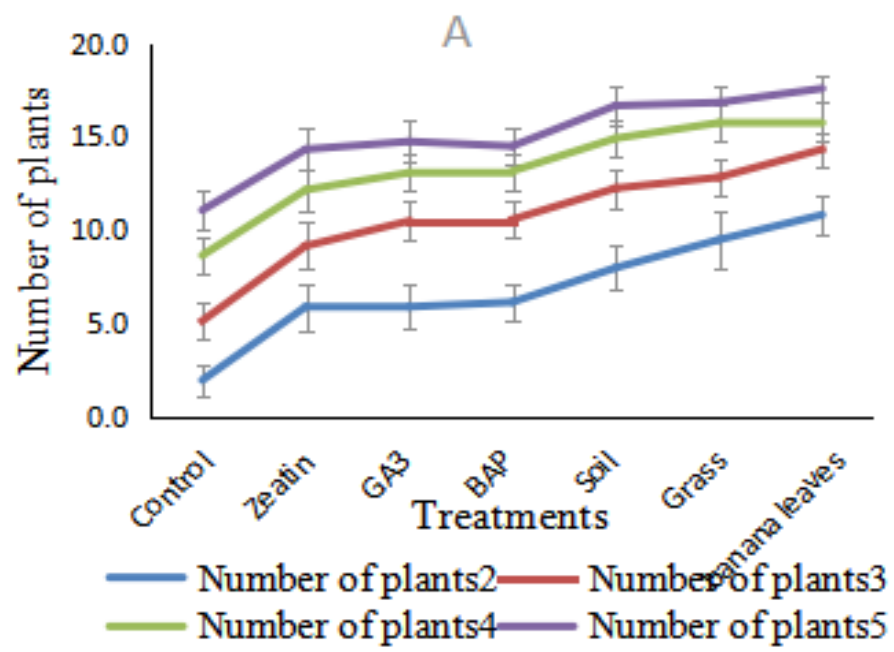
Varieties	Number of sprouts				Sprout quality	
	Week 1	Week 2	Week 3	Week 4	Thickness (mm)	Length (mm)
Shangi	2.02a	2.64a	3.43a	3.83b	4.52a	6.53a
Kenya Karibu	1.05b	1.88b	2.40c	3.29b	3.41b	4.39b
Dutch Robijn	1.31b	2.26ab	2.91b	4.50a	1.92c	2.60c
Mean	1.46	2.26	2.91	3.87	3.28	4.51
LSD	0.44	0.45	0.46	0.61	0.32	0.42
CV	20.38	15.68	20.07	18.53	22.58	21.34

Key: Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$). Different weeks: at pre-sprouting time, sprout quality: at week 4

3.4.2 Influence of plant growth regulators and natural materials on growth parameters under field conditions

Analysis of variance (ANOVA) showed that there were significant differences ($p \leq 0.05$) among the treatments, varieties and in the interaction among Site*Season*Rep*Variety. The effect due to sites was significant ($p \leq 0.05$) for number of plants at week 2, week 3, week 4 and week 5 after planting (Appendix 2).

The interaction between the varieties with treatments showed a significant difference ($p \leq 0.05$) on the germinated plants through all the weeks after planting. The interaction effects due to natural material treatments by variety was highest for the number of plants that established through all the weeks compared to PGR treatments and control (Figure 3.1 A, B and C). Generally, the interaction effects due to Shangi by banana leaves, grass and soil treatments resulted in highest numbers (19, 18 and 17, respectively) on stand count in week 5 after planting compared to Zeatin, GA3, BAP and control (16, 16, 16 and 13) respectively. The interaction between varieties and natural material treatments increased stand count by 56%, 55% and 38% for banana leaves, grass and soil respectively compared to PGR treatments 36%, 36% and 23% for GA3, BAP and Zeatin and control respectively. It was observed that amongst natural material treatments, the interaction between banana leaves treatment and the three varieties gave higher number of plants ranging between 18-19 plants per plot while amongst PGRs the highest number of plants was recorded under GA3 treatment with 15-16 plants per plot (Figure 3.1).



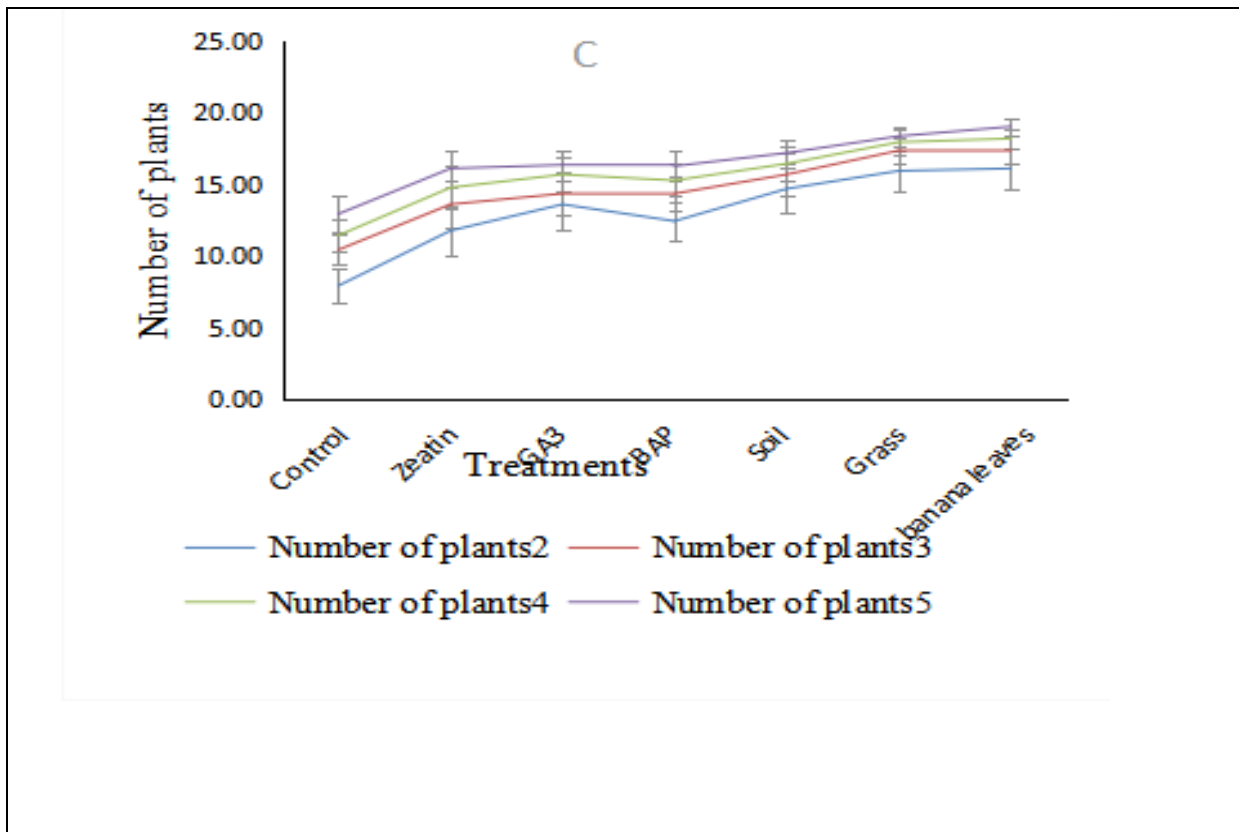


Figure 3.1: Effect of selected interactions between varieties and treatments (soil, banana leaves and grass, GA3, BAP and Zeatin) on germinated plants. Number of plants 2, 3, 4 and 5: weeks after planting. A: Dutch Robijn, B: Kenya Karibu, C: Shangi variety

The treatments showed significant difference ($p \leq 0.05$) on stand count. The plants treated with natural materials had the highest number of plants established across the weeks averaging to 10-18 per plot than plants treated with PGRs (9-15) and control (5-12). It was observed that the percent increase exhibited by natural materials and plant growth regulators treatments on number of plants varied with varieties. Natural materials and PGRs increased number of plants by 57% (means of $17.44 + 18.11 + 16.58$) - 11.81 (control) and 29% (means of $15.39 + 15.56 + 14.92$) - 11.8 (control) respectively. The effect of sites was significant ($p \leq 0.05$) for number of plants through all the 5 weeks after planting. The interactions effects were insignificant ($p \leq 0.05$) (Table 3.4).

Table 3.4: Effects of plant growth regulators and natural materials on germinated plants (stand count) at different weeks after planting in Molo and Egerton sites

Treatments	Stand count				Overall mean
	Week 2	Week 3	Week 4	Week 5	
Grass	12.64a	14.83a	16.56a	17.44b	15.36
BL	12.89a	15.50a	16.61a	18.11a	15.78
Soil	10.89b	13.58b	15.31b	16.58c	14.09
BAP	8.64c	12.06cd	14.11c	15.39de	12.55
GA3	9.28c	12.33c	14.22c	15.56d	12.85
Zeatin	8.58c	11.39d	13.36d	14.92e	12.06
Control	4.58d	7.47e	9.83e	11.81f	8.42
LSD	1.03	0.85	0.69	0.62	
CV	22.97	14.69	10.35	8.44	
variety	***	***	**	**	
Season	*	ns	*	ns	
Site	***	***	***	***	
Season*variety	ns	ns	ns	ns	
Site * variety	ns	ns	ns	ns	

Key: Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$).

The results further showed that significant difference ($p \leq 0.05$) for stand count varied with varieties (Table 3.5). Shangi had the highest number of germinated plants (13-17) compared to Kenya Karibu and Dutch Robijn.

Table 3.5: Mean comparisons of three potato varieties on germinated plants (stand count) at different weeks after planting in Molo and Egerton sites

Stand count					
Varieties	Week 2	Week 3	Week 4	Week 5	Overall mean
Shangi	13.19a	14.73a	15.65a	16.58a	15.03
Kenya Karibu	8.83b	11.94b	13.83b	15.37b	12.49
Dutch Robijn	6.90c	10.69b	13.37b	15.11b	11.52
Mean	9.64	12.45	14.29	15.69	
LSD	1.81	1.38	1.19	0.97	
CV	22.97	14.68	10.35	8.44	

Key: Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$).

The interaction effects between varieties and treatments was significant for plant height. Natural materials treatments resulted in tallest plants for all the varieties compared to the effects of interactions involving PGRs by the varieties. Plant height of 71-83 cm, 68- 81 cm and 65-76 cm were recorded for plants treated with banana leaves, soil and grass respectively across all the varieties at week 5 after plant emergence while 63-74 cm, 63-70 cm 59-74 cm; 46-59 cm in that order, were recorded from plants treated with GA3, BAP, Zeatin and control respectively (Figure 3.2 A, B and C). Amongst natural materials, the highest numbers (71, 71, 83 cm) on plant height were observed from plants treated with banana leaves treatment for all the varieties; 63, 67 and 74 cm from plants treated with GA3 (Figure 3.2).

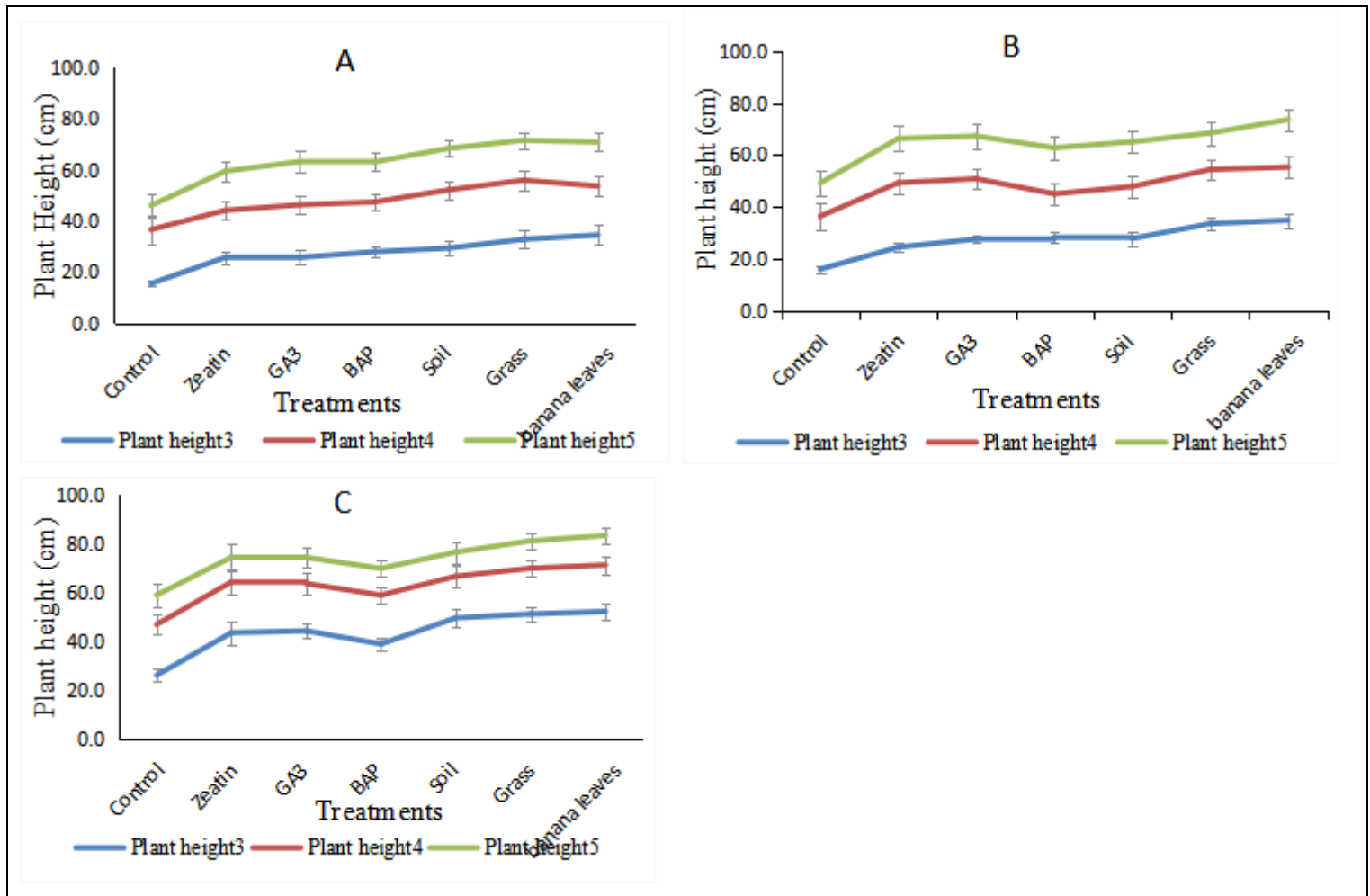


Figure 3.2: The interaction effects between varieties and treatments (soil, banana leaves, grass, GA3, BAP and Zeatin) on potato plant height. Plant height 3, 4 and 5: weeks after planting. A: Dutch Robijn, B: Kenya Karibu, C: Shangi variety

There were significant differences ($p \leq 0.05$) among the treatments and varieties for plant height and number of stems. The sites and seasons had significant effects ($p \leq 0.05$) on potato varieties at week 3, week 4 and week 5 after plant emergence. The significant differences ($p \leq 0.05$) were further observed in the interactions due to Site*Season*Rep*variety (Appendix 3).

Site had a significant ($p \leq 0.05$) effect for plant height and number of stems. Season also showed significant difference ($p \leq 0.05$) for plant height through all the weeks after plant emergence. The natural material treatments produced the tallest plants averaging to 35.56-75.86 cm compared to plant growth regulator treatments (31.22-68.23 cm) and control (19.19-51.37 cm). Pre-sprouting seeds improved vigour of the tuber plants and this was observed on plant heights where natural material treatments (grass, soil and banana leaves) increased plant height by 43%, 36% and 48%; 33%, 30% and 27% PGRs (GA3, Zeatin and BAP) respectively. The number of stems were significantly different ($p \leq 0.05$) among treatments. Plants treated with banana leaves had the highest number of stems while the highest number of stems among PGRs were recorded from GA3. Control treatments recorded lowest number of stems (Table 3.6). The significant difference ($p \leq 0.05$) on plant height varied with varieties. Higher plant height was recorded in Shangi followed by Kenya Karibu and Dutch Robijn in that order. Shangi and Dutch Robijn showed no significant difference on number for stems (Table 3.7).

Table 3.6: Effects of plant growth regulators and natural materials on plant height and number of stems at different weeks after planting.

Plant height (cm)				
Treatments	Week 3	Week 4	Week 5	Overall mean (cm)
Grass	39.14a	60.02a	73.65a	57.60
BL	40.49a	60.02a	75.86a	58.79
Soil	35.56b	55.49b	69.94b	53.66
BAP	31.68c	50.41c	65.19c	49.09
GA3	32.51c	53.56bc	68.23bc	51.43
Zeatin	31.22c	52.54bc	66.68c	50.15
Control	19.19d	39.94d	51.37d	36.83
LSD	3.00	3.21	3.21	
variety	***	**	*	
Season	**	**	*	
Site	*	**	***	
Season*variety	ns	ns	ns	
Site * variety	*	ns	ns	
Number of stems				
Treatments	Week 3	Week 4	Week 5	Overall mean
Grass	2.83a	3.64a	4.42a	3.63
BL	3.03a	3.61a	4.40a	3.68
Soil	2.43b	3.28ac	4.16ab	3.29
BAP	2.65ab	3.14c	3.46c	3.08
GA3	2.67ab	3.43ac	3.95b	3.35
Zeatin	2.34b	3.25c	3.77bc	3.12
Control	1.50c	1.80d	2.33d	1.88
LSD	0.38	0.38	0.41	
Variety	**	***	***	
Season	ns	ns	ns	
Site	**	***	***	
Season*variety	ns	ns	ns	
Site * variety	ns	ns	ns	

Key: Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$), BL: Banana leaves, GA3: Gibberellins, BAP 6-bezylaminopurine

Table 3.7: Means of three potato varieties on plant height and number of stems at different weeks after planting.

Plant height (cm)				
Varieties	Week 3	Week 4	Week 5	Overall mean (cm)
Shangi	43.76a	63.06a	74.02a	60.28
Kenya Karibu	27.47b	48.41b	64.64b	46.84
Dutch Robijn	27.26b	47.95b	63.16b	46.12
Mean	32.83	53.14	67.27	
LSD	5.33	8.25	8.42	
CV	19.65	12.98	10.28	
Season*variety	ns	ns	ns	
Site * variety	*	ns	ns	
Number of stems				
Varieties	Week 3	Week 4	Week 5	Overall mean
Shangi	2.84a	3.50a	4.11a	3.48
Kenya Karibu	1.91b	2.39b	2.94b	2.41
Dutch Robijn	2.73a	3.60a	4.31a	3.55
Mean	2.49	3.16	3.78	
LSD	0.60	0.57	0.61	
CV	33.11	26.08	23.23	
Season*variety	ns	ns	ns	
Site * variety	ns	ns	ns	

Key: Means followed by with the same letter in the same column are not significantly different ($p \leq 0.05$).

There were significant interaction ($p \leq 0.05$) for site by season by variety. When combined data analysis of variance done, site was significant ($p \leq 0.05$) for number of tubers and weight. Seasons and varieties main effects were not significant (Appendix 4).

Location had significant ($p \leq 0.05$) effect on number of tubers and weight when data was combined for both sites, seasons and varieties. The treatments significantly influenced the number of tubers, grade and weight under field trials. Plants treated with grass, banana leaves and soil were significantly ($p \leq 0.05$) different from plants treated with BAP, Zeatin and GA3 and control in terms of number of tubers produced by each plant. The greatest number of tubers, 8, 7, 7 were recorded from plants treated with banana leaves, grass and soil

treatments in that order and lowest 6, 6, 5 and 3 from plants treated with Zeatin, GA3 and BAP and control treatments respectively. Significant differences ($p \leq 0.05$) were observed for small-sized tubers and big-sized tubers. Plants treated with natural materials had the highest number of big sized potatoes (48, 48 and 45) and lowest for GA3, Zeatin, BAP and control treated plants with 27, 27, 25 and 13 respectively. The percent increase of 261% ((48+48+45) - 13) in big-sized potatoes were recorded for natural materials treated plants compared to those with PGRs (103%). Control had significantly ($p \leq 0.05$) higher percent (64%) small sized tubers than natural materials and plant growth regulators.

The results further showed that, plants treated with natural materials, PGRs and control had significant differences ($p \leq 0.05$) for tuber weight. Most weight was recorded from those materials treated with grass (23.63 t ha⁻¹), banana leaves (23.51 t ha⁻¹), and soil (22.20 t ha⁻¹) compared to those treated with BAP (15.85 t ha⁻¹), GA₃ (16.74 t ha⁻¹) and Zeatin (16.35 t ha⁻¹) and control (7.585t ha⁻¹) respectively.

Table 3.8: Effects of plant growth regulators and natural materials on tuber yield

Treatments	Number of tubers	Small size <30 mm	Medium size 30-60 mm	Big size >60 mm	Weight t ha ⁻¹
Grass	7.30b	24.93c	26.98ab	48.09a	23.63a
BL	7.95a	22.57c	29.44a	48.00a	23.51a
Soil	7.01b	27.28c	27.48ab	45.24a	22.20a
BAP	5.39c	48.37b	26.21ab	25.42b	15.85b
GA3	5.66c	48.14b	24.94ab	26.95b	16.74b
Zeatin	5.73c	48.89b	24.47ab	26.64b	16.35b
Control	3.13d	64.38a	22.28b	13.34c	7.85c
Mean	6.02	40.66	25.97	33.38	18.02
LSD	0.59	7.54	6.24	6.21	2.34
CV	21.04	17.00	34.11	26.64	27.98
variety	ns	ns	ns	ns	ns
Season	ns	**	*	ns	ns
Site	***	ns	ns	ns	***

Key: Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$), BL: Banana leaves, GA3: Gibberellins, BAP 6-bezylaminopurine

The varieties showed no significant difference ($p \leq 0.05$) on the number of tubers. The biggest tubers were recorded in Shangi although, there were no significant difference observed among varieties. Kenya Karibu was the highest yielding variety (20.24 t ha⁻¹) followed by Dutch Robijn (17.31 t ha⁻¹) and Shangi (16.50 t ha⁻¹) (Table 3.9).

Table 3.9: Mean comparisons for tuber yield of three potato varieties

Varieties	Number of tubers	Small size <30mm	Medium size 30-60mm	Big size >60mm	Weight (t ha ⁻¹)	Overall mean
Shangi	5.83a	41.30a	23.70a	35.01a	16.50b	24.47
Kenya Karibu	5.80a	39.99a	25.19a	34.83a	20.24ab	25.21
Dutch Robijn	6.44a	40.68a	29.02a	30.31a	17.31b	24.75
LSD	1.33	6.97	7.16	6.14	3.24	

Key: Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$).

3.4.3 Correlation between sprout, growth and yield parameters for greenhouse and field trials

Sprout parameters (number, thickness and length) were positively correlated to growth and yield parameters. Number of sprouts was fairly correlated to stand count and tuber grade with 0.17 and 0.15 but strongly correlated to plant height (0.23), number of stems (0.22), and tuber weight (0.44). The sprout thickness and length had a significantly strong positive correlation to stand count (0.33 and 0.34), plant height (0.31 and 0.26), tuber grade (0.30 and 0.31) and tuber weight (0.25 and 0.26) (Table 3.10). Correlation analysis further showed a fair correlation of 0.15 between sprout thickness and tuber grade. Tuber grade showed no relationship with stand count, plant height, number of stems and number of tubers. The results further showed a fair correlation of 0.14 and 0.16 between sprout thickness and length with number of sprouts.

Table 3.10: Combined Pearson correlation coefficient with probability value on sprout, growth and yield parameters

	Stand count	Plant height	Numb er of stems	Numb er of tubers	Tube r grade (> 60m m)	Tube r weigh t	Numb er of sprout s	Sprout thickn ess	Spro ut lengt h
Stand count	1.00								
Plant height	0.68* **	1.00							
Number of stems	0.50* **	0.56* **	1.00						
Number of tubers	0.71* **	0.58* **	0.47** *	1.00					
Tuber grade(>60 mm)	0.02	0.03	0.07	-0.10	1.00				
Tuber weight	0.49* **	0.52* **	0.45** *	0.49** *	0.19* *	1.00			
Number of sprouts	0.17* *	0.23* **	0.22** *	0.22** *	0.15* *	0.44* **	1.00		
Sprout thickness	0.37* **	0.31* **	0.23** *	0.19** *	0.30* **	0.25* **	0.14* *	1.00	
Sprout length	0.34* **	0.26* **	0.20** *	0.17** *	0.31* **	0.26* **	0.16* *	0.92** *	1.00

Key: *, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$) respectively.

3.5 Discussion

Seed availability at the right planting time is a very important contributory factor in potato production. This study suggests that seeds with different dormancy periods can be available at any time of the planting season once the dormancy period is accelerated. There are several methods involved in dormancy breaking and one of those methods can be the use of chemicals (Ezekiel & Singh, 2005). In this study, the response of three potato varieties varied with tested pre-sprouting treatments (soil, grass and banana leaves; zeatin, BAP, GA₃ and control). The significant differences ($p \leq 0.05$) among the treatments and varieties showed the greatest influence of natural materials and plant growth regulators in breaking dormancy of different varieties. Seeds that were treated with natural materials have been found to have good quality sprouts under greenhouse and obtained higher yields in the field than those that were treated with plant growth regulators (Zeatin, BAP, GA₃) and control. Among the seed tubers that were treated with natural materials treatments; seeds treated with banana leaves had many good quality sprouts. This could be due to the fact that banana leaves contain ethylene that induces sprouting.

In the experiment conducted by Salda and Bayogan, (1986) where they evaluated practical methods of breaking tuber dormancy, they found that more than yellow “saba” bananas and madre cacao leaves gave more sprouts per tuber. They further showed that over 80% tuber sprouting was recorded by seed tubers treated with bananas when compared with dark stored tubers and non-ethylene source treated tubers. The results of this study showed the effectiveness of banana leaves in breaking dormancy which are in agreement with their results. They further mentioned that bananas and madre cacao leaves are ethylene sources which have been found to have high levels of ethylene, according to (Tirtosoekotjo & Bautista, 1984). Rlyski *et al.* (1974) stated that ethylene could prematurely terminate dormancy when applied for a short period.

The natural materials increased sprout quality (thickness and length) by almost 174% and 159% and PGRs by 74% and 48 %, respectively, than the control indicating the importance of pre-sprouting the seeds in potato production. The pre-sprouted seeds germinate faster and mature early, which have been found to increase yields. Grass and banana leaves have been used for so many years in crop production as mulch and for decomposing the soil but there is little information on their use on pre-sprouting seed tubers. These materials produced vigorous sprouts, induced sprouting faster and obtained higher yield when compared to plant growth regulators and control. This could be attributed to increased

temperature generated by the coverage of banana leaves, soil and grass in thin layer in the greenhouse which allowed a portion of light, darkness and warmth which is needed by a seed to germinate. Suttle (2007) reported that heat treatment and dark conditions induce sprouting, which supports the findings of this study. (Bushnell, 1929) who in his study used a small pile of seed potatoes by alternate layers of straw and soil during winter, he discovered that natural materials do maintain temperature. The dormancy period of seed tubers can be reduced by higher temperatures as said by (Deligios *et al.*, 2020).

The potential of banana leaves, grass and soil together with plant growth regulators in terms of performance were seen under field evaluation. More than 50% of the seeds treated with natural materials had emerged in the second week of planting and these included Kenya Karibu and Dutch Robijn varieties that have medium and long dormancy periods while less than 50% had germinated under plant growth regulator treatments. In this scenario, natural materials had increased germination by 57% and PGRs by 29% in week 5 after planting, which was the expected week (28 days) for potato seeds to have emerged. As much as cytokinins and gibberellins are responsible for bud breakage and sprout growth (Suttle, 2004), this study showed that Zeatin, BAP and GA₃ initiated sprouting of seed tubers but they seemed to be very slow compared to natural materials. Thus short, medium and long dormancy periods of Shangi, Kenya Karibu and Dutch Robijn varieties were effectively enhanced by natural materials than PGRs. Hassani (2014), indicated that the application of growth regulator hormones and gibberellic acid caused the postponement of sprouting in his results. However, when compared to control (wash by water) he found out that plant growth regulator hormones caused significant differences in the number of days to break dormancy. As shown by the results of this study, plant growth regulators did enhance sprouting when compared to control, which is in agreement with his results. The effectiveness of natural materials was again reflected on plant height and yield. Natural materials treated plants were tallest, averaging to 75.86 cm compared to 68.23 cm and 51.37 cm obtained from PGRs treated plants and control, respectively. The differences could be attributed to fast and slow emergence due to the quality of sprouts obtained from the greenhouse.

In the yield performance evaluation, Kenya Karibu and Dutch Robijn with medium and long dormancies produced highest tuber yield than Shangi, a known high yielding variety with a short dormancy. However, although Dutch Robijn was the superior in terms of tuber yield, it had relatively high proportion of small and medium sized tubers. The increased yields could be due to the effect of pre-sprouting treatments which have been found to be very effective in hastening tuber dormancy hence increased tuber number, grade and weight.

This result is in line with Johansen (2012), who found that pre-sprouted seeds increased total tuber yield, marketable tubers and tuber numbers per plant in both two years he carried his experiment than cold-stored seeds.

The varieties have different colours of the sprouts. However, this study found that the most dominant colours of the sprouts were green and purple. The colours of the sprouts indicated good health of the seed tubers that were pre-sprouted. In addition, healthy sprouts are normally strong and firm. The pre-sprouted seed tubers especially in light develop chlorophyll hence the sprouts become shorter and hardened (Beukema & van der Zaag, 1990).

Pearson correlation coefficient showed that sprout thickness and length had significantly strong positive correlation to stand count, plant height, tuber grade and tuber weight. This means that when sprouts are thick and long they become more vigorous; hence the higher chances of plants to emergence and grow, that's according to Solomon (2006), 5 point scale of sprout vigour. Moreover, the length and thickness of the sprouts as shown by Pearson correlation coefficient analysis of this study, can increase the size of the tubers and weight due to high growth rate of the crop. However, it is not guaranteed that the length and thickness of the sprouts can increase number of tubers as indicated by the results that the length and thickness was fairly correlated with number of tubers. Still, the number of sprouts resulted in higher number of tubers. The same results were found by Cavalcante *et al.* (2019) that the number of tubers per plant correlated with the number of stems especially when the tubers were more sprouted.

3.6 Conclusion

The findings of this study showed that, the effect of natural materials and plant growth regulator treatments and their interaction with varieties were significant for yield and for hastening tuber dormancy. Although the tested varieties responded differently to the treatments, the natural materials increased sprout quality in terms of length and thickness by 174% and 159% as compared to controls. On the other, PGRs increased sprout quality in terms of length and thickness by 74% and 48%, indicating that natural materials were best for chitting. Overall using natural materials and PGRs increased tuber size by 261% and 103%, respectively. The results suggest that the natural materials (grass, soil and banana leaves) which are readily available and cheaper are effective methods for breaking dormancy for small scale farmers and hence would boost farmers' yields if adopted. PGRs (GA3, zeatin and BAP) also increased yields, but required better facilities like stores and slightly

expensive, hence can be recommended for use by the large scale farmers who continuously plant throughout the year and need seed continuously. Dutch Robijn variety recorded heavy weight than Shangi but it had more number of small and medium tubers. Therefore, Shangi and Kenya Karibu can be recommended under pre-sprouting conditions as high yielding varieties to be used in potato production since they gave both good quality sprouts, good grade and heavy weight. The study recommends further research on the composition of grass and banana leaves as perennial plants and their effectiveness on sprouting; with careful monitoring and evaluation.

CHAPTER 4
EFFECTS OF DIFFERENT LIGHT EXPOSURE REGIMES ON PRE-SPROUTING
AND YIELD PERFORMANCE ON POTATO (*Solanum tuberosum* L.) SEED IN
KENYA

Abstract

The major problems affecting potato (*Solanum tuberosum* L.) production in Kenya include timely availability of well-sprouted seed potato tubers. Appropriate techniques of availing of well-sprouted potato seed for timely planting for different potato varieties with varied seed dormancy periods is one of the major challenges for yield increase. This study was conducted to determine the effects of different light exposure regimes on pre-sprouting, seed germination and yield performance of potato in Central Rift, Kenya. Three light exposure regimes of 8, 12, and 16 hours in three potato varieties. The lighthouse experiment was laid on complete randomized design (CRD) with three replicates while field experiment was laid on randomized complete block design (RCBD). The trial was laid in complete randomized design with three replicates. Data was taken on the number of sprouts, time to pre-sprout, sprout lengths, diameters and colour; emergence, plant height, number of tubers per plant, and tuber weight. Data were subjected to analysis of variance (ANOVA) and means were compared using Duncan multiple range test (DMRT) ($p \leq 0.05$) using SAS software. There were significant differences ($p \leq 0.05$) in different light exposures on measured traits. Sprouting time was reduced from 44 days to 21 days. Further, light exposure regimes significantly increased sprout thickness by 31 to 43 % and sprout length by 15 to 39% when compared with those of control treatment. Light exposure of 16 hours resulted in the highest percent seed germination and tuber weight by 9.5 and 25%, respectively. This suggests that increasing period of light exposure by using simple fluorescence system in pre-sprouting stores will enhance breaking of potato seed dormancy resulting in increased yields.

4.1 Introduction

In Kenya, potato is grown throughout the year in about 217315 hectares of land mainly in highland areas of Rift valley and Western (FAOSTAT, 2018). It is a major cash crop to many small-scale farmers (Muthoni *et al.*, 2013). The major problems affecting potato production in Kenya include timely availability of well-sprouted seed potato tubers (Riungu, 2011). As a physiological requirement, to convert fresh tubers to seed, potato tubers must

undergo between two to three months of dormancy after harvesting which is a big obstacle to achieving high-quality disease-free seed for timely planting (Muchiri *et al.*, 2015). This long period of dormancy should be broken to achieve timely availability of well-sprouted seed potato tubers at the onset of rains. Furthermore, in many areas, potato is grown during short rain season after harvesting of the long rain season crops like maize and wheat. This implies that, it is very important to use potato seed tubers with a high growth ability and a short growth cycle, which is currently a major limitation to potato farmers. Limited availability, low quality and low diseased potato seeds can be improved using a variety of seed technologies that will thrive under smallholder cultivation conditions and also improve the good-quality seed supplies in the local seed industry.

To have an early seed planting materials, the idea of exposing seeds to light can be implemented to increase growth ability with good tuber sprouting. Exposing seed tubers to light before the estimated planting date would help in preventing sprout elongation resulting in strong sprouts, fast emergence, early tuber initiation, increased sprouts maximal vigour and relatively mature yields (van der Zaag & van Loon, 1987). The exposure duration is one of the determining effect of light on dormancy (Ballare & Casal, 2000). Light promotes the multiple sprouting stage and keep sprouts short and strong (Mani, 2015). Pre-sprouting seed potato tubers in light is one way to speed up plant development (Struik & Wiersema, 1999). Light further enhances advanced plant growth and higher early yields (Eremeev *et al.*, 2008). Light exposure methods of pre-sprouting has been found to produce healthier crops and considered very important in regions with cool and short growing seasons (Johansen *et al.*, 2012). Since the dormancy period differs with the cultivars, it would therefore be of great importance to consider factors such as time and age of the cultivar to enable the farmer to have a wider choice for selection of varieties during pre-sprouting time. Under longer season conditions, temperatures and light during the later stages of seed potato storage may be useful in manipulating tuber size distribution and yields of the desired size grades (Haverkort *et al.*, 1990). These are very important aspects to have high growth vigour, which can be defined as fast emergence and establishment of a green plant. This can be beneficial regarding resistance against diseases and weeds and thereby improve both yield and quality. Well sprouted quality seed has a significant potential of increasing farm productivity due to enhanced vigour. Thus, planting a high-quality seed with vigorous sprouts can bring chances of early harvest, early marketing of the produce and more profitable production, contributing to 30% of the total production (Ellis, 1992; Halmer, 2003). However, in the major growing areas of Kenya, the use of poor-quality non pre-sprouted potato seeds is high and this has been found to

accelerate the spread of seed-borne diseases such as bacterial wilt, which has shown to affect 77% of potato farms in the country (Kaguongo *et al.*, 2010; Muthoni *et al.*, 2013).

Furthermore, close to 800 000 farmers were heavily engaged in potato production and due to limited use of high-quality seeds, the potato yields were low, with an average yield of approximately 10 tons per hectare (AGRA, 2019). This makes it important that the pre-sprouted seed tubers be provided at the right time to farmers during planting which occurs throughout the year. In each year, 1.5 million tons of potato is produced, generating livelihood for millions of Kenyans (Kimani, 2016). Potato in Kenya is among those crops contributing to food security and poverty alleviation and it has been found to have the highest yielding capacity in arable land and produces more yields per hectare than any other crops (Chandrasekara, 2016). Therefore, cost effective ways of increasing availability of potato seeds by manipulating their responses to physiological ageing to enhance growth, yield and maturity for increased growing seasons should be deployed in a more cost-effective way. Terminating dormancy in freshly harvested potatoes in this scenario is of great importance since it would enable seeds to sprout adequately, which will enhance early planting and increase the productivity of potatoes (Mustefa *et al.*, 2017). This study determined the effect of light exposure regimes on pre-sprouting and seed potato performance in the lighthouse and field conditions.

4.2 Materials and Methods

4.2.1 Site description

This study was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO), Molo and Egerton University Agro-science Park Research station. Egerton University lies on longitude 35° 35'E, latitude of 0° 23'S and an altitude of 2238 m above sea level. The site has a mean annual rainfall of 1200 mm and the average temperatures range between 10.2 and 22 (Jaetzold *et al.*, 2007). Kenya Agricultural and Livestock Research Organization Molo lies on latitude of 0.2472°S, longitude of 35.7373° 'E and altitude 2480 m above sea level. This site experiences a mean annual rainfall of 1100 mm to 1500 mm and average temperature of 15°C to 25°C. (Jaetzold *et al.*, 2007). Molo represented high altitude while Egerton represented medium altitude zones for potato growing in Kenya.

4.2.2 Germplasm evaluated

Three commercial potato varieties in Kenya, Shangi, Dutch Robijn and Kenya Karibu were used for pre-sprouting, tuberization and yield evaluation. Shangi, a newly released variety has a short pre-sprouting period and short maturation period. Dutch Robijn, the oldest variety has long maturation of 3.5-4.5 months and takes longer period to pre-sprout. Kenya Karibu has moderate pre-sprouting period and long maturity periods of 3.5 months (NPCK, 2019). Shangi and Dutch Robijn are susceptible to late blight while Kenya Karibu is tolerant to late blight (Sinelle, 2018).

4.2.3 Experimental procedure

The experiment was conducted in the lighthouse (Egerton tissue culture room) for 4 to 6 weeks. The seed tubers of each variety were evaluated in cartoons having uniform perforations on their tops to allow light penetration under normal temperatures of 21-23 °C.

The treatments consisted of four daily light exposures of 8, 12 and 16 hours and the control, where tubers were subjected to normal room light conditions. The experiment was laid on a Complete Randomized Design (CRD) with 3 replicates. Light exposures were monitored at different times; at 7 am, the two light exposures (12 h and 8 h) were switched on and that of 8 h was switched off at 3 pm. The 16 h light was switched on at 3 pm and switched off at 7 am of the following day. The light fluorescent tubes 4ft tubes were used for pre-sprouting potatoes, which have been reported to provide brighter and more reliable light with a stronger chit with light illumination ranging between 500-800 lux. Subsequent sprout and quality seed tuber were determined and evaluated in the field. The data collected in the lighthouse and control conditions included number of sprouts by physical counting, every week. The electronic vernier caliper (stainless hardened MARS battery 1,55V) was used to measure the length and thickness (mm) of the main sprouts from the 'eyes'. The colour of sprout was determined using visual assessment. Light received by each variety under light exposures of 8, 12 and 16 hours was taken once at the beginning of the experiment using a light meter (Digital Lux Meter As823).

4.2.4 Evaluation of pre-sprouted potato seed under field conditions.

The pre-sprouted seeds were planted at KALRO Molo and Egerton Agro Science Park field station to determine time to emergence, growth and yield. The experimental plots measured 3 m by 1.5 m in a RCBD design. The plots consisted of four rows, spaced at 0.75 m apart and 0.30 m between plants within the rows. A standard fertilizer (NPK 17-17-17) was

applied at rate of 300 kg ha⁻¹ to the furrows and incorporated into the soil prior to planting (aimed at giving 51 kg ha⁻¹ of N, P₂O₅ and K₂O), respectively to give adequate balanced supply of nutrients to sustain plants' needs and growth.

All agronomic practices such as weeding, spraying and earthing up were maintained according to procedures described by (CIP, 2009). Weeding was done by uprooting immediately after plant emerged while earthing up was done at flowering stage. Early blight and late blight were controlled by Ridomil[®] gold MZ 68 WG (Metalaxyl-M 40 gkg⁻¹ + Mnacozeb 640 gkg⁻¹) at the rate of 50g/20L of water making one pump and alternated with Milor[®] 720 WP (Metalaxyl + Mancozeb 720 gkg⁻¹) at the rate of 50g/20L of water mostly when more rains were received. Spraying was done after every 7 days and 14 days when more and little rains were received respectively. Data on growth and yield parameters were taken. These included tuber emergence recorded after 7, 14, 21, and 28 days after planting; number of stems per plant was physically counted at 7, 14, 21, 28 and 35 days after emergency (DAE); plant height (cm) measured using a ruler from the highest upper leaf base up to the tuber after complete emergence of all the varieties until at flowering stage; number of tubers per plant was counted physically after pulling out tubers (at harvesting time). The grades of tubers were done after harvesting and ranked in three classes; big size: >60 mm diameter-middle size: 30-60 mm diameter- small size: <30 mm diameter, different grades were weighed separately and values recorded were converted to t ha⁻¹. The total tuber yields (kg) was determined as mean weight of tubers per plot then converted to tons per hectare (t ha⁻¹).

4.3 Data analysis

Data were subjected to a normality test and transformed using square root to meet normality distribution and assumption of analysis of variance. ANOVA was performed using SAS version 9.1.3 software. Treatment means were compared using LSD test at p≤0.05. Pearson correlation analysis at 5% level of significance was done to determine the statistical relationship between tuber yields, number of sprouts, length and thickness of sprouts, stand count, plant height, number of stems and grade of tubers.

Statistical model: $Y_{ijklm} = \mu + S_s + B_i + V_j + SV_{sj} + T_k + ST_{sk} + VT_{jk} + STV_{skj} + \epsilon_{ijks}$

Y_{ijks} = Observation

μ = Overall mean

S_s = Site

B_i = Block

V_j = Variety

SV_{sj} = Interaction effect due to site and varieties

T_k = Treatments

ST_{jk} = Interaction effect due to site and treatments

VT_{jk} = Interaction effect due to varieties and treatments

STV_{skj} = Interaction effect due to site, treatments and varieties

ϵ_{ijks} = Random error component.

4.4 Results

4.4.1 Effects of different light exposures on potato seeds under light-house

The results for the analysis of variance (ANOVA) showed that there were significant differences ($p \leq 0.05$) among varieties and treatments used. The significant effect of treatments was observed in week 1 of pre-sprouting and on the sprout quality (Appendix 5). The interaction between varieties and treatments showed that varieties' responses varied with treatments.

Light exposure regimes had significant differences ($p \leq 0.05$) on sprout quality measured on sprout thickness and length (Table 4.1), which varied amongst tested potato varieties. The 8 and 12 hours light exposures treated tubers recorded thicker and longest sprouts of 4.76 mm and 5.09 mm; 8.64 mm and 7.73 mm compared to 16 hours of light exposure and control treated tubers which had 4.66 mm and 3.56; 7.16 mm and 6.21 mm, respectively. Light exposures also significantly increased the sprout thickness by 31 to 43 % and sprout length by 15 to 39% compared to control treatment (room conditions). There was, however, a significant difference exhibited by light hours on number of sprouts. Overall, 12 and 16 hours had the highest number of sprouts (2.67 and 2.56) than 8 hours and control (2.33 and 2.44). The 12 hours of light exposure seemed to have significantly influenced the number of sprouts from week 1 of pre-sprouting to week 4 (1-3 sprouts).

The varietal significant differences ($p \leq 0.05$) were observed on the length and thickness of the sprouts (Table 4.1). Shangi had thickest and longest sprouts (6.19 mm and 11.92 mm) followed by Kenya Karibu (4.61 mm and 6.12 mm) and Dutch Robijn (2.77 mm and 4.27 mm) respectively. The varieties further showed the significant difference ($p \leq 0.05$) on the number of sprouts. Shangi, sprouted within the first week of pre-sprouting and it had the highest number of sprouts in the 4th week. Similarly, Kenya Karibu and Dutch Robijn

developed visible sprouts in the second week of pre-sprouting and had equal number of sprouts averaging to 2 in the last week of pre-sprouting. Dutch Robijin had light green colour on the sprouts while Shangi and Kenya Karibu had purple colour on their sprouts.

Table 4.1: Effects of light exposures treatments on number of sprouts and sprout quality under light house

Variety	Number of sprouts				Sprout quality	
	Week1	Week2	Week3	Week4	Thickness	Length
Shangi	1.000a	1.667a	2.500a	3.583a	6.190a	11.929a
Kenya Karibu	0.250b	1.000b	1.250b	1.583c	4.606b	6.123b
Dutch Robijin	0.250a	1.000b	1.333b	2.333b	2.770c	4.257c
Treatment						
16 hours	0.333b	1.333a	2.111a	2.556a	4.656b	7.158b
12 hours	1.000a	1.222a	1.667ab	2.667a	5.091a	7.731b
8 hours	0.333b	1.222a	1.333b	2.333a	4.778b	8.642a
Control	0.333b	1.111a	1.667ab	2.444a	3.563c	6.213c

Key: Means followed by the same letter in the same column are not significantly different ($p \leq 0.05$). Week 1, 2, 3 and 4: at pre-sprouting time, sprout quality: at week 4

4.4.2 Growth and yield performance of pre-sprouted potato seeds under field conditions

The findings showed that there was significant interaction between varieties on many measured traits across the sites, except on germinated plants (stand count) which was non-significant. There were significant differences ($p \leq 0.05$) observed due to the effect of site on the performance of varieties and for 12 and 16 hours of light treatments (Appendix 6). The significant ($p \leq 0.001$) difference interaction between site and varieties showed that the response of varieties varied with sites.

Light exposures with treatments on Shangi variety showed consistency on plant germination and had the highest number of germinated plants through all the weeks after planting. However, 16 hours of light treatment on Dutch Robijn and Kenya Karibu produced the highest percent germination of 92 % and 96% at week 4 after planting respectively.

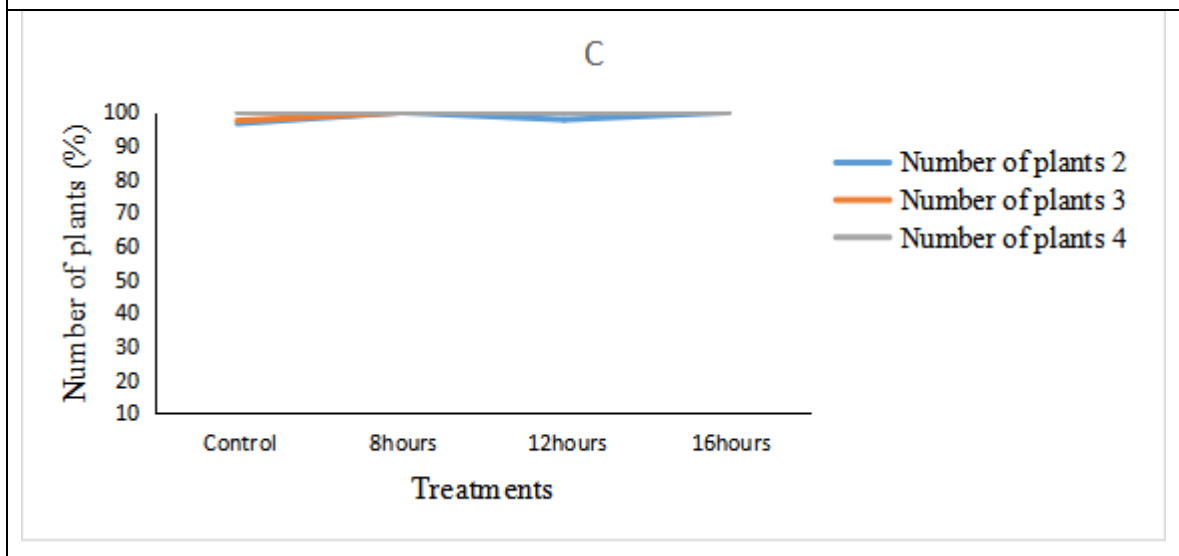
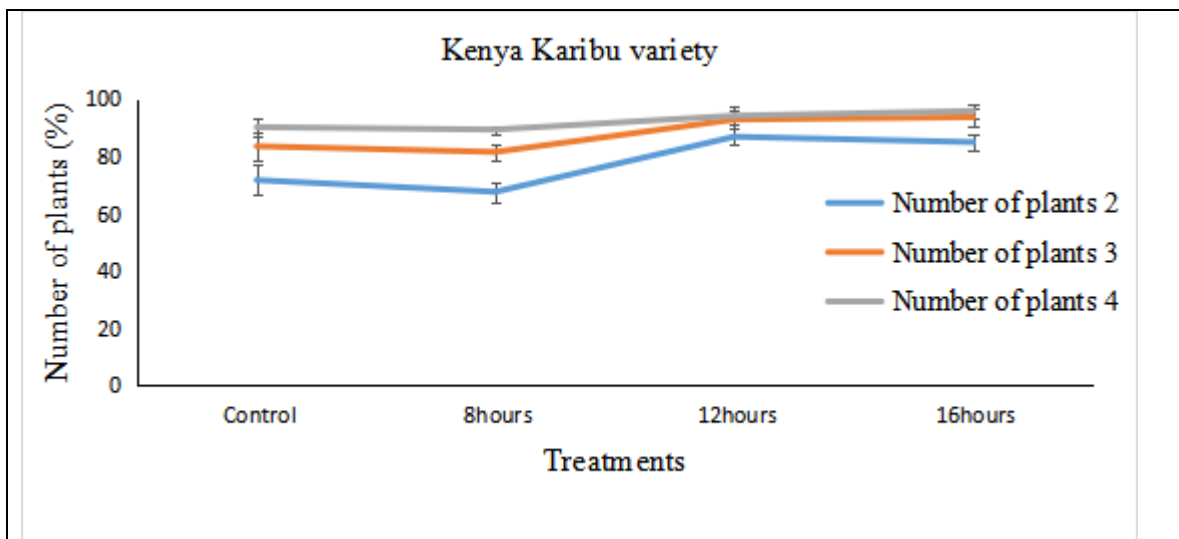
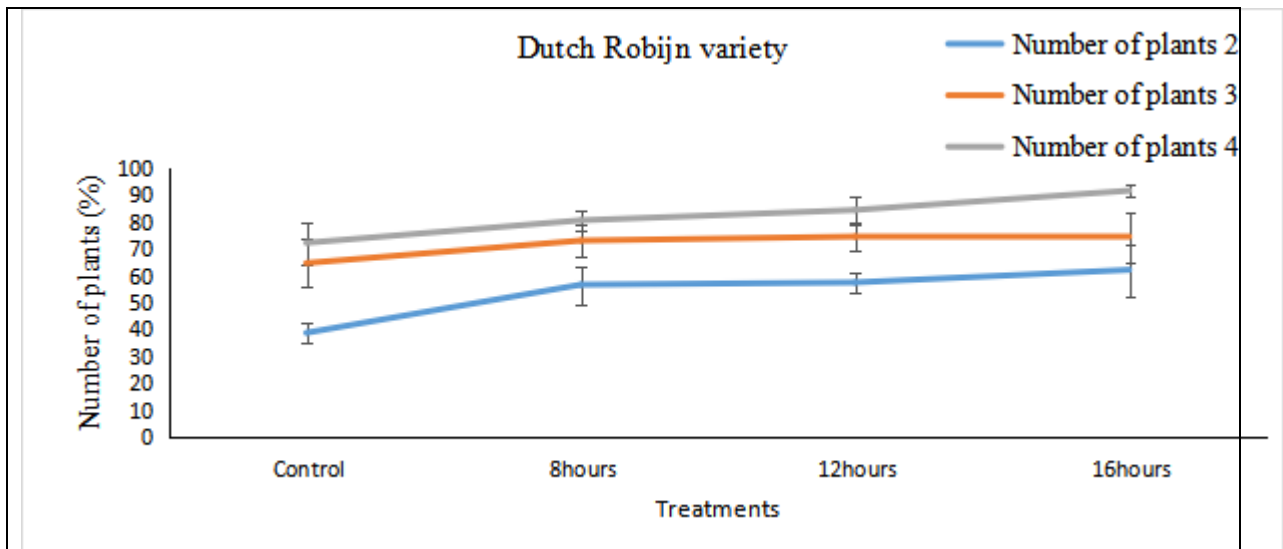


Figure 4.1: Means of number of plants for pre-sprouted potato seed for three varieties under three light exposures and control

The light hour's treatments showed significant difference ($p \leq 0.05$) on number of plants (stand count) at week 2 after planting, where 12 and 16 hours of light exposure were significantly different from control (Table 4.2). The 8 hours of light and control treatments showed no significant differences at week 3 and week 4 after planting. Among the light exposure treatments, the highest percent plant germination was observed for plants that were exposed to 16 hours light (94%) followed by 12 hours (93%) and 8 hours light (89%). Control treatment recorded the least overall 87% germination. Light exposures (16, 12 and 8 hours) increased plant germination by 7%, 6% and 2 % (means of 93.89 and 87.44) respectively. Seed tubers that were exposed to 16 hours of light were observed to have the highest percent germination across the weeks while least was recorded for control treatment.

The results further revealed that there were varietal significant differences ($p \leq 0.05$) on stand count (Table 4.2). Shangi had the highest percent plant germination. At week 2 after planting, Shangi had 97% germination followed by Kenya Karibu (79%) and Dutch Robijn (54%) while in the last week Shangi had complete germination (100%), Kenya Karibu (91%) and Dutch Robijn (82%) in that order.

Table 4.2: Mean separation for site, variety and treatment on stand count at different weeks after planting in Molo and Egerton sites

Stand count (%)			
Site	Week 2	Week 3	Week 4
Molo	79.139a	91.389a	94.944a
Egerton	74.306a	81.194b	88.056b
Variety			
Shangi	98.625a	99.375a	100.0a
Kenya Karibu	77.750b	87.875b	92.375b
Dutch Robijn	53.792c	71.625c	82.125c
Treatment			
16 hours	82.371a	89.333a	95.778a
12 hours	80.722ab	89.111a	92.833ab
8 hours	74.741bc	84.833ab	89.944bc
Control	69.056c	81.889b	87.444c

Key: Means followed by the same alphabetical letter are not significantly different according to DMRT at $p \leq 0.05$

Analysis of variance showed that varieties had significant difference ($p \leq 0.05$) on number of stems and plant height. The significant differences on plant height were observed due to site effect at week 2 and 3 of plant emergence (Appendix 7).

The interaction between varieties and treatments showed no significant difference on plant height. However, the 16 hours of light treatment on Shangi resulted in tallest plants in all the weeks after plant emergence. As regards to Dutch Robijn and Kenya Karibu varieties, control, 8 hours and 16 hours of light exposure had a slight difference of 2 cm on the tallest plants (Figure 4.2).

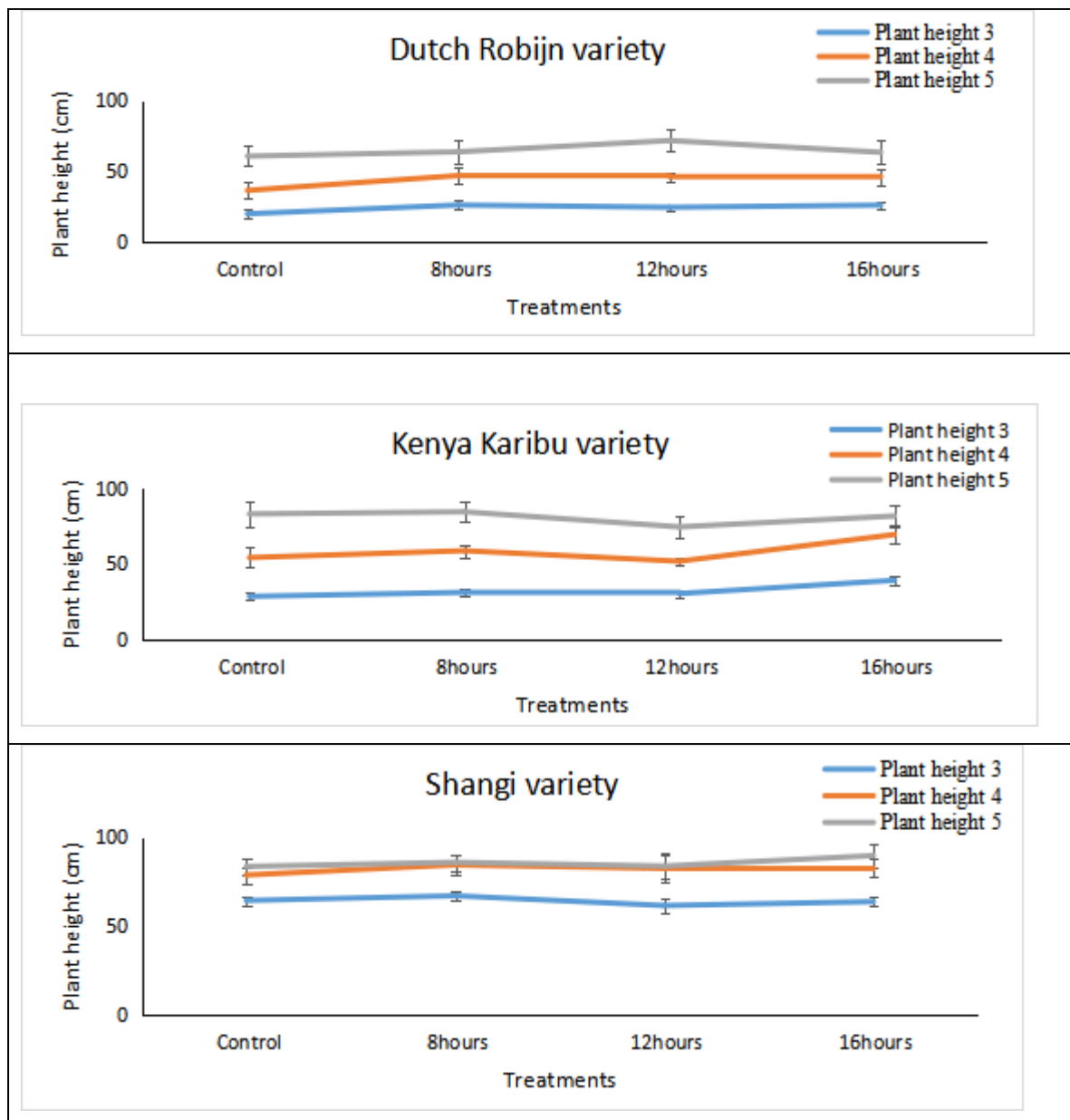


Figure 4.2: Effect of interactions between potato varieties and light exposure treatments (8, 12 and 16 hours) and control (seeds placed under natural room light conditions) on plant height. Plant height 3, 4 and 5: weeks after planting.

Treatments showed no significant differences ($p \leq 0.05$) on plant height at week 5 of plant emergence (Table 4.3). However, plants exposed to 16 hours of light treatment were taller than plants that were exposed to 8 and 12 hours of light and control treatments in that order. On average, the tallest plants from 16 hours of light treatment ranged between 42.93 and 78.14 cm in week 3 and 5 after plant germination and the shortest plants were observed from control treatment with an average of 37.56 to 75.68 cm. Light exposure (8, 12 and 16 hours) treatments increased plant height by 1.14, 2.97, and 3.25% (means of 77.93-75.68) respectively, compared to control treatment. Significant differences ($p \leq 0.05$) were observed on number of stems from week 4 and 5 after plant emergence. Plants exposed to 12 hours of light had more number of stems than those exposed to other treatments. Varieties showed significant differences ($p \leq 0.05$) on plant height (Table 4.3). Tallest plants from week 3, week 4 and week 5 after emergence were recorded in Shangi followed by Kenya Karibu and Dutch Robijn. Shangi recorded the tallest plant (85.62 cm) while Dutch Robijn (64.75 cm) recorded the shortest. Shangi had the most number of stems (4) followed by Dutch Robijn (3) and Kenya Karibu (2). There was significant difference ($p \leq 0.05$) at week 4 and 5 on plant height due to site effects. Molo site exhibited taller plants than Egerton site.

Table 4.3: Effects of light exposures on plant height and number of stems at different weeks after plant emergence in Molo and Egerton sites

Site	Week 3		Week 4		Week 5	
	Plant height (cm)	No. stems	Plant height (cm)	No. stems	Plant height (cm)	No. stems
Molo	40.379a	2.611a	69.490a	3.056a	91.373a	3.167a
Egerton	39.937a	2.111b	53.379b	2.917a	62.770b	2.972a
Variety						
Shangi	64.123a	3.583a	82.139a	4.000a	85.616a	4.083a
Kenya	32.067b	1.958b	58.383b	2.708b	80.851b	2.667b
Karibu						
Dutch	24.285c	1.542c	43.783c	2.250c	64.746c	2.458b
Robijin						
Treatment						
16 hours	42.926a	2.611a	66.004a	2.944ab	78.138a	3.000a
12 hours	41.388ab	2.167b	63.291a	3.056ab	77.928a	3.389a
8 hours	38.756ab	2.389ab	60.029ab	3.278a	76.535a	3.278a
Control	37.563b	2.278ab	56.414b	2.667b	75.683a	2.611b

Means followed by the same alphabetical letter are not significantly different according to DMRT at $p \leq 0.05$

Analysis of variance (ANOVA) showed that there were significant differences ($p \leq 0.05$) among the varieties on number of tubers, small and big sized tubers and tuber weight. The site effect was significant ($p \leq 0.05$) on number of tubers and tuber weight (Appendix 8). There was a significant ($p \leq 0.01$) site by variety interaction effect for big and small tubers while interaction was significant ($p \leq 0.05$) for tuber weight.

The treatments revealed significant differences ($p \leq 0.05$) on number of potato tubers. Tubers that were exposed to 16 hours light had the highest number of tubers averaging 7 (Table 4.4). Exposure of seed tubers to 12, 16 and 8 hours of light treatments increased tuber weights by 24%, 25% and 12% respectively. There were significant differences ($p \leq 0.01$) among the treatments on big sized tubers. Plants that were exposed to control treatment had the highest number of big sized tubers (mean 24) than those that were exposed to 8 (mean 21), 12 (mean 18) and 16 (mean 18) hours of light. Higher tuber yields were recorded from

tubers that were exposed to 16 and 12 hours of light treatment with an average yield of 22.37 and 22.14 t ha⁻¹ while 17.86 t ha⁻¹ were recorded under control treatment.

There were varietal differences ($p \leq 0.05$) observed on number of tubers, grade and weight (Table 4.4). Shangi had the highest number of tubers (8 tubers) followed by Kenya Karibu (6 tubers) and Dutch Robijn (5 tubers). Dutch Robijn had highest number of small tubers (79) compared to Shangi (56) and Kenya Karibu (47). It was observed that Kenya Karibu recorded the largest number of big tuber size (>60 mm) (31 tubers) followed Shangi (23 tubers) and Dutch Robijn (6 tubers) varieties. On average, the highest tuber yield was recorded on Shangi (27.55 t ha⁻¹) followed by Kenya Karibu (24.03 t ha⁻¹) and Dutch Robijn (10.20 t ha⁻¹).

Table 4.4: Mean effects of light exposures on tuber yield at Molo and Egerton sites

Site	Number of tubers	Small size <30mm	Medium size 30-60mm	Big size >60mm	Weight (t ha ⁻¹)
Molo	4.931b	59.365a	19.383a	21.253a	14.089b
Egerton	7.942a	62.479a	18.467a	19.054a	27.098a
Variety					
Shangi	8.408a	56.230b	21.070a	22.698b	27.551a
Kenya Karibu	5.821b	47.108c	21.627a	31.266a	24.028a
Dutch Robijn	5.079b	79.427a	14.078b	6.496c	10.203b
Treatment					
16 hours	7.133a	63.381a	19.022a	17.598b	22.369a
12 hours	6.639ab	63.131a	20.932a	17.730b	22.135a
8 hours	6.267ab	59.829a	17.439a	20.940ab	20.007a
Control	5.706b	57.347a	18.307a	24.346a	17.864a

Key: Means followed by the same alphabetical letter are not significantly different according to DMRT at $p \leq 0.05$

4.4.3 Pearson correlation between sprout, growth and yield parameters for light house and field trails

The correlation analysis results for sprout, growth and yield parameters are presented in Table 20. The results showed that sprout parameters (number, thickness and length) were positively correlated to growth and yield parameters. There were significantly strong and positive correlation between number of sprouts, length and thickness (Table 4.5). The results

further showed that number of sprouts were fairly correlated to stand count with 0.33. However, there was no correlation between number of sprouts and plant height. However, the number of stems were significantly determined by number of sprouts as there was a strong and positive correlation (0.63) between them. Correlation analysis further showed a low and negative correlation between the number of sprouts and tuber grade (-0.11); no relationship between tuber weight and number of sprouts. There was a strong significant correlation between sprout thickness, length, stand count and plant height suggesting that the thicker the sprouts, the higher the chances of plants to germinate; the longer the sprouts the more the plants grow faster. The sprout thickness and length had strong and positive correlation with number of tubers (0.50 and 0.54) and tuber weight (0.58 and 0.59). The higher the plant height, the more the tubers are produced and heavy weight hence the results showed the significant positive correlation between plant heights, number of tubers and weight. There was a significantly strong positive correlation of 0.39 between the number of stems and number of tubers. In general, there was significantly positive correlation between number of stems, number of tubers and tuber weight. The results further showed the significant relationship between tuber grade and tuber weight.

Table 4.5: Combined Pearson correlation coefficient with probability value on sprout, growth and yield parameters

	Number of sprouts	Sprout thickness	Sprout length	Stand count	Plant height	Number of stems	Number of tubers (>60 mm)	Tuber grade (>60 mm)	Tuber weight
Number of sprouts	1.00								
Sprout thickness	0.42**	1.00							
Sprout length	0.62**	0.90**	1.00						
Stand count	0.33**	0.57**	0.54**	1.00					
Plant height	0.16	0.43**	0.36**	0.09	1.00				
Number of stems	0.63**	0.60**	0.69**	0.35*	0.19	1.00			
Number of tubers	0.46**	0.50**	0.54**	0.26*	0.67**	0.39***	1.00		
Tuber grade (>60 mm)	-0.11	0.39**	0.24*	0.28*	0.24*	-0.03	0.04	1.00	
Tuber weight	0.22	0.58**	0.49**	0.31*	0.76**	0.22	0.84*	0.41**	1.00

Key: *, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$) respectively.

4.4.4 Regression analysis

The pre-sprouting time showed the significant effect on number of sprouts. Among the four weeks of pre-sprouting, week 4 was observed to have the highest number of seed tubers with many sprouts (2-3 sprouts) (Fig 8). The results further showed that the longer the pre-sprouting time, the more the sprouts are formed. However in week 1, the seed tubers that were exposed to 12 hours of light treatment developed the visible sprouts. The increased numbers of visible sprouts (3 sprouts) were observed as pre-sprouting period (weeks) continue and this was mostly seen for seed tubers that were exposed to 12 and 16 hours of light treatments. The 8 hours of light exposure and control treatment had the lowest number of sprouts (2 sprouts) developed on the seed tubers in the 4th week.

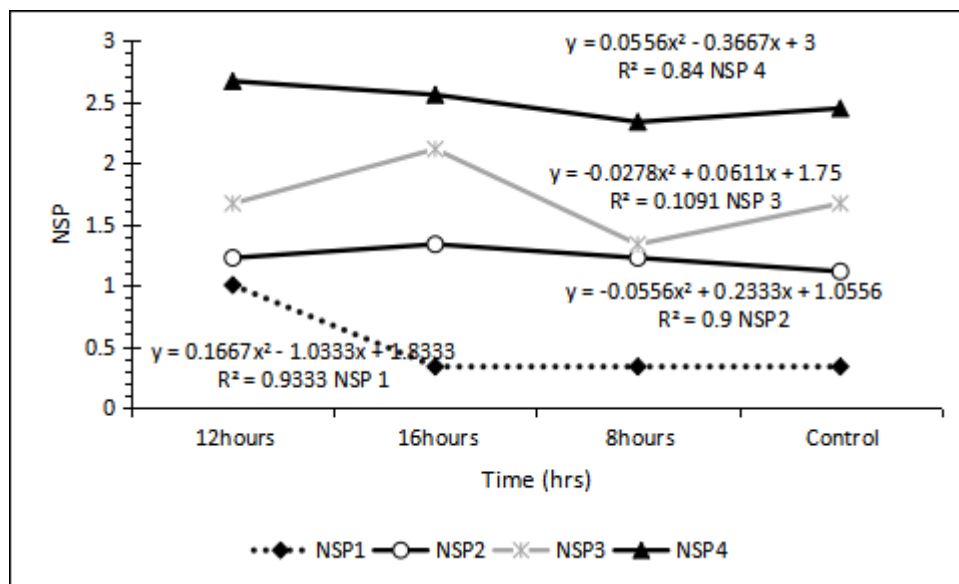


Figure 4.3: Relationship between time and number of sprouts. NSP1, number of sprouts at week 1, week 2, week 3 and 4 of the pre-sprouting period

There was a significant relationship between time and sprout quality (length and thickness of sprouts). The pre-sprouted seed tubers resulted in the tuber sprouts that were thick and long in the last week of pre-sprouting period which was week 4 (Fig 9).

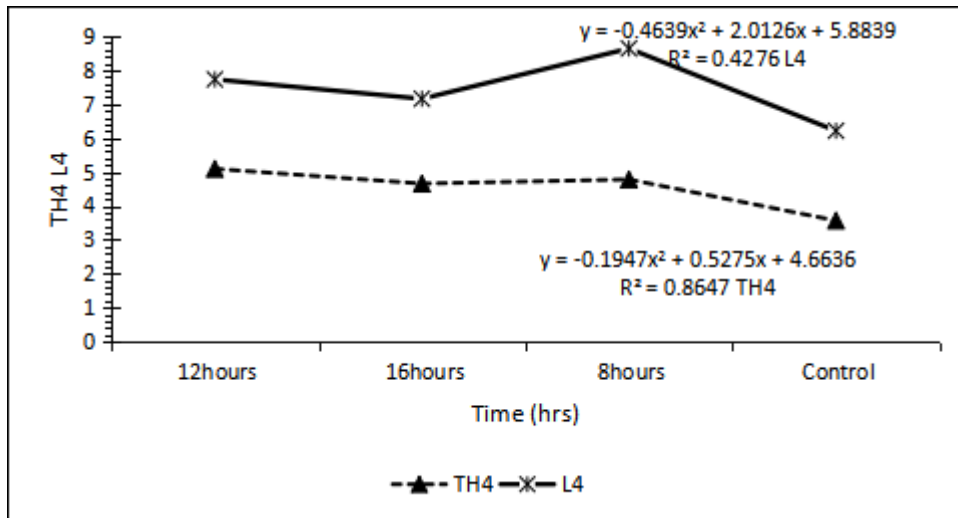


Figure 4.4: Relationship between time and sprout quality. TH4, thickness of the main sprout at week 4 of the pre-sprouting period. L4, length of the main sprout at week 4 of the pre-sprouting period

There was a significant relationship observed between pre-sprouting time and plant heights. The results showed that plants need more sunlight at the stages of growth (Fig 10). The plant height growth increased at week 3 and 4 after plant emergence. At week 5, the plant heights remained slightly constant. Furthermore, the seed tubers that were exposed to 12 hours and 16 hours light treatments recorded the tallest plants while control and 8 hours light exposure recorded the shortest. The more the hours of light received, the more the good early vegetative growth and the quicker the reproductive phase.

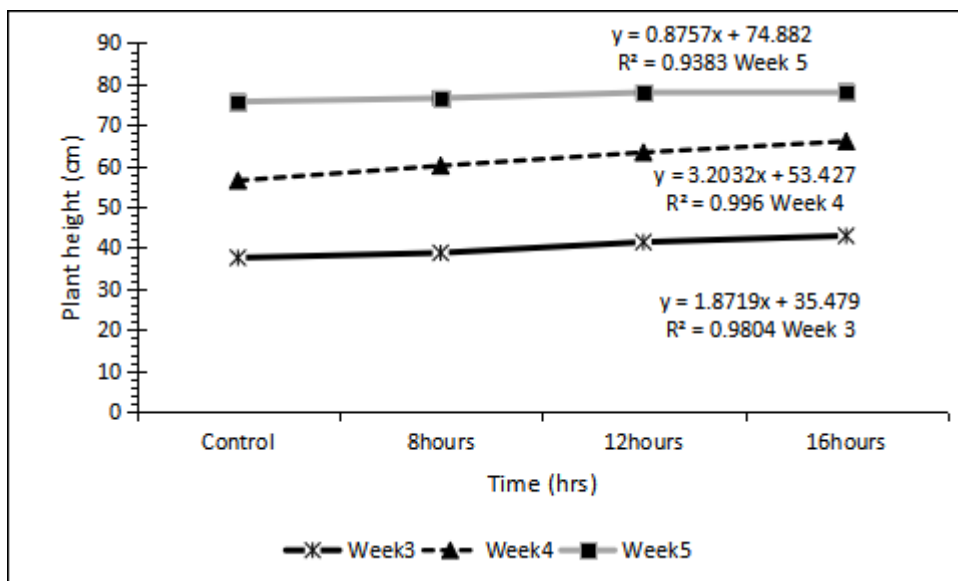


Figure 4.5: Relationship between time and plant heights. Weeks after plant emergence

There was a significant relationship between the duration of light (time) and tuber yield. The plants that were exposed to 12 hours and 16 hours of light treatments accumulated

more biomass and intercepted more radiation which provided photosynthates for the developing tubers which were reflected on number of tubers. The results further showed that when the seed tubers were exposed to more hours light they gave more tubers of small and medium size. It was again observed that, when the seed tubers were exposed to few hours of light, they produced few number of tubers which enabled the tubers to have sufficient space and enough nutrients for utilization hence more of big sized tubers were formed as illustrated by figure 11. The 12 hours and 16 hours treated seed tubers produced plants that gave most tuber weight. The formation of tubers from 12 hours and 16 hours of light exposure treatments was faster than the formation of tubers from control and 8 hours light treatments due to faster plant growth which resulted in higher yields from green-sprouted tubers than for the untreated control.

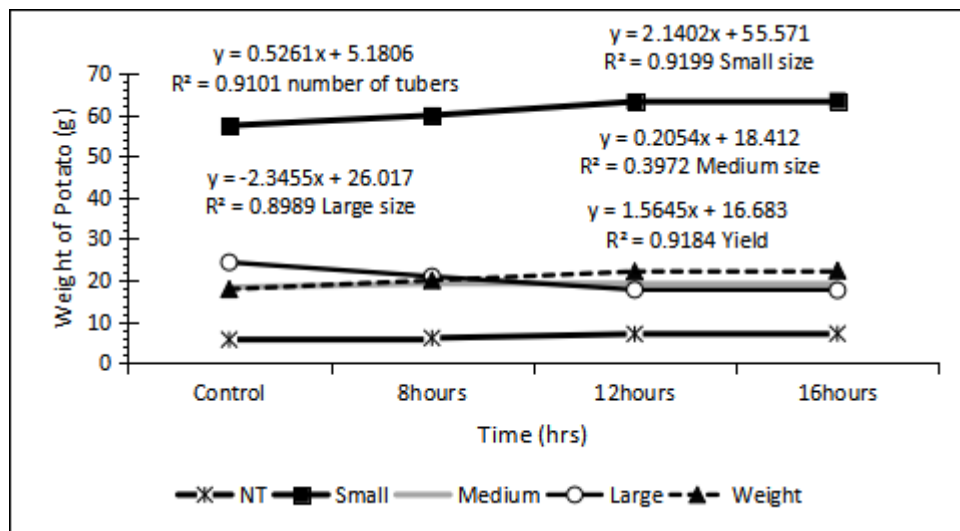


Figure 4.6: Relationship between time and tuber yield. NT, number of tubers, size of tubers, small, medium, large

4.5 Discussion

Time of exposure did not have any significant ($p \leq 0.05$) effect on the number of sprouts, but, there was significant difference ($p \leq 0.05$) observed on sprout quality (length and thickness). This shows that light is an essential factor for the growth and development of potatoes. Sue (2007) also noted that pre-sprouting of potato tubers in light resulted in thick, strong sprouts, which give a plant advantage of growing fast. Although all light exposure treatments and control resulted in good quality sprouts in terms of length and thickness, seed tubers that were exposed to 16 hours of light treatment did not have thick and long sprouts as compared to those exposed to 8 and 12 hours light.

Similarly, Van (1992) reported that as much as long hours of light do shorten the dormancy, growth of sprouts can be associated to innate dormancy which depends largely on long photoperiod (18 hours) light. Suttle (2007) noted that although the presence or absence of light during post-harvest storage has little effect on dormancy duration, it can affect the morphology of emerging sprouts. In this study, there was significant increase on sprout thickness and sprout length attained by light exposures than control. These results are consistent with the findings of Johansen (2017), who evaluated different light exposures of 8, 16 and 24 hours with a constant temperature of 10 °C on four varieties in growth chambers. He found that there was a significant difference in sprout length but the significant decreased with increasing duration of daily light exposure on sprout length. In his results, the light exposure to 8 hours gave the sprout length of 15.1 mm, 16 h (13.6 mm) and 24 h (12.8 mm). Morrow (2014) also indicated that the light treatments significantly influenced the sprouting of broccoli microgreen shoot tissue, but with no significant difference among light treatments.

According to Bushnell (1929), the exposure of seed tubers to a warm light is regarded as hastening early varieties growth. He reported that tubers exposed to light become green, produce short and tough sprouts that adhere during the processes of planting. In the current work, three potato varieties with different dormancy periods were pre-sprouted. The findings have shown that a long dormancy variety like Dutch Robyjn attained 54% plant germination in week 2 after planting. In the 4th week after planting, which is the average expected time in weeks (after 28 days) for potatoes to have emerged; all the tested varieties in this study had 82-100% germination. This indicated the importance of dormancy breaking in potato production and need to be recommended to both small and large scale farmers. The fast emergence could be attributed to the quality sprouts (length and thickness) obtained from the lighthouse after pre-sprouting. Johansen (2012), in his study, he found that pre-sprouted tubers significantly improved emergence for Asterix and Saturna cultivars compared to a cold-stored seed.

Light hour's treatments significantly influenced the varieties ability to sprout. The significant effect ($p \leq 0.05$) was seen on the number of sprouts, length and thickness of the sprouts. Shangi had a higher number of good quality sprouts (length and thickness) than Kenya Karibu and Dutch Robijn suggesting that the thicker the sprouts, the higher the chances of plants to germinate; the longer the sprouts the more the plants grow faster hence there was a strong significant correlation between sprout thickness, length, stand count and

plant height. In this study, varieties had green and purple sprouts. The green and purple sprouts indicated that the pre-sprouted seed tubers produced healthy sprouts due to treatment effect. Green and purple colours further show that the seeds received enough light hence sprouts were able to produce chlorophyll as opposed to white colour which could stunted photosynthesis.

Johansen and Mølmann (2017) stated that the pre-sprouted potatoes either in natural or artificial light speed up plant development. In the current study, there was an increase in plant height as compared to control treatment. The tallest plants were from 16 hours of light treated plants. When light hours are eased, the day becomes longer and this compensates for the low growth temperatures in the field which can secure the growth and development of a crop leading to satisfactory yield. According to Jao and Fang (2004), the 16 hours of light exposure is recommended for optimal growth of potato. Furthermore, the 16 hours photoperiod has been found necessary to maintain the vegetative growth of potato plantlets in vitro (Seabrook, 2005). The 16 hours of light exposure had the highest percent plant germination and plant height, increased tuber weight. Plants exposed to longest hours of light were able to accumulate a larger supply of reserve material for the formation of new tissue as the result of better photosynthesis; therefore they ultimately attained the greatest height. The higher the plant height, the more the tubers are produced and heavy weight hence the results showed the significant positive correlation between plant heights, number of tubers and weight.

Field evaluation further showed that there was a significant difference ($p \leq 0.05$) observed among varieties for the traits observed across the sites. This could suggest that the varieties responses were influenced by the environments under which they were evaluated. The other reason could be differences due to their genotype or the interaction between the genotypes and the environments.

Potato growth and tuber yields have been linked to the duration of the growth cycle, which depends on climate, cultivar, and crop management (Dahal *et al.*, 2019). The differences in growth and in tuber yield among potato cultivars can be explained by differences in accumulated intercepted radiation (Oliveira *et al.*, 2016). There were significant differences ($p \leq 0.05$) observed among varieties on the number of tubers, big-sized tubers and tuber weight across sites.

4.6 Conclusion

Light exposures significantly enhanced the quality of sprout by influencing the thickness and length. This was highly correlated to growth and yield of potato plants once planted in the field. The seed tubers with good quality sprouts in terms of length and thickness can lead to high vigorous plants which will give good yield. Light exposures further reduced the sprouting time by 23 days (44 days to 21 days) which is advantageous in increasing growing cycles per annum. It also significantly increased sprout thickness and sprout length. Light exposure of 16 hours had the highest percent plant germination. The best light regime was 16 hours which increased tuber weight by 25% as compared to 8 hours that increased tuber weight by 12%. The 16 hours of light attained the highest yield for Shangi and Kenya Karibu. These varieties could be recommended when the suitable pre-sprouting conditions are available to the farmers.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

The dormancy period in potatoes varies depending on genotype and conditions of pre and post-harvest (Mani *et al.*, 2014). Priming to sprout after potato harvesting is very necessary for the seed potato tubers that are to be planted soon to enhance the availability of the seeds (Ellis, 1992; Halmer, 2003). The results of the current study showed that breaking the dormancy of seed tubers enabled early planting of the seed tubers that have vigorous sprouts. They further showed that pre-sprouting established good early vegetative growth and quicker reproductive phase which gave early harvests and increased tuber yields. Ellis (1992) and Halmer (2003) found that pre-sprouting decreased the undersized tubers percentage and increased the oversized tubers percentage. For Hagman (2012), there was a higher yield for pre-sprouted treatments as compared to the control treatment due to faster tuber formation. Pre-sprouting further decreases yield losses that may be caused due to late blight. It advances early crop development (Imanparast, 2018).

In this study, there was an increase in plant height from the pre-sprouted seed tubers for all the three tested varieties compared to control-treated plants and this may be due to the fact that cultivation for the tested varieties was at the appropriate season under which the weather patterns (temperature, rainfall) soil type and the ecological setting gave rise to the varieties planted.

The current study results further showed the significant ($p \leq 0.05$) relationship between time and tuber yield. Time is among the factors that significantly affect the growth of plants hence the need to be considered in crop production. In plants storing food in tubers, vegetative growth is best in long day (Hemming, 2009). This makes light duration an important contributory factor in potato production. Sysoeva (2010) found that the number of tubers and tuber weight were higher after a photoperiod of 18 hours than in 12 hours with 11% and 16% .The Light duration affects the quantity of material formed in a plant and influences the use which the plant can make of it. The physiological conditions causing internal dormancy arise from the presence of germination inhibitors inside the seed and can be manipulated by light regimes (Pruski *et al.*, 2003). Light is said to be the electromagnetic radiation that causes photochemical reactions in plants (Golovatskaya & Karnachuk, 2015). It is important for meristematic activity in green plants through photosynthesis and it is required to initiate germination in after ripened seeds (Yan & Chen, 2020).

5.2 Conclusions

The findings of this study showed that the effect of natural materials (grass, banana leaves and soil) and plant growth regulators (GA3, Zeatin and BAP) tests and their interaction with varieties were significant in increasing yield and for breaking potato seed tuber dormancy. Thus they can be used in enhancing pre-sprouting and early seed availability than unchitted potato seed. As compared to control, they produced the most vigorous sprouts, increased crop emergence, plant height and gave more yields for the three different varieties evaluated. The number of sprouting per tuber and number of days to sprouting and dormancy breaking between three cultivars were also significantly different. The light exposures reduced the sprouting time from 44 days to 21 days.

- a) The natural materials (grass, soil and banana leaves) were readily available, cheaper and effective methods for breaking dormancy. The use of grass, soil and banana leaves could be used by small scale farmers and if adopted would boost farmers' yields. PGRs (GA3, Zeatin and BAP) also increased yields, but required better facilities like stores and slightly expensive hence can be used by the large scale farmers who continuously plant throughout the year and need seed continuously.
- b) The natural materials had higher effect on pre-sprouting since they increased sprout quality (length and thickness) by 174% and 159% respectively as compared to controls for all tested varieties.
- c) Similarly, PGRs had lower effect, but they also increased sprout quality (length and thickness) by 74% and 48%, respectively, indicating that natural materials were the best for pre-sprouting.
- d) The utilization of natural materials and PGRs increased size of large potatoes by 261% and 103% respectively as compared to non-chitted treatments. Amongst these, banana leaves had best response
- e) The light exposures significantly increased the sprout thickness and length of the sprouts by 31-43 % on sprout thickness and 15-39% compared to control treatment.
- f) The exposure of seeds to 16 hours of light attained the greatest height and increased tuber weight by 25% as compared to 8 hours (12%). There is therefore a need to increase period of light exposure to enhance breaking of dormancy, using simple fluorescence system in pre-sprouting stores.
- g) Dutch Robijn variety recorded fewer heavier tubers than Shanghi, but Kenya Karibu had more numbers of lower grade (small) and medium sized tubers, leading to highest yields. Therefore Shanghi was faster maturing, easy to produce seed with medium

yields while Kenya Karibu had moderate pre-sprouting, good quality sprouts, good tuber grades and highest yields amongst the three varieties.

5.3 Recommendations

- a) The use of natural materials (dry grass, soil and banana leaves) is recommended as an effective method for breaking tuber dormancy for use by small scale farmers, since they are readily available and cheaper with greater impact of increasing potato yields in Kenya. Banana leaves should be given more preference followed by dry grass.
- b) The use of PGRs (GA3, zeatin and BAP) is recommended for use by large-scale farmers since they can afford improved storage facilities and also cost of PGRs which will support continuous production throughout the year.
- c) The 16 hours exposure is recommended in pre-sprouting tuber seed as compared to 8 hours and 12 hours exposures.
- d) Shangi and Kenya Karibu are the recommended varieties for adoption by farmers since they gave both good quality sprouts, good grade and higher yields as compared to Dutch Robyn.

REFERENCES

- AGRA. (2019). Potato regulations: *A New Drawn for Farmers*. <https://agra.org/news/potato-regulations-a-new-drawn-for-farmers/>. Accessed on 5- November-2019.
- Aksenova, N. P., Sergeeva, L. I., Konstantinova, T. N., Golyanovskaya, S. A., Kolachevskaya, O. O., & Romanov, G. A. (2013). Regulation of potato tuber dormancy and sprouting. *Russian Journal of Plant Physiology*, 60(3): 301-312.
- Amelia, Z. R., & Wulandari, A. S. (2020, July). Effect of 6-BAP application on shoot production of *Melaleuca alternifolia* seedlings. In *IOP Conference Series: Earth and Environmental Science* (Vol. 528, No. 1, p. 012063). IOP Publishing.
- Andrade-Piedra, J. L., Bentley, J. W., Almekinders, C. J., Jacobsen, K., Walsh, S., & Thiele, G. (2016). Case studies of Roots, Tubers and Bananas seed systems. *CGIAR Research Program on Roots, Tubers and Bananas* (pp. 244), RTB Working Paper.
- Asalfew, G. K. (2016). Review on the effect of gibberellic acid on potato (*Solanum tuberosum* L.) tuber dormancy breaking and sprouting. *Journal of Biology, Agriculture and Healthcare*, 7: 68-79.
- Ballaré, C. L., & Casal, J. J. (2000). Light signals perceived by crop and weed plants. *Field Crops Research*, 67(2): 149-160.
- Barani, M., Akbari, N., & Ahmadi, H. (2013). The effect of gibberellic acid (GA3) on seed size and sprouting of potato tubers (*Solanum tuberosum* L.). *African Journal of Agricultural Research*, 8(29): 3898-3903.
- Benkeblia, N., Alexopoulos, A. A., & Passam, H. C. (2008). Physiological and biochemical regulation of dormancy and sprouting in potato tubers (*Solanum tuberosum* L.). *Fruit Vegetable Cereal Science Biotechnology*, 2: 54-68.
- Beukema, H. P., & van der Zaag, D. E. (1990). *Introduction to potato production* (No. 633.491 B4). Wageningen, Pudoc.
- Bhaskar, P. B., Wu, L., Busse, J. S., Whitty, B. R., Hamernik, A. J., Jansky, S. H., & Jiang, J. (2010). Suppression of the vacuolar invertase gene prevents cold-induced sweetening in potato. *Plant Physiology*, 154(2): 939-948.
- Bushnell, J. W. (1929). The normal multiple sprouting of seed potatoes. Ohio Agricultural Experiment Station, Wooster, Ohio.
- Caldiz, D. O. (2009). Physiological age research during the second half of the twentieth century. *Potato Research*, 52(4): 295-304.
- Campos, H., & Ortiz, O. (2020). *The potato crop: its agricultural, nutritional and social contribution to humankind* (pp. 518). Springer Nature.

- Carli, C., Mihovilovich, E., Yuldashev, F., Khalikov, D., & Kadian, M. S. (2010). Assessment of dormancy and sprouting behavior of cip elite and advanced clones under different storage conditions in Uzbekistan. *Potato Research*, 53(4) : 313-323.
- Cavalcante, A. C. P., Soares, M. E. P., de Andrade, G. A. V., da Silva, C. D., dos Santos, C. E. M., & de Aquino, L. A. (2019). Influence of seed tuber size and sprouting stage on the phytotechnical characteristics of the potato variety. *Ágata. Australian Journal of Crop Science*, 13 (2): 282-286.
- Chandrasekara, A., & Josheph Kumar, T. (2016). Roots and tuber crops as functional foods: a review on phytochemical constituents and their potential health benefits. *International Journal of Food Science*, 16: 1-15.
- CIP. (2019). *Farming Success with Potatoes in Kenya*. <https://cipotato.org/crops/potato/>. Accessed on 17-July-2020.
- CIP. (2018). Seed potato production and certification guidelines. Wageningen University.
- CIP. (2008). *International year of potato*. Available at <http://www.fao.org/potato-2008/en/potato/water.html>. Accessed on 8-July-2020.
- Crissman, C., McArthur Crissman, L., & Carli, C. (1993). *Seed potato systems in Kenya: A case study*. International Potato Center.
- Dahal, K., Li, X. Q., Tai, H., Creelman, A., & Bizimungu, B. (2019). Improving potato stress tolerance and tuber yield under a climate change scenario—a current overview. *Frontiers in Plant Science*, 10: 563-569.
- Daniels-Lake, B. J., & Prange, R. K. (2007). The canon of potato science: 41. Sprouting. *Potato Research*, 50(3-4): 379-382.
- Delaplace, P., Rojas-Beltran, J., Frettinger, P., Du Jardin, P., & Fauconnier, M. L. (2008). Oxylipin profile and antioxidant status of potato tubers during extended storage at room temperature. *Plant Physiology and Biochemistry*, 46(12): 1077-1084.
- Deligios, P. A., Rapposelli, E., Mameli, M. G., Baghino, L., Mallica, G. M., & Ledda, L. (2020). Effects of physical, mechanical and hormonal treatments of seed-tubers on bud dormancy and plant productivity. *Agronomy*, 10(1): 33-39.
- Devaux, A., Kromann, P., & Ortiz, O. (2014). Potatoes for sustainable global food security. *Potato Research*, 57(3-4): 185-199.
- Doijode, S. D. (2006). Seed quality in vegetable crops. *Handbook of Seed Science and Technology* (pp 677-702). The Haworth Press.
- De Wit, M., Galvão, V. C., & Fankhauser, C. (2016). Light-mediated hormonal regulation of plant growth and development. *Annual Review of Plant Biology*, 67: 513-537.

- Ellis, R. H. (1992). Seed and seedling vigour in relation to crop growth and yield. *Plant Growth Regulation*, 11(3): 249-255.
- Eremeev, V., L [otilde] hmus, A., Lääniste, P., J [otilde] udu, J., Talgre, L., & Lauringson, E. (2008). The influence of thermal shock and pre-sprouting of seed potatoes on formation of some yield structure elements. *Acta Agriculturae Scandinavica Section B-Soil and Plant Science*, 58(1): 35-42.
- Eremeev, V. (2007). The influence of thermal shock and pre-sprouting on formation of yield structure elements in seed potatoes (Doctoral dissertation, Eesti Maaülikool).
- Essah, S. Y. C., & Honeycutt, C. W. (2004). Tillage and seed-sprouting strategies to improve potato yield and quality in short season climates. *American Journal of Potato Research*, 81(3): 177-186.
- Ezekiel, R. & Singh, B. (2005). Effect of CO₂ treatment on dormancy duration, sprout growth and sugar content in two potato cultivars. *Horticulture Science*, 32: 68-73.
- Fantaw, S., Ayalew, A., & Anley, W. (2019). Yield Performance of Potato (*Solanum tuberosum* L.) Varieties under Rainy Season at Wogera District, Northwestern Ethiopia. *Journal of Academia and Industrial Research*, 7(11): 144-149.
- FAO. (2008, November 4). *International year of potato*. Available at <http://www.fao/potato2008/en/world/Africa.html>
- FAOSTAT. (2020). *Data*. Available at <http://www.fao.org/faostat/data>. Accessed on 13-May-2020.
- FAOSTAT. (2019). *Data*. Available at <http://www.fao.org/faostat/data>. Accessed on 4-August-2019.
- FAOSTAT. (2018). *Data*. Available at <http://www.fao.org/faostat>. Accessed on 4-November 2020.
- FAOSTAT. (2014). *Data*. Available at <http://www.fao.org/faostat/en/data>. Accessed on 4-June-2020.
- Fu, W., Li, P., & Wu, Y. (2012). Effects of different light intensities on chlorophyll fluorescence characteristics and yield in lettuce. *Scientia Horticulturae*, 135: 45-51.
- Gildemacher, P. R., Demo, P., Barker, I., Kaguongo, W., Woldegiorgis, G., Wagoire, W. W., & Struik, P. C. (2009). A description of seed potato systems in Kenya, Uganda and Ethiopia. *American Journal of Potato Research*, 86(5): 373-382.
- GIZ-PSDA Kenya. (2011). Potato value chain. Improving the livelihood of Kenyan farmers by growing value, growing profits. *Deutsche Gesellschaft für Internationale*

Zusammenarbeit (GIZ) and Promotion of Private Sector in Agriculture (PSDA), Kenya.

- Golovatskaya, I. F., & Karnachuk, R. A. (2015). Role of green light in physiological activity of plants. *Russian Journal of Plant Physiology*, 62(6): 727-740.
- Hagman, J. (2012). Pre-sprouting as a tool for early harvest in organic potato (*Solanum tuberosum* L.) cultivation. *Potato Research*, 55(2): 185-195.
- Halmer, P. (2003). Methods to improve seed performance. Seed physiology, applications to agriculture. Food product press, pp 40-48.
- Hajirezaei, M. R., BoÈrnke, F., Peisker, M., Takahata, Y., Lerchl, J., Kirakosyan, A., & Sonnewald, U. (2003). Decreased sucrose content triggers starch breakdown and respiration in stored potato tubers (*Solanum tuberosum* L.). *Journal of Experimental Botany*, 54(382): 477-488.
- Harahagazwe, D., Condori, B., Barreda, C., Bararyenya, A., Byarugaba, A. A., Kude, D. A., & Ochieng, B. (2018). How big is the potato (*Solanum tuberosum* L.) yield gap in Sub-Saharan Africa and why? A participatory approach. *Open Agriculture*, 3(1): 180-189.
- Hartmans, K. J., & Van Loon, C. D. (1987). Effect of physiological age on growth vigour of seed potatoes of two cultivars. I. Influence of storage period and temperature on sprouting characteristics. *Potato Research*, 30(3): 397-410.
- Hassani, F., Zareian A., & Rezvani, E. (2014). Effects of chemical treatments on dormancy breaking and some sprouting characteristics of two potato cultivars in different tuber sizes. *European Journal of Experimental Biology*, 4 (4): 98-102.
- Hassani, F., Mohammadi, M. S., & Mirtaheri, S. M. (2014). Effects of Gibberlic acid, Thio-urea and Carbon di-sulfide treatments on dormancy breaking and some sprouting characteristics of two cultivars of potato (Agria and Burren) in different tuber sizes. In *International Congress on "Green Infrastructure and Sustainable Societies/Cities" GreInSus' 14* (p. 95).
- Haverkort, A. J., & Struik, P. C. (2015). Yield levels of potato crops: recent achievements and future prospects. *Field Crops Research*, 182: 76-85.
- Haverkort, A. J., Van de Waart, M., & Bodlaender, K. B. A. (1990). Effect of pre-planting temperature and light treatments of seed tubers on potato yield and tuber size distribution. *Potato Research*, 33(1): 77-88.
- Hemberg, T. (1985). Potato rest. *Potato physiology* (chapter 11, pp. 353-388). Department of Botany, University of Stockholm.

- Hemming, S. (2009). Use of natural and artificial light in horticulture-interaction of plant and technology. In *VI International Symposium on Light in Horticulture 907* (pp. 25-35).
- Imanparast, F. (2018). Pre-sprouting Importance and Position in Potato Production. *Atatürk Üniversitesi Ziraat Fakültesi Dergisi*, 49(2): 150-156.
- Islamova, D., Kholiyorov, U., Dustmukhammad, K., Shafkarov, F., & Numonov, K. (2020). The relevance of potato farming in the agricultural economy (on the example of the Republic of Uzbekistan). In *E3S Web of Conferences* (Vol. 215). EDP Sciences.
- Jaetzold, R., Schimdt, Hometz, B. & Shisnaya, C. (2007). Farm Management Handbook of Kenya. Natural conditions and farm management information. Volume II B. Nairobi Kenya. Pp 379- 413.
- Jao, R. C., & Fang, W. (2004). Effects of frequency and duty ratio on the growth of potato plantlets in vitro using light-emitting diodes. *Horticulture Science*, 39(2) : 375-379.
- Jiang, Z., Xu, G., Jing, Y., Tang, W., & Lin, R. (2016). Phytochrome B and REVEILLE1/2-mediated signalling controls seed dormancy and germination in Arabidopsis. *Nature Communications*, 7(1): 1-10.
- Johansen, T. J., & Mølmann, J. A. (2017). Green-sprouting of potato seed tubers (*Solanum tuberosum* L.)—influence of daily light exposure. *Potato Research*, 60(2): 159-170.
- Johansen, T. J., & Molteberg, E. L. (2012). Effect of storage and pre-sprouting regimes on seed potato performance in Norway. *Potato Research*, 55(3-4): 279-292.
- Kaguongo, W. P., Ng'ang'a, N. M., Muthoka, N., Muthami, F., & Maingi, G. (2010). Seed potato subsector master plan for Kenya (2009-2014). *Seed potato study sponsored by GTZ-PSDA, USAID, CIP and Government of Kenya*. Ministry of Agriculture.
- Khanal, B., & Uprety, D. (2014). Effects of Storage Temperature on Post-harvest of Potato. *International Journal of Research*, 1(7): 903-909.
- Kimani. E (2016, June 12). Seed potato production and certification guidelines. <http://www.seedsectorplatformkenya.comfilesdownload.pdf>.
- Kumlay, A. M. (2014). Combination of the auxins NAA, IBA, and IAA with GA3 improves the commercial seed-tuber production of potato (*Solanum tuberosum* L.) under in vitro conditions. *BioMed Research International*.
- Kolech, S. A., Halseth, D., De Jong, W., Perry, K., Wolfe, D., Tiruneh, F. M., & Schulz, S. (2015). Potato variety diversity, determinants and implications for potato breeding strategy in Ethiopia. *American Journal of Potato Research*, 92(5): 551-566.

- Mani, F., Bettaieb, T., Doudech, N., & Hannachi, C. (2014). Physiological mechanisms for potato dormancy release and sprouting: a review. *African Crop Science Journal*, 22(2): 155-174.
- Mani, F., & Hannachi, C. (2015). Physiology of potato sprouting. *Journal of New Sciences*, 17(2): 591-602.
- McArthur Crissman, L. (1989). Evaluation, choice and use of potato varieties in Kenya. *Working Paper*, Lima.
- Mehta, A., Singh, B., Ezekiel, R., & Kumar, D. (2010). Effect of CIPC on sprout inhibition and processing quality of potatoes stored under traditional storage systems in India. *Potato Research*, 53(1): 1-15.
- Muchiri, P. D., Gathungu, G. K., Nyankanga, R. O., Ambuko, J., & Landeo, J. A. (2015). Optimization of seed potato (*Solanum tuberosum* L.) tuber dormancy and sprouting capacity through integrated gibberellic acid and benzylaminopurine application. *Journal of Agriculture and Ecology Research International*, 188-198.
- Mukul, A. Z. A., Rayhan, S. J., & Hassan, M. M. (2013). Farmer's profitability of potato cultivation at Rangpur district: the socio-economic context of Bangladesh. *International Journal of Economics, Finance and Management Sciences*, 1(3): 136-144.
- Mumia, B. I., Muthomi, J. W., Narla, R. D., Nyongesa, M. W., & Olubayo, F. M. (2018). Seed Potato Production Practices and Quality of Farm Saved Seed Potato in Kiambu and Nyandarua Counties in Kenya. *World Journal of Agricultural Research*, 6(1): 20-30.
- Mustefa, G., Mohammed, W., Dechassa, N., & Gelmesa, D. (2017). Effects of different dormancy-breaking and storage methods on seed tuber sprouting and subsequent yield of two potato (*Solanum tuberosum* L.) varieties. *Open Agriculture*, 2(1): 220-229.
- Muthoni, J., Kabira, J., Shimelis, H., & Melis, R. (2014). Regulation of potato tuber dormancy: A review. *Australian Journal of Crop Science*, 8(5): 754-759.
- Muthoni, J., Shimelis, H., & Melis, R. (2013). Potato production in Kenya: Farming systems and production constraints. *Journal of Agricultural Science*, 5(5): 182-197.
- Morrow, R. C., Sams, C. E., Barickman, T. C., & Kopsell, D. A. (2014). Sprouting broccoli accumulate higher concentrations of nutritionally important metabolites under narrow-band light-emitting diode lighting. *Journal of the American Society for Horticultural Science*, 139(4): 469-477.

- National Potato council of Kenya. (2019). *Potato variety catalogue*. <http://npck.org/catalogue/>.
- Nunn, Nathan, & Nancy Qian. (2011). The potato's contribution to population and urbanization: Evidence from a historical experiment. *Quarterly Journal of Economics*, 126: 593–650.
- Oliveira, J. S., Brown, H. E., Gash, A., & Moot, D. J. (2016). An explanation of yield differences in three potato cultivars. *Agronomy Journal*, 108(4): 1434-1446.
- Oliveira, J. S., Moot, D., Brown, H. E., Gash, A., & Sinton, S. (2012). Sprout development of seed potato tuber after different storage conditions. *Agronomy New Zealand*, 42: 53-58.
- Pandey, S. K., Singh, J. P., & Gopal, J. (2008). Potato varieties and cropping systems in India. *Potato Journal*, 35(3-4).
- Pinhero, R. G., Coffin, R., & Yada, R. Y. (2009). Post-harvest storage of potatoes. In *Advances in potato chemistry and technology* (pp. 339-370). Academic Press.
- Pruski, K., Astatkie, T., Duplessis, P., Stewart, L., Nowak, J., & Struik, P. C. (2003). Manipulation of microtubers for direct field utilization in seed production. *American Journal of Potato Research*, 80(3): 173-181.
- Rappaport, L., & Wolf, N. (1969). The problem of dormancy in potato tubers and related structures. In *Symposia of the society for experimental biology* (Vol. 23, p. 219).
- Reust, W. (1986). EAPR working group physiological age of the potato. *Potato Research*, 29(2): 268-271.
- Riungu, C. (2011). No easy walk for potatoes. *Horticultural News. The East African Fresh Produce Journal*, 19: 16-17.
- Rykaczewska, K. (2013). Assessment of potato mother tuber vigour using the method of accelerated ageing. *Plant Production Science*, 16 (2) : 171-182.
- Rylski, I., Rappaport, L., & Pratt, H. K. (1974). Dual effects of ethylene on potato dormancy and sprout growth. *Plant Physiology*, 53 (4): 658-662.
- Salda, V. B., & Bayogan, E. R. V. (1986). Practical methods of breaking potato dormancy. *Supplement no. 1*. Northern Philipiness Root and Crops Research Training Center.
- Salgado de Oliveira, J., Moot, D. J., Brown, H. E., Gash, A., & Sinton, S. (2012). Sprout development of seed potato tuber after different storage conditions. *Agronomy Society of New Zealand*, 42: 53-58.
- Salmensuu, O. (2021). Potato importance for development focusing on prices. *Journal of Risk and Financial Management*, 14(3): 137-150.

- Seabrook, J. E. (2005). Light effects on the growth and morphogenesis of potato (*Solanum tuberosum*) in vitro: a review. *American Journal of Potato Research*, 82(5): 353-367.
- Seed & Plant Varieties Act. (2012). Seed Laws and Regulations. Kenyan case. National Council for Reporting Law, Kenya.
- Seo, M., Nambara, E., Choi, G., & Yamaguchi, S. (2009). Interaction of light and hormone signals in germinating seeds. *Plant Molecular Biology*, 69(4): 463-472.
- Shibairo, S. I., Gachango, E., Kabira, J. N., Demo, P., Gildemacher, P., Narla, R. D., & Menza, M. (2006). Effects of Gibberellic Acid (GA₃) on Sprouting and Quality of Potato Seed Tubers in Diffused Light and Pit Storage Conditions. *Journal of Biological Sciences*, 6 (4): 723-733.
- Simon, M. (2017). Seed Classification Systems, Production Requirements and Maintenance (SEMI_s). KEPHIS.
- Sinelle, S. (2018). Potato Variety Adoption and Dis-adoption in Kenya. CIP and Syngenta Foundation.
- Solomon, I. (2006). Effects of Gibberellic acid (GA₃) of sprouting and Quality of Potato Seed Tubers in Diffused Light and Pit Storage Conditions. *Journal of Biological Sciences*. 6 (4): 723-733.
- Sonnewald, S., and Sonnewald, U. (2014). Regulation of potato tuber sprouting. *Planta*, 239(1): 27-38.
- Sonnewald, U. (2001). Control of potato tuber sprouting. *Trends in Plant Science*, 6(8): 333-335.
- Struik, P. C. (2007). The canon of potato science: 40. Physiological age of seed tubers. *Potato Research*, 50(3-4): 375-377.
- Struik, P. C., & Wiersema, S. G. (1999). Seed potato technology. Wageningen Academic Publishers.
- Suttle, J. C. (2004). Physiological regulation of potato tuber dormancy. *American Journal of Potato Research*, 81 (4): 253-260.
- Suttle, J. C. (1998). Involvement of ethylene in potato micro tuber dormancy. *Plant Physiology*, 118(3): 843-848.
- Suttle, J. C. (2007). Dormancy and sprouting. In *Potato biology and biotechnology* (pp. 287-309). Elsevier Science BV.
- Sysoeva, M. I., Markovskaya, E. F., & Shibaeva, T. G. (2010). Plants under continuous light: a review. *Plant Stress*, 4(1): 5-17.

- Tessema, L., & Dagne, Z. (2018). Aeroponics and Sand Hydroponics: Alternative technologies for pre-basic seed potato production in Ethiopia. *Open Agriculture*, 3(1): 444-450.
- Tirtosoekotjo, M. S., & Bautista, O. K. (1984). Acceleration of tomato ripening with ethylene from leaves. *Postharvest Research Notes*, 1 (3): 75-77.
- Van der Zaag, D. E., & Van Loon, C. D. (1987). Effect of physiological age on growth vigour of seed potatoes of two cultivars. Review of literature and integration of some experimental results. *Potato Research*, 30(3): 451-472.
- Van Ittersum, M. K. (1992). *Dormancy and growth vigour of seed potatoes*. Van Ittersum.
- Van Loon, C. D. (1987). Effect of physiological age on growth vigour of seed potatoes of two cultivars. 4. Influence of storage period and storage temperature on growth and yield in the field. *Potato Research*, 30(3): 441-450.
- Ventura, L., Donà, M., Macovei, A., Carbonera, D., Buttafava, A., Mondoni, A., & Balestrazzi, A. (2012). Understanding the molecular pathways associated with seed vigor. *Plant Physiology and Biochemistry*, 60: 196-206.
- Viola, R., Pelloux, J., van der Ploeg, A., Gillespie, T., Marquis, N., Roberts, A. G., & Hancock, R. D. (2007). Symplastic connection is required for bud outgrowth following dormancy in potato (*Solanum tuberosum* L.) tubers. *Plant, Cell & Environment*, 30(8): 973-983.
- Vreugdenhil, D., & Struik, P. C. (1989). An integrated view of the hormonal regulation of tuber formation in potato (*Solanum tuberosum*). *Physiologia Plantarum*, 75(4): 525-531.
- Wang, F. (2008). The importance of quality potato seed in increasing potato production in Asia and the Pacific region. *RAP Publication (FAO)*.
- Wiltshire, J., & Cobb, A. H. (1996). A review of the physiology of potato tuber dormancy. *Annals of Applied Biology*, 129(3): 553-569.
- World Potato Markets (2011). Global potato industry. <https://www.businesswire/en/Research-and-Markets-Global-Potato-Industry-Demand-and-Supply-Production-Consumption-Export-and-Import-Guide>.
- Yan, A., & Chen, Z. (2020). The control of seed dormancy and germination by temperature, light and nitrate. *The Botanical Review*, 86(1): 39-75.
- Zambre, M., Terryn, N., De Clercq, J., De Buck, S., Dillen, W., Van Montagu, M., & Angenon, G. (2003). Light strongly promotes gene transfer from *Agrobacterium tumefaciens* to plant cells. *Planta*, 216(4): 580-586.

APPENDICES

Appendix 1: Analysis of variance for number of sprouts and sprout quality under greenhouse, Egerton site

Sources of variance	d.f	Number of sprouts				
		Week 1	Week 2	Week 3	Week 4	Thick
Season	1	0.22	0.37*	0.35*	0.56**	1.83
Treatment	6	0.83***	1.08***	1.18***	1.15***	22.61
Season*treatment	6	0.04	0.02	0.04	0.02	0.56
Variety	2	1.18***	0.47**	0.79***	0.22	71.65
Season* variety	2	0.10	0.25*	0.26*	0.16	1.13
Variety*treatment	12	0.11	0.07	0.06	0.06	1.07*
Error	94	0.09	0.08	1.06	0.08	0.55
Total	125					
CV		20.38	15.68	20.06	18.53	22.58
R ²		0.57	0.59	0.67	0.66	0.85

*, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$) respectively. CV: Coefficient of Variation, R²: Coefficient of determination

Appendix 2: Analysis of variance for three potato varieties on germination (stand count) at Molo and Egerton sites

Sources of variance	d.f	Stand count		
		Week 1	Week 2	Week 3
Site	1	2853.59***	2565.14***	2328.40***
Season	1	143.25*	44.59	55.25*
Variety	2	871.00***	358.54***	122.61**
Season*variety	2	19.06	14.46	6.21
Site*variety	2	67.49	32.44	2.50
Site * season* Rep* Variety	25	32.26***	19.04***	14.00***
Treatment	6	293.57***	254.04***	193.88***
Variety*treatment	12	3.13	2.56	1.05
Error	198	4.91	3.34	2.19
Total	251			
CV		22.97	14.69	10.35
R ²		0.89	0.89	0.91

*, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$) respectively. CV: Coefficient of Variation, R²: Coefficient of determination.

Appendix 3: Analysis of variance for three potato varieties on plant height and number of stems at Molo and Egerton sites

Sources of variance	d.f	Plant height			Number of stems	
		Week 3	Week 4	Week 5	Week 3	Week 4
Site	1	1240.75*	8078.38**	16851.23***	47.98**	79.12
Season	1	2382.93**	9136.64**	3168.50*	2.64	2.12
Rep	2	48.36	127.20	105.20	0.51	0.41
Variety	2	7522.43***	6204.55**	2913.74*	21.55**	38.41
Season*variety	2	321.36	14.00	82.88	0.91	1.12
Site*variety	2	1280.01*	1160.14	711.43	3.65	2.12
Site* Season*Rep*variety	25	281.02***	674.36***	701.30***	3.54***	3.41
Treatment	6	1777.43***	1694.56***	2280.78***	8.79***	14.12
Variety*treatment	12	69.14	63.07	54.92	0.18	1.12
Error	198	41.63	47.56	47.71	0.68	0.41
CV		19.65	12.98	10.27	33.11	20.12
R ²		0.83	0.86	0.86	0.65	0.41

*, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$) respectively. CV: Coefficient of Variation, R²: Coefficient of determination.

Appendix 4: Analysis of variance for tuber yield

Sources of variance	df	Number of tubers	Small size <30mm	Medium size 30-60mm	Big size >60mm
Site	1	1139.89***	0.91	8.48*	1.80
Season	1	4.15	1.61	4.99	0.18
Rep	2	15.12	0.19	1.48	0.19
Variety	2	10.97	0.53	0.88	3.41
Season*variety	2	2.87	1.26	5.17	0.18
Site*variety	2	4.27	0.92	2.50	5.09*
Site * season* Rep*	25	17.56***	0.67**	1.71*	1.19*
Variety					
Treatment	6	91.70***	8.14***	2.26*	17.67***
Variety*treatment	12	0.59	0.65*	0.71	0.81
Error		1.61	0.36	1.01	0.73

CV	21.04	17.00	34.11	26.64
R ²	0.87	0.53	0.33	0.53

*, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$) respectively. CV: Coefficient of Variation, R²: Coefficient of determination.

Appendix 5: Analysis of variance for number of sprouts and sprout quality under light house.

Sources of variance	d.f	Number of sprouts				Sprout
		Week 1	Week 2	Week 3	Week 4	
Rep	2	0.000	0.278	0.111	0.583	0.129
Treatment (T)	3	1.000***	0.0741	0.9167*	0.185	3.979*
Variety (V)	2	2.250***	1.778***	5.861***	12.250***	35.153
V *T	6	0.250***	0.0741	0.417	0.991**	0.440*
Error	22	0.000	0.088	0.202	0.220	0.086
Mean		0.050	1.222	1.694	2.500	4.522
R ²		1.000	0.688	0.795	0.869	0.978
CV		0.000	24.324	26.526	18.749	6.489

*, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$) respectively. CV: Coefficient of Variation, R²: Coefficient of determination.

Appendix 6: ANOVA for three potato varieties on germinated plants (stand count) at Molo and Egerton sites

Source of variation	d.f	Stand count	
		Week 2	Week 3
Site (S)	1	420.500	1870.681***
Rep	2	62.889	63.500
Variety (V)	2	12079.181***	4665.500***
S*V	2	215.292	675.3889
Treatment (T)	3	663.651**	232.273
S*T	3	88.736	155.940
V*T	6	267.547*	72.370
S*T*V	6	117.160	67.704
Error	46	113.078	99.225
Mean		76.722	86.292
R ²		0.851	0.763
C.V		13.860	11.544

*, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$) respectively. CV: Coefficient of Variation, R²: Coefficient of determination

Appendix 7: ANOVA for three potato varieties on plant height and number of stems

Source of variation	d.f	Plant height (cm)		No. stems		Plant height (cm)		No. stems		Plant height (cm)	
		Week 3	Week 4	Week 3	Week 4	Week 3	Week 4	Week 3	Week 4	Week 3	Week 4
Site (S)	1	3.520	4.500***	4672.061***	0.347	14726.14					
Rep	2	62.197	0.264	166.567	0.597	132.166					
Variety (V)	2	10700.788***	27.931***	8994.532***	19.764***	2870.494					
S*V	2	239.708**	1.293*	217.069	1.264*	120.100					
Treatment (T)	3	107.224	0.648	309.039*	1.162*	24.516					
S*T	3	10.467	0.056	15.749	0.162	16.929					
V*T	6	53.700	0.023	118.938	1.301**	138.020*					
S*T*V	6	46.811	0.458	119.234	0.356	45.950					
Error	46	38.498	0.264	91.585	0.336	54.044					
Mean		40.158	2.361	61.435	2.986	77.0711					
R ²		0.928	0.849	0.860	0.788	0.899					
C.V		15.451	21.757	15.576	19.422	9.539					

*, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$) respectively. CV: Coefficient of Variation, R²: Coefficient of determination.






Appendix 8: ANOVA for tuber yield in Molo and Egerton sites

Sources of variance	d.f	Number of tubers	Small size <30mm	Medium size 30-60mm	Big size >60mm
Site (S)	1	5.418***	1.822	1.714	0.862
Rep	2	0.205	3.899*	0.104	0.905
Variety (V)	2	2.258***	26.978***	3.277*	30.408***

S*V	2	0.144	3.631*	1.792	1.926*
Treatment (T)	3	0.212	0.841	0.370	0.775
S*T	3	0.156	0.778	0.118	0.228
V*T	6	0.543	0.359	1.146	0.39
Error		0.111	1.066	0.834	0.602
Mean		2.681	7.751	2.717	2.615
R ²		0.675	0.584	0.320	0.699
C.V		12.45	13.32	33.600	29.664

*, **, ***, significant at ($p \leq 0.05$), ($p \leq 0.01$), ($p \leq 0.001$) respectively. CV: Coefficient of Variation, R²: Coefficient of determination

Appendix 9: National commission for science-technology and innovation research license

 REPUBLIC OF KENYA	 NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION
Ref No: 623081	Date of Issue: 20/July/2020
RESEARCH LICENSE	
	
This is to Certify that Miss.. 'MALEKHOOA Suzan SUZAN of Egerton University, has been licensed to conduct research in Nakuru on the topic: EFFECTS OF PLANT GROWTH REGULATORS,LIGHT AND NATURAL MATERIALS ON VIGOR,GROWTH AND YIELD OF POTATO (Solanum tuberosum L.) IN KENYA for the period ending : 20/July/2021.	
License No: NACOSTI/P/20/5814	
623081 Applicant Identification Number	 Director General NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION
Verification QR Code	
	
NOTE: This is a computer generated License. To verify the authenticity of this document, Scan the QR Code using QR scanner application.	

Appendix 10: Published article on the effect of different light exposure regimes on pre-sprouting and yield performance on potato tuber (*Solanum tuberosum* L.) seed in Central Rift, Kenya

Vol. 17(7), pp. 1039-1048, July, 2021
DOI: 10.5897/AJAR2021.15622
Article Number: 87484AB67332
ISSN: 1991-637X
Copyright ©2021
Author(s) retain the copyright of this article
<http://www.academicjournals.org/AJAR>



African Journal of Agricultural
Research

Full Length Research Paper

Effects of different light exposure regimes on pre-sprouting and yield performance on potato (*Solanum tuberosum* L.) seed in Central Rift, Kenya

Moletsane Malekhoa S.*, Kimurto Paul K. and Oyoo Maurice E.

Department of Crops, Horticulture and Soils, Egerton University, Njoro, Kenya.

Received 2 May, 2021; Accepted 18 June, 2021

The major problems affecting potato (*Solanum tuberosum* L.) production in Kenya include timely availability of well-sprouted seed potato tubers. Appropriate techniques of availing well-sprouted potato seed for timely planting for different potato varieties with varied seed dormancy periods is one of the major challenges for yield increase. A study was conducted to determine the effects of different light exposure regimes on pre-sprouting, seed germination and yield performance of potato in Central Rift, Kenya. Three light exposure regimes of 8, 12, and 16 h were evaluated in lighthouse for their effects on breaking dormancy and enhancing pre-sprouting in three potato varieties. The lighthouse experiment was laid on complete randomized design (CRD) with three replicates while field experiment was laid on randomized complete block design (RCBD). Data collected on the number of sprouts, sprout lengths, diameters and colour; emergence rate, plant height, number of tubers per plant, and tuber weight were subjected to analysis of variance (ANOVA) and means were compared using Duncan multiple range test ($P < 0.05$). There were significant differences ($P < 0.05$) in different light exposures on traits. Light exposure regimes significantly increased sprout thickness by 31 to 43% and sprout length by 15 to 39% when compared with those of control treatment. Light exposure of 16 h resulted in the highest percent seed germination and tuber weight by 9.5 and 25%, respectively. This suggests that increasing period of light exposure by using simple fluorescence system in pre-sprouting stores will enhance breaking of potato seed dormancy resulting in increased yields.

Key words: Potato yield, light, exposure, sprout quality, pre-sprouting dormancy.

INTRODUCTION

In Kenya, potato is grown throughout the year in about 217315 ha of land mainly in highland areas of Rift valley and Western (FAOSTAT, 2018). It is a major cash crop to many small-scale farmers (Muthoni et al., 2013). The major problems affecting potato production in Kenya include timely availability of well-sprouted seed potato tubers (Riungu, 2011). As a physiological requirement, to

convert fresh tubers to seed, potato tubers must undergo between two to three months of dormancy after harvesting which is a big obstacle to achieving high-quality disease-free seeds for timely planting (Muchiri et al., 2015). This long period of dormancy should be broken to achieve timely availability of well-sprouted seed potato tubers at the onset of rains. Furthermore, in many

*Corresponding author. E-mail: khowymoletsane@gmail.com.

Author(s) agree that this article remain permanently open access under the terms of the [Creative Commons Attribution License 4.0 International License](https://creativecommons.org/licenses/by/4.0/)