SEED QUALITY OF SOYBEAN (*GLYCINE MAX* [L.] MERRILL) GENOTYPES UNDER VARYING STORAGE AND PRIMING METHODS, MOTHER PLANT NUTRIENT PROFILES AND AGRO-ECOLOGIES IN KENYA

Chirchir, Grace Jepleting
(Master of Agricultural Studies)
A99/24919/2011

A Thesis Submitted in Fulfillment of the Requirements for the Award of the Degree of Doctor of Philosophy in Seed Science, School of Agriculture and Enterprise Development

Kenyatta University

October 2015

DECLARATION

I, Grace Jepleting Chirchir, declare that this thesis is my original work and has not been presented for a degree in any other university or any other award.

Signature ------------------------------- Date 28-10-2015

Chirchir Grace Jepleting
Department of Agricultural Science and Technology

SUPERVISORS

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors

Signature ------------------------------- Date 28-10-2015

Dr. Joseph P Onyango Gweyi

Department of Agricultural Science and Technology

Kenyatta University.

Signature ------------------------------- Date 28.10.2015

Dr. Maina Mwangi

Department of Agricultural Science and Technology

Kenyatta University.

Signature ------------------------------- Date 28/10/2015

Dr. Desterio Ondieki Nyamongo
Genetic Resources Research Institute,

Kenya Agricultural and Livestock Research Organization.

DEDICATION

To my beloved husband Engineer Zakayo Chirchir and our children: Sifa Kimutai, Shalom Kiptoo, Baraka Kiprotich and Mwema K. Kerich.

ACKNOWLEDGEMENTS

I thank the Almighty God for his present help, without which this work would not have been accomplished.

I thank my supervisors Dr. Joseph Onyango Gweyi, Dr. Maina Mwangi and Dr. Desterio Nyamongo for their unfailing guidance during proposal development, field and lab work, data analysis and thesis writing. It was a pleasure and a privilege working under their very supportive and strict guidance. I am indebted to the Officer in Charge of Genetic Resource Research Institute Mr. Zachary Muthamia and the entire Staff for all the support they offered during laboratory and field research work. I am also greatly indebted to Dr. Nicholas Korir for teaching me how to use statistical packages, which contributed immensely to my writing. I cannot forget Dr. Patrick Muthoka of National Museums of Kenya for his guidance and training on seed longevity. It was a pleasure working together.

I am very grateful to the Sub County Agricultural Officer Meru South Mr. Stephen Mokaya and his staff for the logistical support they gave me during the soybean farm household survey. I thank the two farmers from Meru South who gave me their in-house stores to conduct the soybean seed storage experiment, Mrs. Leah Gicheru and Lucy Moffat. They were very cooperative.

I thank the National Council for Science Technology and Innovation (NACOSTI) for partially funding this research. I also thank the Government of Kenya through the Ministry of Agriculture Livestock and Fisheries and the Directorate of Personnel Management who granted me leave to pursue this course. Last but not least, I thank my family for all the moral and practical support they offered me throughout the course of this study.

TABLE OF CONTENTS

DECLARATION...I

DEDICATION …. II

ACKNOWLEDGEMENTS III

TABLE OF CONTENTS IV

LIST OF FIGURES X

LIST OF TABLES XII

PLATES ……… XV

LIST OF ABBREVIATIONS AND ACRONYMS XVI

ABSTRACT …… XVII

CHAPTER ONE...1

1. INTRODUCTION 1

1.1. Background to the Study 1

1.2. Statement of the problem...3

1.3. Research justification 4

1.4. Research Objectives 5

1.4.1. Overall objective 5

1.4.2. Specific Objectives 5

1.5. Research Hypotheses..6

1.6. Significance and output of the study 6

1.7. Conceptual Framework 7

CHAPTER TWO...9

LITERATURE REVIEW...9

Overview...9

2.1. Soybean production in Kenya 9

2.2. Soybean seed supply and quality...11

2.3. Factors affecting soybean seed productivity and quality 13
2.3.1. Genetic factors 13
2.3.2. Environmental factors 15
2.3.3. Agronomic practices 17
2.3.4. Mother-plant nutrition 18
2.4. Seed storage conditions 23
2.5. Seed treatments 25
2.5.1. Chemical Seed dressing 25
2.5.2. Seed dressing with ash 26
2.5.3. Seed priming 26
2.5.4. Post-priming seed storage 31
2.6. Seed vigor 32
2.6.1. Seedling growth tests 35
2.6.2. Seed accelerated ageing 36
2.6.3. Electrical Conductivity test 37
2.6.4. Comparative seed longevity testing and Potential storability index (p_{50}) 38
2.6.5. Seedling field emergence 39
2.7. Relationships between Seed germination, viability and vigor 40
CHAPTER THREE 42
MATERIALS AND METHODS 42
3.1. Objective 1: To evaluate soybean production, seed handling and quality in key soybean production areas of Meru South, Eastern Kenya 42
3.1.1. Description of soybean farm household survey Study sites 42
3.1.2. Farm-household survey 44
3.1.3. Farm saved seed sampling and analysis 47
3.1.4. Data Analysis 48

3.2. Objective 2: To evaluate the effects of storage agro-ecology, storage containers, seed dressing and genotype on soybean seed quality under ambient conditions..49

3.2.1. Description of Soybean seed storage experimental sites 49

3.2.2. Soybean seed storage experimental layout 51

3.2.3. Laboratory Seed quality analysis 53

3.2.4. Statistical analysis 58

3.3. Objective 3: To determine the effect of osmo-priming and hydro-priming on soybean seed viability and vigor. 59

3.3.1. Soybean seed storage experiment in Meru South 59

3.3.2. Osmo and hydro-priming treatments 60

3.3.3. Post-priming seed storage 61

3.3.4. Seed Quality tests...61

3.3.5. Statistical Analysis 62

3.4. Objective 4: To determine the influence of mother plant nutrition, genotype and agro-ecology on soybean productivity, seed longevity and vigor. 63

3.4.1. Description of field research experimental sites 63

3.4.2. Soil sampling and analyses 65

3.4.3. Experimental design...67

3.4.4. Field data collection 69

3.4.5. Laboratory seed quality tests 70

3.4.6. Statistical Analysis 72

CHAPTER FOUR 73

RESULTS AND DISCUSION...73

Overview...73

4.1. Objective 1: Soybean production, seed handling and quality in key soybean production areas of Meru South, Eastern Kenya 73

4.1.1. Demographic characteristics of soybean growing households 74

4.1.2. Soybean production in Meru south 78

4.1.3. Soybean seed sources and handling 92

4.1.4. Soybean marketing and uses 99

4.1.5. Soybean utilization by farm-households in Meru South.....................101

4.1.6. Constraints to soybean production 102

4.1.7. Farm-saved soybean seed quality 103

4.1.8. Summary of findings on Soybean farm household survey 105

4.2. Objective 2: Effects of storage agro-ecology, storage containers, seed dressing and genotype on soybean seed viability and vigor under ambient conditions. 107

4.2.1. Effect of storage duration in different agro-ecologies on germination and vigor of soybean 107

4.2.2. Effects storage at different agro-ecologies on seed quality of soybean …..110

4.2.3. Influence of Genotype on storability of soybean seed 117

4.2.4. Effect of storage container on storability of soybean seed 121

4.2.5. Effect of Seed dressing on germination and vigor of soybean. 129

4.2.6. Summary of findings on soybean seed storage experiment................136

4.3. Objective 3: Influence of osmo-priming and hydro-priming on soybean seed quality and storability. 138

4.3.1. Effect of priming on germination percent of soybean 138

4.3.2. Effect of priming on seed leachate conductance (Electrical Conductivity) of soybean. 140

4.3.3. Effect of priming on Mean Germination Time of soybean.................144

4.3.4. Effect of priming on Germination Index (GI) of soybean. 147

4.3.5. Effect of priming on Time to 50% Germination of soybean 149

4.3.6. Effect of priming on Energy of Emergence (EE) of soybean 152

4.3.7. Effect of priming on Speed of Emergence (SE) of soybean 154

4.3.8. Effect of Priming on Seedling Vigor Index of soybean......................157

4.3.9. Effect priming on storability of soybean. 159

4.3.10. Summary of findings on priming and post-priming storage 168

4.4. Objective 4: Influence of mother plant nutrition, genotype and agro-ecology on soybean productivity and seed quality. 170

4.4.1. Soil type and average initial soil fertility level for experimental sites 170

4.4.2. Growth and yield of soybean genotypes in response to N and P fertilization and agro-ecology. 171

4.4.3. Soybean seed quality as influenced by mother plant nutrition, genotype and agro-ecology 179

4.4.4. Summary of findings 191

CHAPTER FIVE 192

5. CONCLUSIONS AND RECOMMENDATIONS 192

Introduction 192

5.1. Conclusions 192

5.2. Recommendations 194

5.3. Areas for further research 196

6. REFERENCES 198

APPENDIX 1: Soybean Survey Data Collection Questionnaire 226

APPENDIX 2: Discussion Guide for Qualitative Data 231

APPENDIX 3: Farmers from whom farm-saved soybean seed was sampled from various agro ecologies in meru south sub-county; from 19^{th} - to 26^{th} february 2013 232

APPENDIX 4: Effect of N And P Fertilization on Growth and Yield Components of Soybean 233

APPENDIX 5: Accelerated ageing germination % and p50 of soybean genotype Gazelle and TGx 1740-2F (SB 19). 234

APPENDIX 6: Seed leachate conductance of soybean genotype Gazelle and TGx 1740-2F(SB19) after accelerated ageing 235

APPENDIX 7: ANOVA Tables 236

APPENDIX 8: Soil sampling 243

APPENDIX 9: Field Experimental Layout - RCBD 243

APPENDIX 10: Early maturing soybean Gazelle and late maturing TGX 1740 2F244

APPENDIX 11: Seed germination in incubator set at alternating temperature 20/30^{0}C 244

APPENDIX 12: Priming in osmotic solutions kept in a walk in germination room at 25^{0}C 245

APPENDIX 13: Priming reduced germination percent but enhanced vigor 245

LIST OF FIGURES

Figure1.1: Conceptual Framework. 8

Figure 2.1: Relationships between seed vigor, viability, and deterioration. 34

Figure 2.2: Relationships between Seed germination, viability and vigor. 40

Figure 3.1: Soybean farm household survey sites in Meru South Sub-county 43

Figure 3.5: Experimental plots layouts at (a) GeRRI – Muguga and (b) Nkoroi – Kajiado North 68

Figure 4.2: Institutions that introduced soybean farming 81

Figure 4.3: Sources of soybean Seed in Meru South Sub-county 93

Figure 4.5: Soybean production constraints in Meru South Sub-County 102

Figure 4.6: Changes in seed moisture content (fwb) of farm saved seed of soybean Gazelle sampled from different agro-ecologies: Upper midland II(UM2), Upper Midlands III(UM3), Lower Midland III(LM3) and Lower Midland IV(LM4) regions of Meru South. 104

Figure 4.7: Seed leachate conductance (EC) and germination % of farm-saved seed genotype Gazelle sampled at UM2(Upper midland II(UM2), Upper Midlands III(UM3, Lower Midland III(LM3) and Lower Midland IV(LM4) regions of Meru South 104

Figure 4.9: Influence of seed dressing with Ash and Apron Star® on soybean genotype Gazelle and SB19 accelerated ageing germination percent at 123 days after storage at Upper Midland II (UM2) and Lower Midland IV (LM4) storage sites in Meru South. 135

Figure 4.10: Relationship between priming concentration (Fig. a) and priming duration (Fig. b) on electrical conductivity of soybean Gazelle and TGx 1740 2F (SB 19) after 8 months of seed storage. 143

Figure 4.11: Effect of N (25kg-1ha) and P (60kg-1ha) fertilization on seed yield of soybean genotypes Gazelle and TGx 1740-2F grown at Lower highlands III(Muguga) and Upper midlands IV(Nkoroi) during short rains of October –November 2013. 173

Figure 4.12: Effect of genotype and agro-ecology on soybean (a) Plant height (b) Number of branches (c)Number of pods/plant (d) Number of seeds per pod (e) 1000 seed weight (f) Seed yield 175

Figure 4.13: Seed survival curves for seed lots of genotype Gazelle grown in two agro-ecologies Muguga (LH3)and Nkoroi(UM4) under fertilizer treatment (A)N 0kg^{-}1ha + P 0kg^{-}1ha; (B)N 25kg^{-}1ha; (C)P 60kg^{-}1ha and (D) N 25kg^{-}1ha + P 60kg^{-}1ha..179

Figure 4.14: Seed survival curves for seed lots of genotype TGx 1740-2F grown in two agro-ecologies Muguga (LH3) and Nkoroi (UM4) under fertilizer treatment (A) N 0kg^{-}1ha + P 0kg^{-}1ha ; (B) N 25kg^{-}1ha; (C) P 60kg^{-}1ha and (D) N 25kg^{-}1ha + P 60kg^{-}1ha..180

Figure 4.15: Effect of accelerated aging (41^{0} C, 100% relative humidity) on germination and seed leachate conductance of soybean seed variety Gazelle and TGx 1740-2F (SB19). 190

LIST OF TABLES

Table 3.1: Soybean farmers sampled during the survey by wards 45

Table 3.2: Dosage and active ingredients of seed dressing chemicals used on soybean seeds...51

Table 4.1 Characteristics of Farm Households Head and respondents 74

Table 4.2: Type of dwelling structures owned by survey households 76

Table 4.3 Other crops produced by soybean growing farm households in year 2013 78

Table 4.4 Experience of farmers in soybean cultivation 80

Table 4.5 Proportion of farmers growing soybean in different seasons.....................81

Table 4.6:Distribution of soybean planting and harvesting seasons during the (2012/2013) growing season...82

Table 4.7: Soybean varieties grown and farmer preferences 83

Table 4.8: Land preparation and cropping system for soybean.................................85

Table 4.9: Types of nutrients applied to soybean in Meru South Sub-county 87

Table 4.10:Inorganic fertilizer application rates on soybean in Meru South Sub-County during the short rains October/November 2013.........................87

Table 4.11:Manure application rates on soybean crop by survey households in Meru South Sub-county during the short rains October/November 2013........87

Table 4.12:Soybean pests and diseases prevalent in Meru South Sub-county...........89

Table 4.13: Hectarage under soybean during the 2012/2013 cropping season in Meru South Sub-County 90

Table 4.14:Average yields (Kg ha^{-1}) of soybean produced by farm households during the 2012/2013 cropping year in Meru South Sub-County 91

Table 4.15: Seed production and processing in Meru South sub-county...................94

Table 4.16: Soybean seed storage methods in Meru South Sub-county 97

Table 4.17: Soybean seed storage period before next planting season in Meru South Sub-county (N=304) 98

Table 4.18: Level of field germination of soybean reported by survey households ..99

Table 4.19: Soybean marketing by farm-households in Meru South Sub-county....100

Table 4.20: Seed germination and vigor of soybean genotype Gazelle and SB19 at UM2 –Kirege and LM4-Igambatuntu as influenced by seed storage duration in Meru South sub-county 109

Table 4.21: Effects of seed storage agro-ecology and storage period on studied seed quality traits of soybean Gazelle during storage at UM2 Kirege and LM4 Igambatuntu 111

Table 4.22: Effects of seed storage agro-ecology and storage period on studied seed quality traits of soybean genotype SB19 (TGx 1740-2F) during storage at UM2 (Kirege) and LM4 (Igambatuntu) 112

Table 4.23: Comparison of means of studied traits in soybean as influenced by genotype and seed storage period at Upper Midlands II (UM2) Kirege site. 117

Table 4.24:Comparison of means of studied traits in soybean as influenced by genotype and seed storage period at Lower Midlands IV (LM4) Igambatuntu site, Meru South Sub-county. 119

Table 4.25:Comparison of means of studied traits in soybean genotype Gazelle as influenced by storage containers and seed storage periods at Upper Midlands II -KIREGE site 122

Table 4.26: Comparison of means of studied traits in soybean genotype TGx 1740 2F (SB19) as influenced by storage containers and storage periods at UM2 - Kirege seed storage site... 123

Table 4.27: Comparison of means of studied traits in soybean genotype Gazelle as influenced by storage containers and storage periods at LM4 – Igambatuntu storage site 124

Table 4.28: Comparison of means of studied traits in soybean genotype TGx 1740-2F (SB19) as influenced by seed storage containers and storage periods at LM4 –Igambatuntu storage site 125

Table 4.29: Comparison of means of studied germination and vigor traits of soybean genotype Gazelle as influenced by seed dressing and storage periods at Upper Midlands II (UM2)-Kirege site 129

Table 4.30 : Comparison of means of studied germination and vigor traits of soybean genotype TGx 1740-2F(SB19) as influenced by seed dressing and storage periods at Upper Midlands II (UM2)-Kirege site..................... 131

Table 4.31: Comparison of means of studied germination and vigor traits of soybean genotype Gazelle as influenced by seed dressing and storage periods at Lower Midlands IV (LM4) - Igambatuntu site. 132

Table 4.32: Comparison of means of studied germination and vigor traits of soybean genotype TGx 1740-2F (SB19) as influenced by seed dressing and storage periods at Lower Midlands IV - Igambatuntu site. 133

Table 4.33: Germination Percent (GP) of soybean genotypes as affected by seed priming Concentration and Priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South......................139

Table 4.34: Electrical conductivity (µs/cm/g) of soybean genotypes as affected by seed priming Concentration and Priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South............141

Table 4.35: Mean Germination Time (MGT) of soybean seed as affected by genotype, seed priming Concentration and Priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South145

Table 4.36: Germination Index (GI) of soybean genotypes as affected by seed priming concentration and priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South......................148

Table 4.37: Time to 50% germination (T50) of soybean genotypes as affected by seed priming Concentration and Priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South............150

Table 4.38: Energy of Emergence (EG) of soybean genotypes as affected by seed priming concentration and priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South......................153

Table 4.39 : Speed of Emergence (SE) of soybean genotypes as affected by seed priming concentration and priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South......................155

Table 4.40: Comparison of means of Seedling Vigor Index (SVI) of soybean genotypes as affected by seed priming concentration and priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South..158

Table 4.41: Comparison of means of studied traits in soybean Gazelle after 0-months of post-priming storage as influenced by priming concentration and duration 160

Table 4.42: Comparison of means of studied traits in soybean seed Gazelle after 8-months of post-priming storage as influenced by priming concentration and duration. 161

Table 4.43: Comparison of means of studied traits in soybean genotype SB19 after 0-months of post-priming storage as influenced by priming Concentration and Duration 163

Table 4.44: Comparison of means of seed quality traits in soybean genotype SB19 after 8 - months of post-priming storage as influenced by priming Concentration and Duration 164

Table 4.45: Means comparison of seed quality traits as influenced by soybean genotype after 8 months postpriming storage. 167

Table 4.46: Initial soil properties at field experimental sites 170

Table 4.47: Effect of Nitrogen (N) and Phosphorous (P) fertilization on growth and yield components of soybean Gazelle and TGx 1740 2F grown at LH3 agro-ecology. 172

Table 4.48: Effect of Nitrogen (N) and Phosphorous (P) fertilization on growth and yield components of soybean Gazelle and TGx 1740 2F grown at UM4 agro-ecology (Nkoroi)... 172

Table 4.49: The effect of interactions between genotype and agro-ecology (LH3 and UM4) on soybean growth and yield components 177

Table 4.50: Effect of genotype, agro ecology and N and P fertilizers on time for viability to decline to 50% (p50)... 181

Table 4.51: Effect of Phosphorus and Nitrogen fertilization on seed leachate conductance of soybean genotype Gazelle and SB 19 grown LH3 and UM4 agroecologies at harvest.. 181

Table 4.52: Comparison of means of seed leachate conductance (EC) of soybean genotypes grown at LH3 and UM4 agro-ecologies. 185

Table 4.53: Effect of growing agro-ecology (LH3 and UM4) on seed leachate conductance of soybean Gazelle and SB19. 188

LIST OF PLATES

Plate 3.1: Jenway 4020 conductivity meter... 57

Plate 3.2: Preconditioning of seeds 57

Plate 3.3: Accelerated ageing box 57

Plate 3.4: Seed priming procedures (a) soaking seeds in priming agents (b) air drying primed seeds on shelves (c) seed drying in cloth bags. 60

Plate 3.5:Experimental design RCBD (a); topdressing with N at R1 stage (b); supplementary irrigation (c) and harvesting when seeds rattle in pods (d). 69

LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	-	Agro-ecological zone
AGRA	-	Alliance for a Green Revolution in Africa
EC	-	Electrical conductivity
EG	-	Energy of Emergence
FAO	-	Food and Agriculture Organization
FURP	-	Fertilizer Use Recommendation Project
GI	-	Germination Index
GP	-	Germination Percent
GTZ	-	German Agency for Technical Cooperation
HH	-	Household
ICIPE	-	International Centre for Insect Physiology and Ecology
ISFM	-	Integrated Soil Fertility Management
ISTA	-	International Seed Testing Association
KALRO	-	Kenya Agriculture and Livestock Research Organization
KARI	-	Kenya Agricultural Research Institute
KTDA	-	Kenya Tea Development Agency
LH0	-	Lower Highlands (0) agro-ecological zone
LH1	-	Lower Highlands (I) agro-ecological zone
LH3	-	Lower Highlands (III) agro-ecological zone
LM3	-	Lower Midlands (III) agro-ecological zone
LM4	-	Lower Midlands (IV) agro-ecological zone
LM5	-	Lower Midlands (V) agro-ecological zone
LSD	-	Least Significant Difference
MGT	-	Mean Germination Time
MPa	-	Mega Pascals
P_{50}	-	Time for viability to decline by 50%.
PEG	-	Polyethylene glycol
SDA	-	Seventh Day Adventist Church
SE	-	Speed of Emergence
SOCO	-	Soy and Climbing Bean Commercialization Programme.
SSA	-	Sub-Saharan Africa
SVI	-	Seedling Vigor Index
T50	-	Time to 50% germination
TA	-	Tropical alpine AEZ zone
TGX	-	Tropical Grain Crosses
TSBF	-	Tropical Soil Biology and Fertility.
UH0	-	Upper Highlands (0) Agro-ecological zone
UM1	-	Upper Midlands (I) Agro-ecological zone
UM2	-	Upper Midlands (II) Agro-ecological zone
UM3	-	Upper Midlands (III) Agro-ecological zone
UM4	-	Upper Midlands (IV) agro-ecological zone.

ABSTRACT

Soybean is one of the most important sources of protein and vegetable oil in the world. The demand for soybeans in Kenya is high yet production is negligible due to various challenges, one of which is lack of a well-organized soybean seed system. Soybean seed has been known to deteriorate rapidly in the tropics but the rates vary with the environment, initial quality of the seed and genotype. The broad objective of the research was to enhance soybean seed longevity and vigor through manipulation of storage and priming methods, mother plant nutrition and agro-ecology. A socio-economic survey was conducted to evaluate soybean enterprise, seed handling and quality in Meru South - Tharaka Nithi County. A seed storage trial was done to assess the effect of agro-ecology, genotype, seed dressing and storage materials on soybean seed longevity and vigor. Soybean genotypes tested Gazelle and TGx 1740-2F(SB19) were dressed with wood ash and Apron star® and stored in sealed plastic cans and synthetic gunny bags in farmers stores at Kirege (UM II) and Igambatuntu (LM IV) in Meru South. Monitoring of seed quality during 8 months of storage was done by moisture content, germination, electrical conductivity and accelerated ageing tests at Genetic Resource Research Institute Laboratory, Muguga. The effects of osmo and hydro-priming seed invigoration techniques on soybean seed quality and storability of primed seed was assessed. The influence of mother plant nutrition, genotype and agro-ecology on soybean productivity and seed quality was carried out at Muguga (LH3) and Nkoroi in (UM4) during the short rains of October-November 2013; and seed quality analyzed using accelerated ageing and electrical conductivity tests. Soybean farmers survey revealed that soybean was grown mostly by older (>40yrs -79%), small scale (0.9Ha) mixed farmers on small parcels (0.05ha) and producing low yields of about 283 kg ha^{-1} . Soybean was newly introduced (<4yrs - 89%) crop, grown mainly in the short rains (84%) as a pure crop (77%), with main varieties being Gazelle (82%) and TGx 1740-2F (14%). Due to lack of assured markets, the crop was mainly grown for own use (74%) mostly as composite flours. Due to lack of a certified seed, farmers relied on farm-saved-seed, stored in synthetic gunny bags (89%) for 1-8 months, with viability ranging from 0% in the warmer LM4 to 100% in the cooler UM2. The seed storage study showed that hermetic storage in sealed plastic Jeri cans, seed dressing with wood ash and storage in cooler agro-ecologies (UM2) was found to be effective and low cost seed storage method for enhancing soybean seed viability and vigor. Soybean genotype SB19 had higher viability, longevity and vigor than Gazelle. Priming enhanced seed vigor by reducing seed leachates, but reduced germination. The 24 h priming duration and PEG -1.0 Mpa was the most beneficial treatment for SB19 but not for Gazelle. Primed seed retained high vigor after 8 months of post priming storage than non-primed seed. The manipulation of mother plant nutrition genotype and agro-ecology revealed that soybean grown in cooler LH3 had greater longevity and vigor, but with lower yields than seed grown in the warmer LM4; and TGx1740-2F resisted field weathering than Gazelle. Nitrogen and Phosphorus fertilization had no effect on soybean productivity, but N_{25} and N_{25}+ P_{60} enhanced seed longevity, but these effects varied with site and genotype. The study recommends establishment of source of quality seed, streamlining marketing and promoting utilization of soybean to enhance production of the crop. Seed dressing with ash and storage in hermetically sealed plastic cans in the cooler highlands is recommended for better seed quality. In addition seed should be produced with good nutrition, in the cooler highlands for enhanced longevity. Priming is recommended for enhancing vigor of SB19.

CHAPTER ONE
INTRODUCTION

1.1. Background to the Study

Soybean (*Glycine max* (L.) Merrill) is a drought tolerant multipurpose crop grown for edible oil, industrial use, human food, livestock feed and as a source of bio-energy (Myaka *et al*., 2005) The crop is of a high commercial value as it contains about 40-45% protein, 20-22% oil, 20-26% carbohydrate, a high amount of Ca, P and vitamins (Rahman *et al.*, 2011). Processed soybean products such as flour, oil, soya milk, soya beverage, snacks and chunks have a long shelf life and soybean milk is important for feeding babies with lactose intolerance (Karuga and Gachanja 2004). Moreover, the promiscuous dual purpose soybean varieties have been proven to improve soil fertility through nitrogen fixation under Kenyan conditions (Vanaluwe *et al*., 2003). The crop therefore has the potential to improve food and nutrition security, alleviate poverty in rural areas, protect the environment and increase incomes through increased productivity and value addition (Mathu *et al*., 2010).

The demand for soybeans in the Kenyan market is high, standing at between 50,000 and 100,000 metric tons, against a negligible domestic production of 1,000 to 5,000 MT per year (MOA, 2012). The deficit is met through importation. The government aims to achieve self-sufficiency in vegetable oil and protein meal and is encouraging local production of oil seeds. Soybean is one of the principle seeds under consideration but its expansion has been met with major drawbacks (MOA, 2012).

Among the challenges faced in the promotion and production of soybean are competition with cheap vegetable oil imports; lack of well-organized markets, processing and poor seed systems. This has led to low soybeans production base to meet the required volumes for industry (MOA, 2009). In spite of this drawback however, much success has been achieved in soybean research and development in Kenya. This has led to availability of high yielding, drought tolerant, early maturing and adaptable varieties for the short day tropical conditions (Myaka *et al*., 2005; Mathu *et al*., 2010). In spite of this achievement, soybean seed system in Kenya is not well developed, hence farmers use mixed varieties sourced from markets that result into low yields (MOA, 2009).

Soybean is one of the most sensitive agromatic seeds where significant deterioration can occur prior to harvest and just under one year of storage making it impossible for farmers to use their own seed for planting in the subsequent season (Priestley, 1986; Horlings, *et al*., 1991). Soybean seed cannot be stored satisfactorily under ambient tropical conditions with high temperature and high moisture but it can store fairly well with low temperature and low seed moisture (Gregg, 1982). Losses in seed quality occur during field weathering, harvesting and storage, and are exacerbated if seeds are exposed to high temperatures and/or humidity (Shatters *et al*., 1994).

One of the major problems with soybean production in Kenyan tropics is the retention of seed viability between harvest and the next planting season since seed viability can deteriorate fairly rapidly after harvest. Given that seed storage is usually at ambient temperatures rather than in climate controlled rooms, the viability will be related to temperature during the off season when the seed has to be stored (Tinsley, 2009). Ng, (1988) however reported that the rapid rate of soybean seed deterioration under adverse tropical storage conditions can be arrested by storing seed in dry-cold conditioned stores. Such a facility, however, would be uneconomical for both on-farm and commercial seed production. Consequently, cheaper alternatives for enhancing soybean seed longevity and vigor under ambient conditions are needed.

The National Seed Policy (2010) clearly states that there is lack of information on viability and longevity of seed under different storage conditions in Kenya. Consequently, there is need for experimental data collection and evaluation on soybean seed production, storage and seed quality across various climatic zones in Kenya and on this basis, this study was initiated.

1.2. Statement of the problem

Soybean demand in Kenya has outstripped production; hence there is a growing need to focus on policies and strategies that enhance production in order to achieve self-sufficiency and saving of foreign exchange (MOA, 2012).

Although soybean can be grown from 0-2200 m above sea level in Kenya, there is a greater potential for increasing soybean production in the lower altitudes where temperature and rainfall favor its production (Mathu *et al*., 2010).. However, one major constraint to soybean production in the tropics is the rapid loss of seed viability and vigor during storage under ambient conditions (Nkang and Umho 1996). The challenge therefore in the Kenyan tropics would be loss of soybean seed viability between harvest and the next planting season, leading to low crop stand establishment, hence productivity. Soybean seed longevity and vigor has been reported to be affected by various factors; such as seed storage periods, ageing conditions of high temperature and moisture, seed packaging materials and inherent qualities of the species (Kandil *et al.*, 2013). There is however little information reported in the literature on the effects of these less-than-ideal storage environments on the germination and vigor of soybean seed. Most of the information currently available describes better methods to evaluate seed vigor and germination, and proper storage environments for long-term storage of seed. For example, reducing seed moisture to below 7% and low temperature storage of about 5^0C has been found to be effective in maintaining soybean seed longevity and vigor (Cromarty *et al*., 1985) but this procedure is difficult to achieve under ambient farm conditions. Reports on the effect of mother plant nutrition (Lot *et al.,* 1995; Krueger *et al*,. 2013), seed storage containers (Pessu *et al.,* 2005; Akter *et al.*, 2014, Wambugu *et al.,* 2009) and seed invigoration techniques such as priming (Carlos and cantliffe, 1992; Hardegree, 1998; Mubshar *et al*. 2006) as well as seed dressing (McDonald 1994; Adebisi *et al*., 2004) on soybean seed productivity, seed longevity and vigor have shown variable outcomes - both adverse and positive effects depending on genotype, environmental conditions and type of treatments used

1.3. Research justification

Soybean is a crop with potential to increase income and nutrition security and hence reduce poverty among the small scale farmers in the soybean growing areas. Farmers however face the problem of getting viable seeds due to poor maintenance of seed viability between harvest and the subsequent planting season. Therefore exploring various seed quality enhancement techniques such as mother-plant nutrition, seed dressing and storage techniques as well as priming on locally grown soybean genotypes may offer opportunities for farmers to improve seed viability, longevity and vigor under ambient tropical conditions. However, the effectiveness of these procedures on soybean genotypes grown and stored in contrasting agro-ecologies in Kenya has not been determined, hence the reason for the current research.

This study therefore sought to develop effective methods for enhancing soybean seed viability, longevity and vigor under Kenyan conditions. The findings will contribute towards the development of a viable seed management system that will enhance productivity, profitability and sustainability of soybean farming, resulting in substantial increase in yields, enhanced human health and incomes.

1.4. Research Objectives

1.4.1. Overall objective

The overall objective of this study was to determine appropriate protocols that enhance soybean seed longevity and vigor through manipulation of seed production and storage environments, storage methods, mother plant nutrition and priming.

1.4.2. Specific Objectives

i. To evaluate soybean enterprise, seed handling and quality in key soybean production areas of Meru South Sub-county in Meru County, Kenya.

ii. To evaluate the effects of storage agro-ecology, storage containers, seed dressing and genotype on soybean seed quality under ambient conditions.

iii. To determine the effect of osmo-priming and hydro-priming on soybean seed viability, longevity and vigor.

iv. To determine the influence of mother plant nutrition, genotype and agro-ecology on soybean seed productivity, longevity and vigor.

1.5. Research Hypotheses

The study was guided by the following hypotheses:

i. Soybean enterprise, seed handling and quality does not vary in key production areas of Meru South Sub-county in Meru County, Kenya.

ii. Storage agro-ecology, storage containers, seed dressing and genotype do not significantly influence soybean seed viability and vigor under ambient conditions of Meru South sub-county.

iii. Osmo-priming and hydro-priming have no significant effect on soybean seed viability and vigor.

iv. Mother plant nutrition, genotype and agro-ecology have no significant effect on soybean seed productivity, longevity and vigor.

1.6. Significance and output of the study

The significance of the study is to build a scientific basis for enhancing soybean seed viability, longevity and vigor for increased crop productivity throughout soybean growing areas in order to meet present and future soybean commodity demand. The outputs of this research will contribute towards understanding the constraints facing soybean enterprise and seed system, leading to designing of better strategies in the development of the soybean value chain. Further, the outputs will aid in designing better storage methodologies for enhanced soybean seed quality under ambient conditions; as well as determine the effectiveness of priming as soybean seed invigoration technique. In addition, the effect of enhanced soybean mother plant nutrition and production agro-ecology on soybean seed productivity, longevity and vigor was determined. These outputs will contribute towards the development of appropriate and effective methods for enhancing soybean seed productivity, seed longevity and vigor thus providing a technical basis for adoption in soybean production systems, leading to enhanced soybean production in Kenya. This will lead to improvement in food and income security of farmers in soybean growing ecologies in Kenya and in countries with similar agro-ecological conditions.

1.7. Conceptual Framework

The concept surrounding this study is that there is a complex interaction of agro-ecology, mother-plant nutrition, genotype, seed dressing and storage containers that affect soybean seed viability, longevity and vigor (Fig 1.1). These include; climate related factors (such as rainfall, temperature and relative humidity), soybean agronomic practices (mainly plant nutrition) and seed treatments (such as seed dressing and priming) as well as seed storage practices. This study integrates these factors within the four (4) objectives and focuses on assessing soybean production and seed systems, evaluation of seed storage methods, application of mother plant nutrition and use of seed dressing and priming techniques for seed quality enhancement.

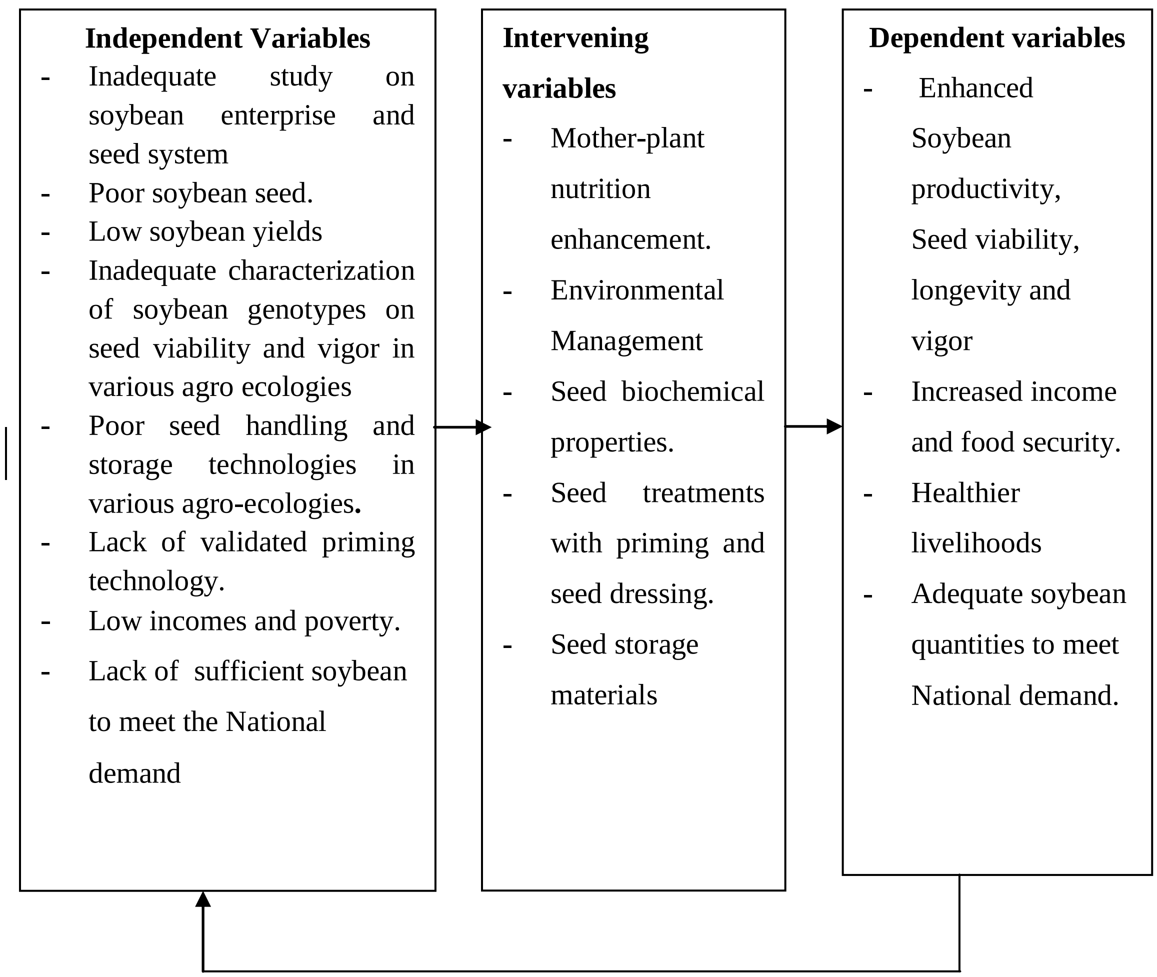

Figure1.1: Conceptual Framework.

CHAPTER TWO

LITERATURE REVIEW

Overview

The goal of this chapter is to review the critical points of current knowledge including substantive findings as well as theoretical and methodological contributions to the subject matter. The thematic areas covered are: soybean production and seed systems; seed quality characteristics; factors influencing seed quality - environmental, genetic, mother-plant nutrition; techniques for determining seed viability, longevity and vigor; seed storage techniques and effects of storage environments, agro-ecology and packaging on seed quality; seed treatment techniques such as seed dressing, osmo-priming and hydro-priming.

2.1. Soybean production in Kenya

Soybean in Kenya is grown from sea level to 2,200 m above sea level, under rainfall regime of 300 to 1200mm, mainly in areas where maize and common beans are grown. It grows to a height of 60–120 cm, maturing in 3 to 6 months depending on variety, climate, and location (Mathu *et al*., 2010). Altitude influences temperature which in turn affects the initiation of flowering and maturity. At very high altitudes, flowering may not occur and the crop remains vegetative. Soybean is therefore a crop that requires warm climates and is suitable for low to medium altitudes (Ogema *et al.*, 1988). The most commonly grown soybean genotypes in Kenya are Nyala, Gazelle and Duicker, mainly due to seed availability rather than farmer preference (Kaara et al., 1998). Five soybean genotypes (Hill, Black Hawk, EAI 3600, Nyala and Gazelle) were officially released in 2009 for specific growing areas with a yield potential of up to 2.0 tons ha^{-1}. Two promiscuous genotypes types (TGX) series SB 19 and SB 8 from IITA with ability to fix nitrogen, high grain and biomass yield were also released in May 2010 (Mahasi *et al.,* 2011). Soybean yields under Kenyan conditions have been found to be low in spite of availability of appropriate technologies for immediate adoption by farmers (Mahasi *et al.,* 2011). The National soybean yield is estimated at 800 kg ha-1 (FAO, 2008), but with variability ranging from 560 kg ha^{-1} (Western Kenya) to 1100 kg ha^{-1} (Eastern Kenya) (Mahasi *et al.,* 2011). Soybean however has potential for higher yields of 3000–3600 kg ha^{-1}, provided farmers use well adapted, high-yielding varieties and better crop management practices (Chianu *et al.,* 2008).

Soybean grows best when planted in pure stands because of its sensitivity to shading unlike the common bean. Also the presence of *Rhizobium japonicum* in the soil enables some varieties to fix nitrogen of 44 -103 kg N ha^{-1} annually, hence contributing to improved soil fertility (Kasasa *et al.,* 2000; Sanginga *et al.,* 2003). When grown in rotation with other crops, the subsequent crop often benefits from the surplus nitrogen left in the soil after soybean has been harvested. Consequently, soybean has been known to increase maize yields by up to 25% (Chianu, 2006). Reports show that the soybean can grow in areas where soils have been mined due to the continuous cultivation of nutrient demanding crops, hence resource poor farmers who cannot afford sufficient quantities of inorganic fertilizers for sustainable agricultural production can grow soybean (Mathu *et al.,* 2010).

Although it has been reported that soybean being a recent introduction in much of Africa has fewer disease and insect problems than other grain legumes (Misiko *et al*., 2008), pests and disease problems of soybean in Africa have increased in recent years. The soybean aphid has been reported as a major threat to soybean production with other pests being armyworms, bean leaf beetles, cutworms, foliage-feeding caterpillars, grasshoppers, potato leafhoppers, seed corn maggots, spider mites wireworms and mealy bugs. The diseases include sudden death syndrome, powdery mildew, root rots, leaf spots and soybean rust (Kandel, 2010).

In Kenya, smallholder (usually non-commercial) farmers (with land holding ranging from 0.1 to 0.2 ha) almost wholly undertake soybean cultivation. Occasionally however, soybean is grown by large-scale farm enterprises such as Hugo Wood (located in Narok), George Nightingale farm (Njoro), Menengai Feedlot (Njoro), Timau soybean production (Meru), Kisima farm (Meru), Rumuruti Kisima (Laikipia district), Hortitec Seed Company (Naivasha), Delamere Estates (Naivasha), Elkana Owgeas, Western Seed Company (Kitale), Mwea irrigation scheme managed by National Irrigation Board (Kirinyaga district), and KARI (Njoro) (Chianu *et al*., 2008). Inspite of this low production, demand for soybean in Kenya is high; amounting to about 120,000 MT p.a. but production is negligible ranging from 1,000 - 5,000 MT p.a. (MOA, 2012). Sustainable production remains a problem- one cited reason is the lack of a well-organized soybean seed system.

2.2. Soybean seed supply and quality

Although research in Kenya has come up with adaptable high yielding varieties, soybean production is still negligible, due to various challenges among which is a weak seed system (MOA, 2009). For success of soybean production, there is need for a secure seed supply system, which can deliver good quality seed of improved and new varieties to farmers. However, in Kenya, there is no seed company that produces certified soybean seed, hence farmers use mixed varieties sourced from the markets with poor seed viability as seed is stored in ambient tropical conditions. Seed merchants not willing to deal with soybean because of self-pollination, hence farmers tend to recycle seedsof poor quality (MOA, 2009).

Generally, soybean seed deteriorates during storage; hence maintenance of seed quality is a primary concern for seed merchants and farmers. Losses in seed quality occur during field weathering, harvesting and storage, and are exacerbated if seeds are exposed to high temperatures and/or humidity (Harrington, 1972; Roberts, 1973, Shatters *et al*., 1994); pest and pathogen damages (Kulik, 1995). Seeds treatment with broad-spectrum fungicides such as Thiram and Carboxin is effective against a wide range of seed storage pathogens (Chanhan *et.al*., 1984; Subramanya *et.al.*, 1988; FAO, 1999). Moreover, seeds must be dried to 3-7% moisture content, (depending on oil) content and stored in hermetically sealed containers in order to prolong storage life (Hurburgh, 2008). Although Tinsley (2009) reported that the higher elevations in Kenya are cooler and thus have extended soybean seed viability compared to the lower elevations with warmer temperatures which experience greatly reduced seed viability, adequate research on how farmers can extend seed viability, longevity and vigor under ambient conditions is still lacking.

High quality seeds are largely defined as seeds with high vigor; and vigor comprises those seed properties that determine the potential for rapid, uniform emergence, and development of normal seedlings under a wide range of field conditions (AOSA, 2009).

Soybean seed deteriorates rapidly in the tropics and rates vary with factors that affect seed quality such as genotype, environment and management practices (Bellaloui *et al.*, 2011).

2.3. Factors affecting soybean seed productivity and quality

To achieve maximal seed vigor of a given cultivar in seed production, efforts must focus on: producing a seed crop in the best possible environment for development of vigorous seeds; harvesting as soon as possible after physiological maturity (PM); handling, conditioning, and storing seed to minimize damage and slow rate of deterioration (AOSA, 2009). The genetic constitution of the seed and the environmental conditions it is subjected to before and after harvest, affect seedling emergence and field establishment of soybean seed (Harrington, 1972).

2.3.1. Genetic factors

Genetic differences have been known to determine the rate of seed deterioration (Hinson and Hartwig, 1977). The importance of genotype on seed quality has often been overlooked in favor of environmental factors; however genotypic differences in seed quality characteristics can be exploited in the selection of superior seed. Changes occurring in seed during aging are very significant for seed longevity and the rate at which the seed aging process takes place depends on the ability of seed to resist degradation changes by protection mechanisms which are specific for each plant species (Balešević-Tubić, *et al*., 2010). Genetic factors such as hard-seediness, seed size, seed coat color, resistance to diseases, and seed chemical composition influence the expression of seed vigor (AOSA, 2009).

Deterioration of soybean seed quality has been associated with large seed size and permeable seed coats (Horlings *et al.,* 1991). Soybeans with impermeable seed coats have been found to maintain seed quality when exposed to adverse weather conditions (Hartwig and Potts, 1987). In addition, soybean lines with small seed size and/or black seed coats have been shown to exhibit greater resistance to field weathering than large seeded types with lighter coloured seed coats (Horlings, *et al*., 1991). Kuchlan *et al.*, (2010) found that genotypic variations in seed coat characteristics of soybean determine the longevity of soybean seeds, particularly with regard to the gap between the seed coat and cotyledon, and the shape and distribution of hourglass cells in the seed coat. Good storer black-seeded varieties were found to have a lesser gap between the seed coat and cotyledon than the poor storer yellow-seeded varieties.

Seed size has been found to be an important physical indicator of seed quality that is affected by genotype, environment and management practices (Robinson, 1974). The relationship of seed size to seed quality however is variable among species. Mosavian and Eshraghi-Nejadi (2013) found that large wheat seeds had no advantages over small ones in seed viability and vigor, while Willenborg *et al.*(2005) found that germination increased with increasing seed size in oat cultivars (*Avena sativa* L.) under water stress condition. Saranga *et al.,* (1998) found a negative correlation between seed vigor and embryo mass in sunflower, but with the large seeds germinating and emerging later than small seeds. Sung (1992) however, showed that soybean seed size had a direct effect on seed germination and vigor, while Singh *et al*., (1978), found strong negative correlation between germination and seed weight among soybean genotypes. Results of a study by Amico *et al*., (1994) showed that higher vigor that occurred in larger seeds is due to the larger food reserves in these seeds.

Balešević-Tubić, *et al.,* (2011) showed that differences in biochemical characteristics of soybean varieties affected the degree of seed damage and the ability of seed to resist the negative consequences of aging. The chemical structure of soybean seed (20-22% of oil) enables some specific processes, very often degrading in nature. The composition of fatty acids is the most important factor which determines oils susceptibility to oxidation. The types of fatty acids present in oil, and in particular number of their double bonds, determine the type and extent of chemical reactions which occur during the storage time (Morello *et. al.,* 2004). Lipid Auto-oxidation and increase of free fatty acid content during storage are the most often mentioned reasons for accelerated damage of seed of oily plant species (Lekić, 2003). Accumulation of active oxygen species and free radicals has often been considered as one of the most important factors of seed aging (Bailly, 2004). Although genetic factors play a key role in determining soybean seed quality, the environmental conditions in which the seed is produced and stored determine its longevity and vigor.

2.3.2. Environmental factors

For soybean, one of the major constraints to sowing is the low seed germination and vigor under field conditions. Both pre-harvest and postharvest factors play a critical role in determining the rate of physiological and pathological deterioration. Temperature, relative humidity and the length of pre-harvest period after attainment of harvest maturity in the field determine the extent of deterioration due to fungal infections (Hinson and Hartwig, 1977) and changes in specific enzyme activities (Priestley 1986). Other environmental factors that may affect seed formation and development include; light, water and the kind and quantity of available nutrients (Pallais *et al*., 1987). Drought stress during seed fill and pathological damage of seed has been shown to affect seed yield, viability and vigor (Dornbos *et al.,* 1989). Seeds developed under moisture stress, nutrient deficiency and extreme temperatures often result in light, shriveled poor-vigor seed. Seed mechanical damage, whether induced by harvesting or conditioning equipment, as well as improper storage conditions are among the factors that adversely affect seed vigor (AOSA, 2009).

Field storage conditions of high humidity and temperature synergistically accelerate physiological deterioration and pathological damage of seed. Moisture content determines the rate at which seeds deteriorate and has profound impact on storage longevity of seeds. Drying has been known to increase the longevity of soybean seeds (Ellis *et al.*, 1982) hence reducing seed moisture to the range of 4 to 7% essentially ensures retention of high germination for a year or more at ambient temperatures. The critical moisture content is the level below which further reduction in moisture content no longer increases seed longevity in hermetic storage (Rao *et al.,* 2006). Critical moisture content for soya bean (*Glycine max*) has been found to be 3.3% (Ellis, 1998). When seeds are stored in equilibrium with a relative humidity of less than 68% no microbial growth will occur (McDonald and Nelson 1986).

With regard to temperature, fruit or seed size has been found to be positively related to increasing air temperature during development (Tompsett &Pritchard, 1993; Stanley *et al*., 2000; Daws *et al*., 2004). Seeds of late maturing annuals of temperate species may be shed at an earlier developmental point when seeds are smaller and with less developed embryos, due to reduced developmental heat sum (Wagner & Mitterhofer, 1998). Work by Daws *et al*. *(*2004) on *Aesculus hippocastanum* revealed that seeds developed under warm conditions had significantly lower water content, and their embryonic axes had more negative osmotic potential than seeds developed under cooler climatic conditions.

Moreover, unfavorable environmental conditions can cause oxidative stress in plant tissue, and development of superoxide radical, hydrogen peroxide, and hydroxyl radical, which are the most active, toxic and destructive products of oxidative stress (Morello *et. al.,* 2004).

2.3.3. Agronomic practices

Several research findings have proven that agronomic practices during seed production affect seed quality. Seed germination and vigor have been found to improve with application of Nitrogen fertilizer on soybeans (Marcos-Filho *et al.,* 1994), by timely planting of garden pea (Hampton 2,000) and with inoculation of rice seed with rhizobial strains (Biswas *et al.,* 2000). Keigley and Mullen, (1986) reported that soybean germination and seedling vigor for seeds maturing in high temperature stress (32/28^{0}C) reduced with increase in the accumulated days of high temperature after flowering.

Seed yield has been reported to increase with improved agronomic practices. Verde *et al.,* (2013) reported that application of manure, lime and Phosphate fertilizer significantly influenced the nitrogen uptake and increased yields of soybean in the Central Highlands of Kenya.

2.3.4. Mother-plant nutrition

The use of high quality seeds with appropriate fertilization and seed rate are essential to establish a suitable plant population in a soybean field for better returns (Ajouri *et al*., 2004). The production of vigorous seed is generally associated with ideal growth conditions of the mother plants. Conditions that disfavor complete seed development, therefore, result in lack of uniform germination, low seedling vigor and decreased seedling performance under field conditions (Dickson, 1980). Increased assimilate transport towards the developing reproductive structures is required for production of high quality seed (Krauss, 1978).

Several soybean growers and researchers have observed favorable as well unfavorable effects of the application of mineral nitrogen and phosphorus depending upon the cultivar, quantity and source of nutrients, sowing date and plant population/area, as well as environmental conditions.

2.3.4.1. Effects of Phosphorus fertilization

Phosphorus has important effects on photosynthesis, nitrogen fixation, root development, flowering, seed formation, fruiting and improvement of crop quality (Brady, 2002). The composition of soybean seeds has been found to be affected by phosphorus fertilization as it affects the concentrations of protein, oil, and the fatty acid profiles in soybean seed. Phosphorous has been found to increase oil (Gaydou and Arrivets, 1983) and protein in the seed (Gaydou and Arrivets, 1983; Israel *et al*., 2007) and to affect the fatty acid profiles within the seed oils (Gaydou and Arrivets, 1983) by increasing oleic acid concentration, decreasing linoleic acid concentration (Gaydou and and Arrivets, 1983; Israel *et al.,* 2007).

Phosphorus deficiency in soybean can result in poor nodulation, reduced seed viability, and decreased percentage of fully developed seeds (Bishnoi *et al.,* 2007). However, high levels of phosphorus nutrition has been found to negatively impact soybean seed germination and vigor due to increases in seed leakage as a result of poor membrane integrity (Krueger *et al* 2013, Heydecker, 1972), as the leaked assimilates provide a food source for seed-borne fungi which kill the seed (Simon and Raja 1972). Lott *et al.*, (1995) found that higher phosphorus concentrations in the seed may result in more phosphorus leakage during germination and higher pathogen loads, but their relationship was unclear. Similarly, Krueger *et.al.*, (2013) reported that phosphorous fertilization effects on soybean seed quality were unclear since fertilization rates can have a positive effect on yield and composition in some growing locations and years but not in others. These results indicate that soybean seed quality response to phosphorus fertilization varies greatly among production environments and responses are not well understood hence further work on this is required. These results are of particular importance for seed producers because many of the environments where soybean seeds are produced tend to have high levels of available phosphorus (Sims *et al.,* 2000).

Phosphorus fertilization however has been found to increase soybean grain yield in soils with low soil test phosphorus levels (Bishnoi *et al*., 2007; Borges and Mallarino, 2000; Thalooth *et al.,* 1989), regardless of placement method (Borges and Mallarino, 2000). Although soybean in Kenya has been reported to grow in areas where soils have been mined due to the continuous cultivation of nutrient-demanding crops (Mathu *et al.*, 2010), benefits of mineral and organic manure fertilization have been established. Fertilizer application has been reported to increase productivity of soybean in Kenya; for example rates of 125Kg ha^{-1} (Mathu *et al.*, 2010) and 250kg ha^{-1} (Mahasi *et al.*, 2011). Phosphate fertilizer has been found to increases nodulation, biomass production and grain yield in promiscuous, dual purpose soybean under Western Kenyan conditions (Vanlauwe *et al*., 2003). Consistent use of manure, Di-ammonium Phosphate and Mavuno fertilizers have been found to increase yields of soybeans in Central Highlands of Kenya (Abuli *et al*., 2012). Work by Mugendi *et al*. (2010) in Meru South District, Central Highlands of Kenya also showed that soil amendments with Phosphorus, Potassium and Sulphur fertilizers was desirable to achieve maximum benefits from soybean production.

2.3.4.2. Effects of Nitrogen fertilization

The relationships between nitrogen nutrition, the accumulation of proteins in the seed and its possible influence on physiological seed quality (with respect to nucleic acid synthesis, formation of new tissues of the embryonic axis and enzyme activity) has been observed in different studies (Ching and Rynd, 1978; Bulisani and Warner, 1980; Hadavizadeh and George, 1988). Proteins are fundamental components of cell membrane system, whose integrity determines its selective permeability and is directly related with seed performance (Bewley and Black, 1985).

In tobacco, Nitrogen application to the mother plants, increased seed germination and enhanced germination uniformity (Thomas and Raper, 1979). In lettuce, a linear relationship was found between seedling vigor, nitrogen supply and general soil fertility

(Soffer and Smith, 1974). Higher yields were obtained from common bean (Phaseolus vulgaris) from seed of low weight but with high nitrogen content than from heavy seed with low nitrogen content (Ries *et al.,* 1970). Soybean response however to the addition of nitrogen fertilizer are contradictory and are found to depend on cultivar, quantity and source of nitrogen, sowing date and plant population/area, as well as environmental conditions (Gibson, 1976; Marcos-Filho *et al.*, 1994). Soybean seeds grown with *bradyrhizobium japonicum* inoculant were found to be of higher yield and better seed quality than with the use of mineral nitrogen (Marcos-Filho *et al.,* 1994). Soybeans have been found not to respond to applications of nitrogen fertilizer, as long as they are well nodulated with rhizobia bacteria, however, irrigated soybeans with high yield potential have been found to respond to Nitrogen application at the R3 growth stage (Mengel, 2011).

2.3.4.3. Effect of Biological Nitrogen fixation

Soybean plays an important role in the global and agricultural nitrogen cycles by facilitating biological nitrogen fixation when in symbiosis with rhizobia bacteria (*Bradyrhizobia* sp.). Soybean has been shown to fix an average of 175 kg N ha^{-1} per year in irrigated production and 100kg N ha^{-1} year in dry land production (Unkovich and Pate, 2000). Thies *et al.* (1991) surveyed rhizobia populations prior to planting and found little to no yield response to inoculation at rhizobia populations above 100 cells g-1 soil. Moderate responses were observed between 10 and 100 cells g-1 soil, while the greatest responses occurred below 10 rhizobia g-1 soil. Rhizobia populations were maintained over time if soybean is regularly incorporated into the crop rotation and inoculation of seed is recommended for fields having no prior soybean history (Thies *et* *al.*, 2012). Soybean yield response to rhizobia inoculation has been found to be positively correlated to the soil rhizobia population levels (Furseth and Conley, 2011). In addition, inoculation of soybean with rhizobia has been reported to increase germination and vigor of soybean (Marcos-Filho *et al.,* 1994).

Soybean varieties grown in Kenya are broadly categorized into traditionally locally bred and the promiscuous dual purpose varieties which were developed by the International Institute of Tropical Agriculture (IITA) between the mid- 70s and early 90-s (Sanginga *et al.,* 2003). The 'traditionally-bred' soybean varieties in Kenya do not contribute much to the soil N status because of most of the N fixed is removed by harvesting the grains. The 'dual-purpose', promiscuous soybean varieties, however produce a substantial amount of grain and leafy biomass and nodulate freely with the indigenous *Bradyrhizobium spp*. populations, avoiding the need for inoculation, a technique that has often failed in Sub Saharan Africa (Mpepereki *et al.*,2000). Some of the traditionally bred varieties include Gazelle, Sable, EAI 3600, SCS1, Nyala, Duiker and Tamura. The dual-purpose varieties include the SB series such as SB9, SB10, SB11, SB13, SB14, SB15, SB19 and SB20 have shown significantly higher total biomass production at 50% podding than the local varieties. It has been found that when these new improved varieties are planted in rotation with maize or sorghum, the productivity and sustainability of crop production is enhanced (Sanginga *et al.,* 2001; Sanginga *et al.,* 2003). Although optimum levels of Mother-plant nutrition can lead to production of good quality seed, the ways in which seed is handled and stored after harvest impacts on seed quality.

2.4. Seed storage conditions

Storage conditions play a key role in the maintenance of seed quality during storage. Storage temperature and relative air humidity are two major external factors affecting storage duration and degree of seed deterioration (Harrington, 1972; Roberts, 1973). Other factors include stresses before seed storage, initial seed quality (Ellis and Roberts, 1980), pest and pathogen damages in storage (Kulik, 1995) and the species.

Seed deterioration can be defined as deteriorative changes occurring with time that increase the seed's vulnerability to external challenges and decrease the ability of the seed to survive (Bewley and Black, 1985; Copeland and McDonald, 1999). Normally the rate of deterioration will increase when seed moisture content and storage temperature increase. Interdependence of these two factors during seed storage and their subsequent effect on grain moisture has been recognized by Harrington (1973) who suggested the three "rules of thumbs" regarding optimal seed storage. The first one which can be applied to seeds with grain moisture from 5% to 14% states that each 1 % reduction of seed moisture doubles the storage life of the seeds; the second one states that for each 10 °F (5.6 °C) decrease in seed storage temperature storage life of seed is doubled; and the third one states that arithmetic sum of relative humidity and storage temperature should not exceed 100 for safe seed storage, or 120 as later reported (Bewley and Black, 1985; Copeland and McDonald, 1995; Harrington, 1973).

Thomas (1980) reported that safe storage of soybean was achieved with moisture content below 12%, temperature less than 10^0C and relative humidity less than 70%, and that seeds from warm dry regions and with large embryos tend to have longer longevity than those with small embryos from moist regions.

In Kenya, soybean seed quality deteriorates during storage but with the degree of deterioration increasing in the lower altitudes where temperature and relative humidity is high. Poor storage conditions greatly affect seed vigor (Heydecker, 1979). Types of containers used in storage determine the degree of regulation of temperature, relative humidity and seed moisture content. Appropriate containers that can provide suitable conditions for the maintenance of seed quality during storage are very essential for seed preservation.

The effects of storage containers on long term storage have been determined by several researchers. Wambugu *et al.*, (2009), while working with maize seed in Western Kenya found that seed treatment with either Mortein Doom® or cow dung ash, then storing in airtight plastic containers maintained seed viability and vigor more than using the traditional methods of hanging maize cobs over the fireplace and storing in gunny bags. While working on soybean, Pessu *et al.*, (2005), showed that storing seed in polythene bag and metal tin in Southern Nigeria, maintained germination at 58.7 – 86.0% at the end of a 12 – month period, unlike soybean stored in bamboo bin and clay pot, whose germination dropped to zero after four months of storage. Similarly, research results by Monira *et al.*, (2012) and Akter *et al.*, (2014) in Bangladesh, showed that storing soybean seed in ambient conditions in polythene bag and tin container preserved soybean better than storing in a cloth bag. The seed stored in cloth bags gained more moisture and lost viability and vigor faster than seed stored in tin container and polythene bag.

Farmers in Kenya store their soybean seed under ambient conditions before the next planting season using locally available storage containers. However, very little work has been carried out in Kenya to determine most appropriate soybean seed storage containers, storage periods and storage agro-ecologies for enhanced seed longevity and vigor.

2.5. Seed treatments

Rapid and uniform field emergence is essential to achieve high yields of good quality in annual crops. Among the techniques that have been known to enhance seed quality of a variety of crops are seed dressing and priming.

2.5.1. Chemical Seed dressing

Seeds are treated to reduce the invasion of pathogens following planting; hence seed dressing “artificially” enhance seed vigor of seed lots inherently low in seed vigor (McDonald, 1994). Seed dressing has been shown to have beneficial effects in prolonging storage life of soybean seed under ambient tropical conditions. Results by Adebisi *et al.* (2004) in Nigeria showed that soybean seed dressed with fungicides and/or insecticides (Apron Plus, Almithio and Aldrex T) showed significantly longer storage life than untreated seeds even though soybean seed deterioration was not totally arrested. However the effectiveness of seed dressing in planted soybean is debatable and has been reported to depend on several factors. Kleczewski (2013) reported that fungicide seed treatments could increase the germination of poor quality seed if the low quality was due to the activity of a fungal pathogen or if seeds were planted into an environment that delayed germination (e.g. cold, wet soils) but not due to seed age or mechanical damage. Fungicide seed treatments have also been known to significantly reduce soybean nodulation hence biological nitrogen fixation (Zilli *et al.,* 2009).

2.5.2. Seed dressing with ash

Wood ash has been found to be effective in seed preservation. Ash has been reported as a desiccant and is suitable in storage of tropical grain products (Hayma, 1990). Work by Oguntande and Adekunle (2010) in Nigeria on maize, melons and beans revealed that wood-ashes of *Nauclea diderrichii* and *Piptadeniastrum africanum* proved to be effective in preserving the seeds, eliminating the fungi and preventing the manifestation of weevils (*C. maculatus*). Benlate, an orthodox fungicide proved to be effective against the fungal attack but did not prevent the weevils (*C. maculatus*) invasion (Oguntande and Adekunle 2010). Nyarko *et al*., (2006) similarly found that wood ash of *Afzelia Africana* was effective in maintaining viability of roselle seeds when stored in plastic containers and polythene sacks, as it had the highest mean vigour index and % germination after 12 months of ambient storage in Ghana.

2.5.3. Seed priming

Seed quality may be improved by production techniques or by seed pre-treatments with water (hydro-priming), osmotic solutions (osmo-priming) and matric materials (matri-priming) (Hur, 1991; Harris *et al*., 1999; Caseiro *et al*., 2004, Kaya *et al*., 2008; Pill *et al.,* 1991). Seed priming has been found to be a suitable method to enhance seed and seedling vigor, leading to better stand establishment and yield (Bruggink *et al.,* 1999; Khalil *et al.,* 2010).

Priming has been described as a pre-plant physiological seed conditioning that can improve seed performance by reducing time to germination and seedling emergence and also by increasing the tolerance of seeds to stress conditions such as adverse temperatures and lack of water (Caseiro *et al*. 2004). During priming, seeds are held at a water potential that allows imbibition, but prevents radicle extension (Bradford, 1986) thus suspending the seeds in the lag phase. The beneficial effects of seed priming have been attributed to physiological and biochemical changes including early DNA replication, increased RNA and protein synthesis, increased α-amylase activity, greater ATP availability and energy of germination, faster embryo growth, repair of deteriorated seed parts and reduced leakage of metabolites, which allow seeds to begin the germination sequences before sowing and consequently improve emergence (Ruan *et al.,* 2002; Giri and Schillinger, 2003; Basra *et al.,* 2003; Farooq *et al.,* 2006). Generally, the major effect of seed priming on seedling growth resulted from earlier germination which gave the seedlings more time to grow.

Seed priming has been found to be more effective at second stage of seed germination (breaking down of storages and transition of nutrients to embryo axis) which makes RNA ratio increment, protein synthesis improvement and ATP increment for faster growth of deteriorated embryo and improvement of seed emergence (Ruan *et al.*, 2002; Giri and Schillinger, 2003; Basra *et al*., 2003; Farooq et al., 2006; and Fu et al., 1988). Improvement in priming is affected by some factors such as plant species, water potential from priming factor, priming duration, temperature, vigor and primed seed storage conditions (Mubshar et al., 2006), although priming treatments can have a negative effect on subsequent germination responses (Hardegree, 1998; Carlos and Cantliffe, 1992).

Although priming is one of the physiological methods, which improves seed performance leading to faster and synchronized seed germination (Sivritepe and Dourado, 1995), differences in the effect of priming on germination and longevity of low and high quality seed lots and on seeds with different maturity have been described (Wechsberg, 1994; Powell *et al*., 2000; S´liwin´ska and Jendrzejczak, 2002; Demir, 2003).

The effects of seed priming on various crops have been reported. Seed priming has been successfully demonstrated to improve germination and emergence in seeds of many crops, particularly of vegetable species (Taylor *et al*., 1998) and field crops including wheat (Basra *et al.,* 2003), maize (Afzal *et al*., 2002), sweet corn (Chiu *et al*., 2002), rice (Farooq *et al*., 2005) mung bean (Khan *et al*., 2005), barley (Abdulrahmani *et al.,* 2007), lentil (Ghassemi-Golezani *et al*., 2008), cucumber (Ghassemi-Golezani and Esmaeilpour, 2008), hybrid sunflower (Hussain *et al*., 2006), winter rapeseed (Ghassemi-Golezani *et al.,* 2010) and soybean (Sadeghi *et al.,* 2011). Priming has also been reported to enhance seedling emergence and improve yields of soybean (Arif *et al*., 2008). Ghiyasy, *et al*., (2008) reported that osmo-priming maize (*Zea mays* L.) seeds with polyethylene glycol 8000 (PEG 8000) at -0.5 MPa osmotic potential improved emergence, grain and biological yields compared with other treatments; while Demir, *et al.,* (2006) reported that seed priming significantly increased germination percent; germination speed and seedling dry weight of sunflower. However, priming under drought conditions produced abnormal seedlings.

Seed priming however, has been reported to decrease viability and vigor of various crops. Seed priming was found to decrease germination percentage in barley and corn (Sharif *et al*., 2006) and reduced rate of seedling emergence and plants per unit area in sunflower (Hussain *et al.*, 2006). Ghassemi-Golezani *et al.*, (2011) while evaluating the effects of priming methods on seed invigoration and field performance of soybean (cv. 'Zan') found that germination percentage, seedling dry weight and field emergence percentage and rate of soybean decreased as a result of seed priming. On the other hand Rouhi *et al*., (2011) reported that while hydro-priming decreased rate of germination, osmo-priming at osmotic potential -12 bars, for 12 hours improved germination and vigor of soybean seed lots cv. 'Sari'.

The effect of length of priming on seed germination and vigor has been investigated with variable outcomes. Dezfuli, *et al*., (2008) study revealed that maize seeds hydro primed for 36 hours had the lowest values of time of 50% germination (T50) and Mean Germination Time (MGT), followed by 24 h and 48 h seed treatments. The lowest germination rate was observed in osmo-primed seeds which were subjected to PEG-6000 solution while maximum final germination was recorded in seed hydro primed for 36 h. Sadeghi , *et al.,* (2011) investigated the effect of osmo-priming soybean (cultivar 033) on germination behavior and seed vigor, using polyethylene glycol 6000 at -0.4, -0.8, -1.2, -1.6 and-2 MPa with distilled water as control for 6, 12, 24 and 48 hours at 25°C. The results indicated that different osmotic potential and priming duration had significant effect on germination percentage, mean germination time, germination index, the time to get 50% germination, seed vigor and electrical conductivity of seeds. The study found that the 12 h priming duration and -1.2Mpa osmotic potential treatment had most effect on studied traits. The -1.2 MPa increased germination percent, germination index but decreased mean germination time, the time to get 50% germination and electrical conductivity of seeds. In soybean seed, Rouhi H.R *et al.,* (2011) recommended the best treatment combination to be osmo-priming with polyethylene glycol (PEG 6000) osmotic potential -12 bar for 12 hours for soybean seed lots cv. ‘Sari’.

On-farm seed priming with water is a low-cost, low-risk technology that can be easily adopted by resource-poor farmers. It has potential of increasing the yield of tropical and sub-tropical annual crops in marginal areas by a combination of better crop establishment and improved individual plant performance. Clark *et al.,* (2001) reported that on farm maize seed priming was beneficial in maize emergence when grown in relatively dry seed beds but not when grown in favorable conditions. Harris, *et al*., (2005) on the other hand tested the opportunities for resource-poor farmers to use seed hydro priming as a vehicle for applying bio-fertilizers (Rhizobia) in chick pea and found that combining Rhizobium inoculation with seed priming significantly increased nodulation but had little effect on yield. Moreover, observations in the field have shown that some primed crops show enhanced resistance to disease, either as a consequence of increased vigor, altered phenology or due to some more fundamental mechanism associated with exposure of seeds to anaerobic conditions during priming. For example, Harris, *et al*., 2005 reported that hydro-priming for 8 h before sowing significantly reduced the incidence of downy mildew in a highly susceptible cultivar of pearl millet.

The results of priming among varieties, species and seed lots have been variable (Heydecker, 1977). Due to the variability in response, Bradford (1986) suggested that treatment conditions must be optimized for each seed lot and maximum priming can be achieved through various combinations of temperature, water potential and treatment duration. Due to such variability in response to priming, there is still need to investigate whether application of seed priming techniques can reduce the deleterious effects of loss of seed viability and vigor among soybean genotypes stored in various agro-ecologies in Kenya

2.5.4. Post-priming seed storage

Storing of primed seed has been studied by various researchers with variable outcomes. Priming has been shown to be both beneficial (Georghiou et al., 1987; Wechsberg, 1994) and detrimental (Argerich *et al.*, 1989; Tarquis and Bradford, 1992) to subsequent longevity. There are many examples of priming increasing the rate of germination (Argerich and Bradford, 1989; Argerich *et al.*, 1989; Lanteri *et al.,* 1993; Powell *et al.,* 2000), and some of increases in ability to germinate (Georghiou *et al.*, 1987; Demir, 2003). However, when combined with subsequent desiccation, the effect of priming is not consistently positive. It has been shown that the longevity of primed seeds in storage is often reduced (Van Pijlen *et al.*, 1996; Taylor *et al.*, 1998). In some cases, the benefit to germination is lost on desiccation, or partly retained on desiccation but lost rapidly in storage (Heydecker and Gibbins, 1978).

The effect of priming, particularly with respect to subsequent longevity, can be influenced by the conditions immediately after priming. For example, a mild water stress or heat shock following priming restored the ability of seeds from several species to withstand deterioration during storage (Bruggink *et al*., 1999). Similarly, Gurusinghe and Bradford (2001) noted an improvement in longevity for seeds given a slow-drying, high temperature treatment after priming. Drying seeds slowly after priming may induce the synthesis of late embryogenesis abundant (LEA) proteins, while incubating seeds at high temperatures may induce heat shock proteins, both of which may provide protective mechanisms that are beneficial to seed longevity (Gurusinghe *et al*., 2002). Soeda *et al*., (2005) noted that seeds dried at different rates after priming showed differential gene expression: genes expressed solely after slow drying were similar to those with functions in DNA protection and stress tolerance. However, Schwember and Bradford (2005) found that the longevity of lettuce seeds given either a slow- or fast-drying treatment after priming was reduced compared with non-primed seeds.

Abnavi and Ghobadi (2012) while working on wheat cultivars Cross Alborz and Sardari concluded that storing primed seed for 30-60 days improved germination characteristics than in freshly primed seed. Butler *et al.* (2009) however, analyzed the effects of priming on seed longevity in air-dry storage on *Digitalis Purpurea* L. and found that extent of prior deterioration and the post-priming desiccation environment affect the benefits of priming to the subsequent survival of mature seeds. It was also found that rehydration–dehydration treatments may have potential as an adjunct or alternative to the regeneration of seed accessions maintained in gene banks for plant biodiversity conservation or plant breeding.

2.6. Seed vigor

Vigor comprises those seed properties which determine the potential for rapid uniform emergence and development of normal seedlings under a wide range of field conditions

(AOSA, 1983). Seeds may be classified as viable in a germination test which provides optimum temperature, moisture and light conditions to the growing seedlings; however, they may not be capable of continuing growth and completing their life cycle under a wide range of field conditions (AOSA 2009). A vigorous seed lot is one that is potentially able to perform well even under environmental conditions that are not optimal for the species (ISTA, 2011). Seed vigor therefore is a measure of the extent of damage that accumulates as seed viability declines until seed is unable to germinate and eventually dies.

Seed vigor is often evaluated by laboratory tests based on biochemical and biophysical characters (Abdul-Baki and Anderson 1973). In many cases, but not always, laboratory tests of germination may predict field performance (Hall and Wiesner, 1990; Johnson and Wax, 1978). Vigor tests are designed to reveal subtle signs of damage, and provide a more reliable indicator of field/greenhouse performance than viability (germination) tests. Generally, seeds start to lose vigor before they lose their ability to germinate (Figure 2.1); therefore vigor testing is an important practice in seed production programs (West 1986).

Detailed descriptions of commonly used vigor tests have been published in the Seed Vigor Testing Handbooks developed by the seed vigor committees of the AOSA and ISTA. Vigor test methods have been developed and successfully used for several major agronomic crops (AOSA, 1993; Hampton & TeKrony, 1995).

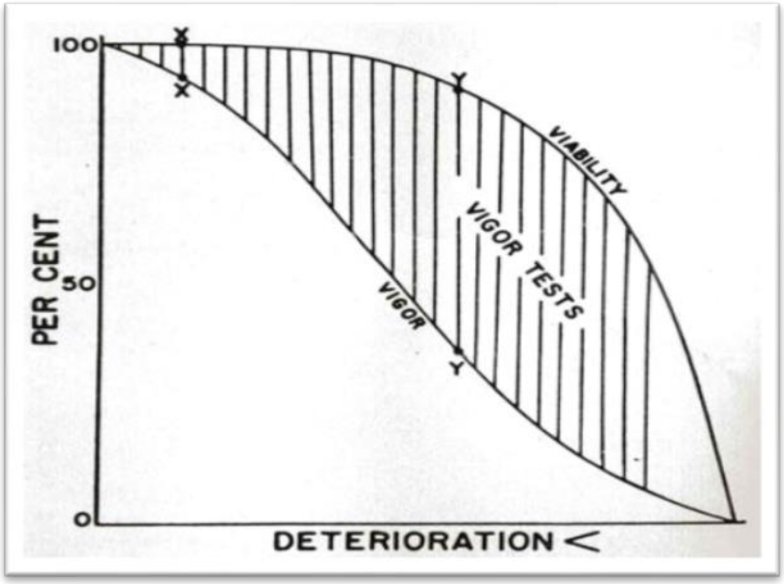

Figure 2.1: Relationships between seed vigor, viability, and deterioration.

The X and Y points on the vigor and viability curves illustrate the increasing gap between germinability and vigor with increasing deterioration *(Source: West, 1986).*

These tests involve measurement of some aspect of seed performance or condition that reflects the stage of seed deterioration hence an indication of field performance. The three major categories of vigor test methods are (AOSA 1993, Gupta, 1993):

a. Stress tests (e.g. accelerated aging (AA); cold test; saturated cold test; saturated salt accelerated ageing (SSAA), cool test and controlled deterioration)
b. Seedling growth and evaluation tests e.g. standard germination test; seedling growth rate tests (e.g. Mean Germination time, Time to 50% Germination, Germination Index, Speed of Emergence, Energy of Emergence, Seedling Vigor Index) as well as seedling weight tests.
c. Physiological or biochemical tests (e.g. tetrazolium, electrical conductivity and respiratory capacity tests).

Vigor tests provide a better estimation of field emergence than germination tests when sub-optimal conditions exist (McDonald Jr., 1980). Egli & TeKrony (1995) demonstrated that soybean seed lots with accelerated ageing germination higher than 80% or standard germination above 95% had a high probability of producing adequate seedling emergence under a relatively high variation of environmental conditions.

2.6.1. Seedling growth tests

Seedling growth tests are based on the principle that vigorous seeds grow at a faster rate than poor vigor seeds even under favorable environments. Vigorous seeds rapidly germinate, metabolize and establish in the field (Gupta 1993). 'Therefore, any method used to determine the rapidity of growth of the seedling will give an indication of seed vigor level (Gupta, 1993). Such tests include: Mean Germination time, Time to 50% Germination, Germination Index, Speed of Emergence, Energy of Emergence, Seedling Vigor Index as well as seedling weight tests.

Mean Germination Time (MGT) describes the average time for a seed to germinate, or the delay (lag period) from the start of imbibition to radicle emergence. The major cause of differences in vigor is seed ageing, leading to seed deterioration. One of the first effects of ageing is an increase in MGT (Guy and Black, 1998; Bailly *et al*., 2002). The more deteriorated the seed lots, the higher the MGT, that is, the greater the lag period from the start of imbibition and radicle emergence (Mathews and Powell, 2011). This association between deterioration and the length of the lag period has been explained by the need for more time for metabolic repair in the more deteriorated seeds before germination processes can begin (Matthews and Khajeh, 2007; Matthews *et al*., 2011).The differences seen in the germination curves described by the MGT have been related to the seed vigor of maize, expressed as both the rate and final level of emergence (Khajeh *et al.,* 2009; Matthews *et al*., 2011). The seed that has the longest average delay (high MGT), is the latest to start to germinate and has the greatest spread of germination over time. It is perceived by many researchers that MGT is the most relevant trait in seed germination to be influenced by priming (Girolamo and Barbanti, 2012).

Germination Index (GI) is used as a measure of the speed of germination. Numbers of seedlings emerging daily are counted from day of planting the seeds in the medium till the time germination is complete and the seed lot having greater germination index is considered to be more vigorous (Gupta, 1993).

Seedling Vigor Index (SVI) on the other hand is calculated by multiplying germination (%) and seedling length at the time of final count (Gupta 1993). The seed lot showing higher seedling vigor index is considered to be more vigorous (Abdul-Baki and Anderson, 1973).

2.6.2. Seed accelerated ageing

Accelerated aging is a well-established seed vigor test used for large-seeded agronomic crops such as soybean (Association of Official Seed Analysts, 2009; TeKrony, 1995). Differences in the initial level of deterioration or ageing of seed lots can be identified by accelerated ageing (AA) test for *Glycine max,* which is an ISTA-validated vigor test (ISTA 2011). In this test, seeds are subjected to high temperature (41^0 to 43^0C) and relative humidity (100%) over a few days (eg.72 h) to induce aging, and subsequently evaluation is done by a standard germination test. Parrish and Leopold (1978) reported the changes observed in soybeans seeds during accelerated ageing (41^0C, 100% relative humidity) were as a result of subsequent loss of vigor, decline in early respiratory activity, increased leakage of electrolytes, losses of as much as 10% dry weight from imbibing cotyledons, and a decrease in the swelling response of the imbibing system (seed plus water). Each of these changes that occur with aging is interpreted as resulting from deteriorative changes in membranes.

The accelerated ageing (AA) test can be used to estimate field emergence and storage longevity of various crop seeds (Association of Official Seed Analysts, 2009; TeKrony, 1995). This test has been found to provide an accurate estimate of field emergence of soybean seedlings. However, as seedbed environmental conditions become less favorable, the ability of the AA test to estimate field performance significantly decreases (Reynaldo *et al,* 2004). Rastegar *et al.*, (2011), studied the effects of AA on soybean germination indices and found that the rapid aging environment significantly reduced germination percent, means of daily germination, mean germination time, coefficient of velocity of germination, germination index and germination uniformity but increased percentage of abnormal seedlings.

2.6.3. Electrical Conductivity test

Electrical conductivity (EC) test is one of the biochemical tests used to quantify the leakage of electrolytes from the seed coat with respect to age, storage life, and environmental factors such as temperature, humidity and mother plant nutrition (ISTA, 1993). EC test hence indirectly quantifies degradation and disorganization of the cytoplasmic membranes (Delouche; Baskin, 1973; Robert, 1973). Research has established that naturally or artificially aged or mechanically damaged seeds show more conductivity than normal healthy seeds (Edge and Burries, 1970; Parrish and Leopold, 1978; Loeffler e*t al*., 1988; Hampton, 1995). A high correlation has also been found between seed deterioration and carbohydrates leaked from them (Keeling, 1974; Powell, 1988). All of the cultivated species (rice, soybean, maize, wheat, sunflower, green pea, lupine, cotton, alfalfa, barley, tomato, onion, sugar beet, pepper, dry bean, floral and forestry seeds) could be assayed by this test (ISTA, 1995).

Electrical conductivity test has been standardized to evaluate the physiological potential of soybean seeds (Hampton and TeKrony, 1995) and is one of the best evaluation tests of soybean seed vigor (Abdul Baki and Anderson, 1970; Yaklich *et al.*, 1979; Loeffler et al., 1988;) and it is recommended in the Manual of Vigor Tests (ISTA, 1995). The electrical conductivity test of soybean seed is a more efficient indicator of field emergence than germination test (Salinas *et al*., 2010)

2.6.4. Comparative seed longevity testing and Potential storability index (p_{50})

Seed longevity of different species and/or seed lots can be compared by generating a single seed survival curve using a carefully controlled ageing environment. The controlled ageing test generates a measure of the longevity of a collection that can be compared with the known longevity of 'marker' species under the same conditions. Whilst the method does not allow accurate prediction of seed longevity for test species, comparison with marker species enables ranking into longevity categories. This method can also be used to investigate the effects of factors, such as maturity or postharvest handling, on seed quality (Newton *et al.,* 2009). Using this method, seed viability (percentage germination) is plotted against the ageing period (days) to create a seed survival curve. Analysis is then done using probit analysis (a type of regression analysis) to fit the viability equation (Ellis & Roberts, 1980):

$$v = K\text{i} - p/\sigma$$

Where: *v* is the viability (in probits) of the collection after *p* days in the ageing environment. Ki is the y-intercept and a measure of the initial seed viability (in probits), and σ (sigma) is the time for viability to fall by 1 probit. The time for viability to decline to 50% (*p*50) can be read off the seed survival curve or calculated using the equation:

$$p_{50} = K\text{i} \times \sigma$$

P50 values are used to rank species, allowing longevity comparisons between species and with the marker species in the screen. P_{50} has been known to increase with improved storage conditions that are cooler and/or drier (TeKrony *et al*., 2000)

2.6.5. Seedling field emergence

Information regarding the relationship between laboratory seed vigor testing and seedling field emergence is very important to estimate seed performance after sowing and help producers adopt the best procedures to improve stand establishment. A close association between planting environmental conditions, seed physiological quality and seedling field emergence in soybean seed has been established (Reynaldo *et al.*, 2004). Vigor tests are more adequate than standard germination tests in estimating field performance; however, no test is considered adequate under highly unfavorable environmental conditions. Egli and TeKrony (1995) demonstrated that soybean seed lots with AA germination higher than 80% or standard germination above 95% had a high probability of producing adequate seedling emergence under a relatively high variation of environmental conditions. These investigators also emphasized the difficulty in establishing a consistent relationship between laboratory and field results, since environmental conditions in the seedbed are highly variable and unpredictable.

Many researchers have reported significant correlation coefficients between laboratory results concerning evaluations of physiological potential (standard germination and vigor tests) and field emergence (TeKrony & Egli, 1977; Yaklich & Kulik, 1979). More recently, Egli & TeKrony (1995; 1996) found significant correlation between laboratory tests and seedling emergence. These authors also used the field emergence index to characterize seedbed conditions.

2.7. Relationships between Seed germination, viability and vigor

The relationship between seed germination, viability and vigor has been well documented in literature (Fig 2.2).

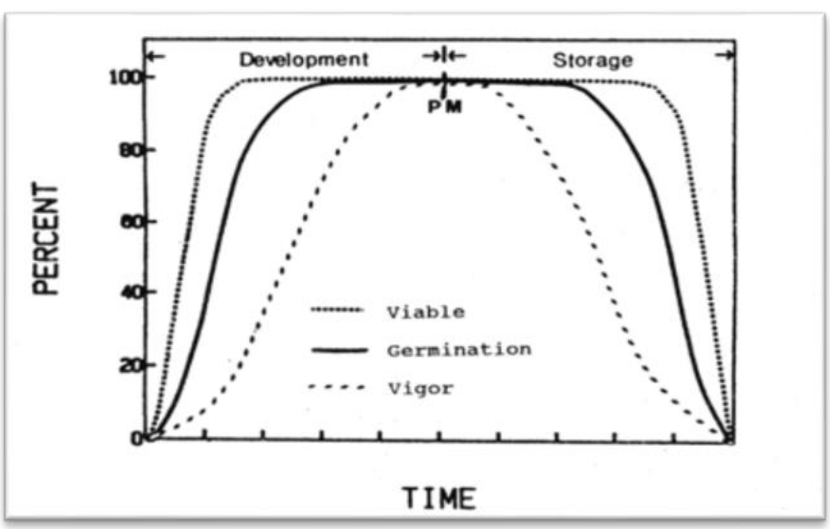

Figure 2.2: Relationships between Seed germination, viability and vigor.
(Source: AOSA, 1983)

AOSA (1983) has described clearly the relationship between seed germination, viability and vigor as follows: The seed embryo is known to be viable soon after fertilization, but does not reach its maximum germination potential until much later during maturation. Maximum seed vigor occurs even later and is closely associated with the accumulation of maximum dry weight of the seed, which is termed physiological maturity (PM). The maximum physiological quality for seed of most plants (except some fleshy-fruited species) occurs at PM. Seeds of most crops are high in seed moisture (30-60% fresh weight basis) at PM, which prevents commercial harvest. Seed deterioration begins immediately after PM while the seed is in storage on the plant and continues after harvest. Deterioration may occur rapidly over a few days, or it may take several years to measure noticeable changes in seed quality. As deterioration occurs, physiological quality changes in inverse order of seed development, with seed vigor declining first followed by loss of germination and viability (AOSA, 1983).

CHAPTER THREE

MATERIALS AND METHODS

Introduction

This chapter outlines a description of the study area, research designs used to achieve each research objective, data collection methods for secondary and primary data, laboratory procedures as well as methods used in statistical data analysis. The research was carried out in Meru South, Tharaka Nithi County; Kikuyu, in Kiambu County and Kajiado North, in Kajiado County of Kenya from year 2013 to 2014.

3.1. Objective 1: To evaluate soybean production, seed handling and quality in key soybean production areas of Meru South, Eastern Kenya

In order to achieve this objective, a soybean farm-household survey was conducted in Meru South Sub County, Tharaka Nithi County in February 2013. During the survey, farm saved seed was randomly sampled from households who had some seed to spare for quality analysis. The respondents were selected using purposive sampling targeting soybean growing households.

3.1.1. Description of soybean farm household survey Study sites

The farm household survey was carried out in Meru South Sub-County, Tharaka Nithi County, Kenya (Fig. 3.1). This site was chosen because it is soybean growing area with contrasting climatic conditions.

Meru South sub-county is densely populated with high agricultural potential. The sub-county is situated between Longitudes 37^0 18’37”and 37^0 28’33”East and Latitude 00^0 07’23” and 00^0 26’19” South (NEMA, 2007). It lies to the East of Mt. Kenya and borders the Sub-counties of Embu East to the South, Maara to the North West and Tharaka to the East (Figure 3.1 and 3.2).

The Sub-county covers an area of 445 Km^2, of which 65% is arable and 35% is made up of forest reserves, roads, urban/market centers and steep/rocky areas. About 40% of the arable land falls under ASAL (MOA, 2013). Administratively, the sub-county is divided into three wards Chuka, Magumoni and Igambang'ombe wards (Figure 3.1).

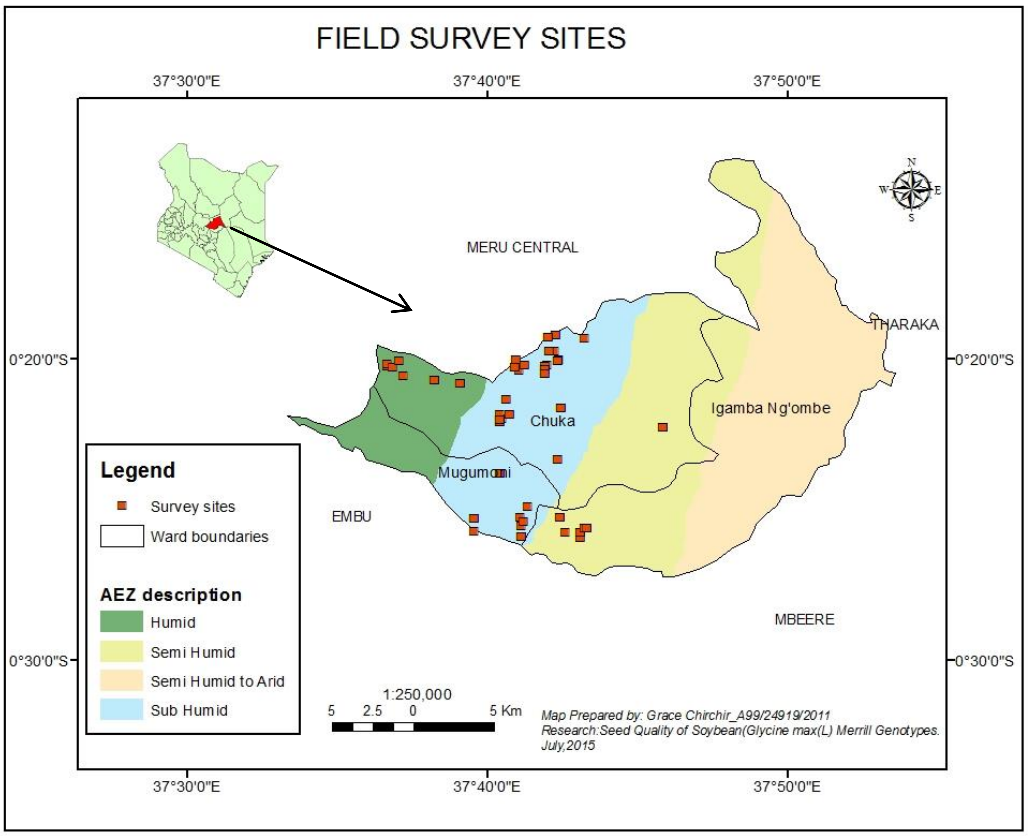

Figure 3.1: Soybean farm household survey sites in Meru South Sub-county

The altitude of Meru South ranges from 500 m and 5,199 m above sea level, but with the cultivated area lying between 500 and 2,200 m above sea level. The great range of altitude leads to a wide range of climatic conditions and Agro-ecological zones (MOA, 2013). The sub-county has ten agro-ecological zones ranging from TA, UH0, LH0, LH1, UM1, UM2, UM3, LM3, and LM4 to LM5 (Jaetzold, et al., 2006b). The highlands cause lower temperatures and force rain bearing winds to deposits most of the moisture on the windward side (East of Mt. Kenya.) where the sub-county lies. Temperatures range from very cold (below freezing) on Mt. Kenya to very high (45^{o}C) in the lower areas of Igambang'ombe. The mean daily temperature is 25^{o}C (MOA, 2009). The rainfall pattern is bimodal; with first rains (March to May) and second rains (October to December), but with the second rains being more reliable than the first rains. The annual rainfall ranges from 2,200mm in the slopes of Mt. Kenya to 500 mm in the lower areas of Igambang'ombe ward (NEMA, 2007).The main soil types are Ando-humic-Nitosols in LH1, Cambisols in UM1 –UM3 and Ferralsols/Luvisols in LH3-LH5 (Jaetzold *et al*., 2006b).

The farms are smallholdings ranging from 0.1 to 2 ha with an average of 1.2 ha per household and farmers practice small-scale rain-fed, mostly non-mechanized agriculture that involves little use of external inputs. The region is characterized by complex farming systems demonstrated by perennial cash crops, food crops, trees and livestock (MOA, 2013).

3.1.2. Farm-household survey

The Farm household survey was conducted in Meru South Sub-county of Eastern Region of Kenya from 19th to 26th February 2013. The survey was conducted in order to determine the existing soybean seed production systems, storage and quality under farm conditions in contrasting soybean growing agro-ecologies of Meru South Sub-county. The aim of the survey was to characterize soybean agronomic systems and the farm household; identify farmer preferences for soybean varieties; document on-farm soybean seed management scenario (seed production, processing and storage) for designing future strategies of seed production; assess the status of soybean adoption, utilization and marketing and to determine the quality of farm saved soybean seeds under various climatic conditions. It is envisaged that the data collected will provide information for policy makers and entrepreneurs for designing future strategies of seed production and development of soybean industry.

The survey was carried out in in 12 wards and 49 villages using a representative sample of 308 soybean growing farmers from Chuka, Mugumoni, Igambang'ombe wards, (UM2, UM3 LM3, LM4) regions (Jaetzold *et al.,* 2006b). Most respondents (85%) were from Mugwe, Mariani, Ituguruturu, Karingani and Mukuuni wards where majority of soybean growers were found (Table 3.1).

Table 3.1: Soybean farmers sampled during the survey by wards

Ward	Frequency (%)
1. Mugwe	101 (32.8)
2. Itugururu	46 (14.9)
3. Mariani	44 (14.3)
4. Karingani	38 (12.3)
5. Mukuuni	36 (11.7)
6. Rubate	12 (3.9)
7. Muiru	12 (3.9)
8. Thuita	7 (2.3)
9. Mwonge	6 (1.9)
10. Gitareni	4 (1.3)
11. Mitheru	1 (0.3)
12. Kiangondu	1 0.3)
N	**308 (100)**

3.1.2.1. Pre-testing of questionnaire

The questionnaire was pretested on 18/2/13 using the local language (Meru) in Keringani and Kiangondu villages using a sample of 10 farmers. The questionnaires were then revised accordingly.

3.1.2.2. Sample size and sampling

The survey was conducted from 19th to 26th February 2013. The data collection methods of this research involved the use of both qualitative and quantitative methods. Qualitative methods included focused group discussions and key informant interviews while quantitative methods involved administration of structured questionnaires. The tools of data collection during the survey included structured questionnaire (Appendix1) form collecting primary data from soybean farmers, as well as themes for focused group discussions and key informant interviews (Appendix 2). Interviews were conducted by properly trained and carefully selected enumerators recruited from the local community. The targeted respondent was the household head, but in their absence, the spouse of the household head or a close relative/next of keen was interviewed.

Data was collected on socio-economic characteristics, source of seed, soybean varieties grown, agronomic system, preference utilization, seed handling and storage. The number of households to be interviewed during the survey was calculated using the formula adopted from Fischer *et al.,* (1998).

$$N=\frac{z^2pq}{d^2} = \frac{1.96^2 0.5(1-0.5)}{0.05^2} = 384$$

Where: N is the required sample size;

z is normal deviation (1.96) which corresponds to 95% confidence interval;

P is proportion in the population growing soybean estimated at 50% since it is not known.

q is 1-p

d is degree of accuracy (0.05) (Fischer *et al.*, 1998).

Using this formula, the required sample size N was 384, but with an allowance of 10% attrition, hence the respondents were expected to be 422. However, because of limited number of households growing soybeans, only 308 farmers were interviewed.

Selection of households was done according to purposive criterion sampling method to interview farmer households that grow soybean seeds from soybean growing areas in Meru South Sub-county. In addition to the above sample size, two focused group discussions (FGDs) were held to tease out the main issues as relates to soybean seed production system. Ten key informants were selectively interviewed with respondents from research/extension, seed companies, traders, processors and Soybean Development projects and programs. The key informants were individuals who have had previous experience with the communities that were interviewed on soybean industry. They helped identify important clusters of soybean growers, entry points, community institutions and decision-making mechanisms. The GPS coordinates of the data collection points was taken and used to generate a map showing survey sites (Fig.3.1).

3.1.3. Farm saved seed sampling and analysis

In order to determine the quality of farm saved seed, thirty samples (half kg each) of soybean seed was randomly obtained from farmers that participated in the soybean seed survey conducted in Meru South Sub-County in February 2013. The samples obtained were of the short rains crop harvested in Jan/Feb. 2013 from four agro-ecological zones – Upper Midlands 2 (UM2), Upper Midlands 3 (UM3), Lower midlands 3 (LM3) and Lower Midlands 4 (LM4) (Jaetzold *et al*., 2006b). All the sampled seed had been planted in October 2012 and harvested in January/February 2013 hence had been at most stored only for one month before sampling. The seed was packed in hermetically sealed plastic (used vegetable oil) Jeri cans that had been thoroughly cleaned and dried before use. The seed was then transported to the Genetic Resource Research Institute Laboratories, Muguga in March/April 2013 for seed quality analysis using standard germination and electrical conductivity tests as well as determination of seed moisture contents.

3.1.4. Data Analysis

Information from the survey questionnaire was coded on a numerical scale and entered into a spreadsheet. The responses were summarized and similar responses combined, coded and analyzed using IBM® SPSS Version 20. The analysis involved data summary by frequencies, charts and histograms. Missing data was excluded on a case by case basis. Seed quality tests were analyzed using SAS statistical software Version 9.2 and separation of means was done using least significant difference (LSD) Tukey's studentized range (HSD) test ($p \leq 0.05$), where applicable.

3.2. Objective 2: To evaluate the effects of storage agro-ecology, storage containers, seed dressing and genotype on soybean seed quality under ambient conditions

The experiment on the effects of genotype, seed dressing, storage containers and storage agro-ecologies on soybean seed viability and vigor under ambient conditions was set in two distinct agro-ecologies in Meru South Sub-county, Eastern region of Kenya.

3.2.1. Description of Soybean seed storage experimental sites

Seed storage experiments were located in two contrasting soybean growing agro-ecologies of Meru South Sub-county (Fig. 3.2). Site1- Mugwe Ward, Kirege village in humid agro-ecological zone (Upper Midlands II -UM2) and Site 2 was set at -Itugururu Ward, Igambatuntu Village in semi-humid agro-ecological zone (Lower Midlands IV -LM4).

Seed storage site 1- Kirege (UM2)

Kirege lies within the humid Upper Midlands II (UM 2) agro-ecology. The area is classified as the main Coffee Zone and receives annual average rainfall of 1500 to 2400 mm bi-modally, with Long rains coming in March-June and short rains from October to December, and is characterized by two medium cropping seasons. The altitude of this zone ranges from 1280 to 1680 m above sea level, with an annual mean temperature of $18.2^0$to 20.6^0C (Jaetzold *et al.,* 2006b). The storage experiment was conducted in a farmer's in house store at Kirege village (00^0 20.580''S, 037^0 37.189' E, altitude 1529m above sea level) located at 00^0 20.580''S, 037^0 37.189' E, and altitude 1529 m *above sea level*

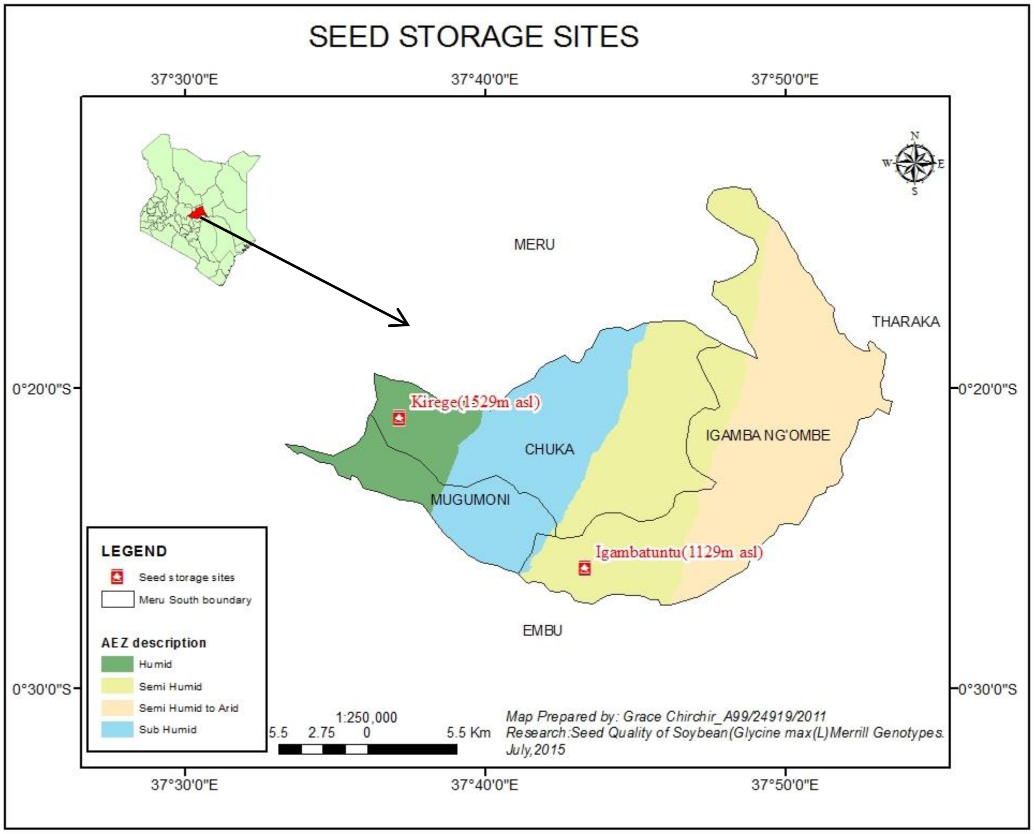

Figure 3.2: On-farm seed storage experimental sites at Kirege (UM2) and Igambatuntu (LM4)

Seed storage site 2- Igambatuntu (LM4)

Igambatuntu seed storage site lies within the semi humid Lower Midlands IV (LM 4) agro-ecology. This area lies within the Marginal Cotton Zone, and receives annual rainfall varying from 800 to 1050mm. The rains are bimodal, with long rains occurring in March-June and short rains - October to December, characterized by short and a short to very short cropping season. The altitude of this zone ranges from 760 to 1300 m above sea level and has an annual mean temperature is 21.0 to 23.5^{0}C (Jaetzold *et al*., 2006 b). The storage experiment was conducted in a farmer's in house store at Igambatuntu village (00^{0} 06'19.4"N, 037^{0} 54' 49.7''E; altitude 1129 m above sea level.)

These two sites were chosen to simulate the environmental conditions soybean seed would be subjected to in a typical farmer's storage facility in two diverse environments that would influence seed longevity.

3.2.2. Soybean seed storage experimental layout

Two soybean genotypes commonly grown by farmers in Meru South Sub-county Gazelle and TGx 1740-2F (SB19), of the 2013 harvest were obtained from two farmers in February 2013.Two genotypes were placed in two different storage environments following an initial seed quality evaluation. The storage treatments were set in continuous non-climate controlled farmers in-house stores, in a Completely Randomized Design (CRD) with three replications (Figure 3.3). The seed dressing used was wood ash and commercial seed dressing fungicide Apron Star® (Syngenta), with untreated as control. The wood ash was obtained from two local farmers' kitchens in Chuka ward, blended to make a uniform sample and sifted to remove debris. The trade name and active ingredients and rates of the seed dressing used are presented in Table 3.2.

Table 3.2: Dosage and active ingredients of seed dressing chemicals used on soybean seeds

Chemical name	Active ingredient	Recommended dose	Chemical type
Apron® Star 42 WS 	20% Thiamethoxam 20% metalaxyl-M 2% difenoconazole	10 g Apron star for 4 kg of seed (250g/100kg seed)	Fungicide/insecticide
Wood Ash 	19 % wood ash	400 g of ash to 2.1 kg seed	Ash

Experimental layout

	Rep1	Rep.2	Rep.3
1.	V_2P_2	V_2G_0	V_1G_2
2.	V_2P_0	V_1P_2	V_1P_0
3.	V_1G_2	V_1G_0	V_2G_1
4.	V_1P_1	V_1P_1	V_2G_0
5.	V_1P_0	V_2G_2	V_1G_1
6.	V_1G_0	V_1G_2	V_1P_1
7.	V_2G_1	V_1G_1	V_1P_2
8.	V_1P_2	V_2G_1	V_2P_0
9.	V_2G_2	V_2P_0	V_2P_1
10.	V_1G_1	V_2P_1	V_1G_0
11.	V_2G_0	V_1P_0	V_2G_2
12.	V_2P_1	V_2P_2	V_2P_2

(a) Kirege (UM2)

	Rep. 1	Rep. 2	Rep.3
1.	V_1G_0	V_2P_1	V1P1
2.	V_1G_2	V_2P_0	V_1P_0
3.	V_2G_1	V_1G_1	V_2G_2
4.	V_2G_0	V_1P_0	V_2P_2
5.	V_2P_1	V_1G_2	V_2P_0
6.	V_2G_2	V_1P_1	V_1G_0
7.	V_1G_1	V_2G_1	V_1P_2
8.	V_1P_1	V_2G_2	V_2P_1
9.	V_2P_0	V_2G_0	V_2G_0
10.	V_1P_2	V_2P_2	V_1G_1
11.	V_1P_0	$V1G_0$	V_1G_2
12.	V_2P_2	V_1P_2	V_2G_1

(b)–Igambatuntu (LM4)

Figure 3.3: Soybean seed storage experimental layout at (a) Kirege (UM2) and (b) Igambatuntu (LM4)

Legend for figure 3.3

CODE	TREATMENT
V_1P_0	Gazelle variety untreated and stored in air tight containers
V_1P_1	Gazelle variety treated with Apron star and stored in airtight plastic containers
V_1P_2	Gazelle variety treated with wood ash and stored in airtight containers
V_1G_0	Gazelle variety untreated and stored in gunny bags.
V_1G_1	Gazelle variety treated with Apron star and stored in gunny bags
V_1G_2	Gazelle variety treated with wood ash and stored in gunny bags
V_2P_0	TGx-1740-2F (SB19) variety untreated and stored in air tight plastic containers
V_2P_1	TGx-1740-2F (SB19)treated with Apron star and stored in airtight containers
V_2P_2	TGx-1740-2F (SB19)) treated with wood ash and stored in airtight containers
V_2G_0	TGx-1740-2F (SB19) untreated and stored in gunny bags.
V_2G_1	TGx-1740-2F (SB19)treated with Apron star and stored in gunny bags
V_2G_2	TGx-1740-2F (SB19) treated with wood ash and stored in gunny bags

Soybean seed was mixed with Apron star at the recommended rate of 10g $^{-}$1kg seed and ash at the rate of 400g per 2.1kg of seed (Table 3.2). Apron Star® is a seed treatment fungicide-insecticide mixture for controlling downy mildew, damping-off diseases as well as for protection of seeds and seedlings against early season insect pests and soil borne diseases in beans, sorghum, maize, cotton and vegetables.

The seed was then and agitated thoroughly until the surfaces of the seeds were uniformly coated. Immediately after the seed dressing, seed samples (2.5 kg) from each seed lot was stored in three replicates in (a) 3 liter yellow plastic vegetable oil Jeri cans (Nairobi Plastics Ltd –NPL) and lids screwed on to ensure air tight conditions were maintained and (b) synthetic gunny bags (Biryani Pakistani Rice bags, M/S.H.M Traders) and tied with a sisal twine. An untreated control seed lot was also included in the tests for each variety to give a total of 36 experimental units per site.

The seed lots were stored under ambient conditions for eight months from 14thMarch 2013 to 14th November 2013. The seeds were sampled after 0, 4 and 8 months of storage for quality tests at the Genetic Resource Research Institute Laboratories (S 01^{0}12.955'; E 036^{0}37.859', altitude 2100m above sea level, AEZ LH3). The standard germination, electrical conductivity and the accelerated aging tests (AOSA, 2009) were performed to monitor any changes in seed quality caused by storage conditions.

3.2.3. Laboratory Seed quality analysis

Seed moisture contents, germination, electrical conductivity and accelerated ageing tests were performed following the ISTA (2007) rules.

3.2.3.1. Determination of seed moisture

Seed moisture contents were determined using a Grain moisture meter (GMK-303RS, G-Won Hitech Co. Ltd) which measures the electric properties of seed moisture either by conductivity or capacitance within the range of 6-25% range. Four replicates per seed lot were sampled, placed inside the moisture meter, ground and readings taken.

3.2.3.2. Germination and seedling growth tests

Seeds of soybean (*Glycine max* (L.) Merill) were treated for 40 seconds with sodium hypochlorite solution (3.85 % active ingredient) diluted with water in 1:2 ratio for 40 seconds and then surface washed with distilled water three times, to retard saprophytic fungal growth. Seeds were then germinated by placing 50 seeds per replication in four replicates in germination boxes using 500mls plastic containers with lids, containing 1% water agar under laboratory conditions (ISTA, 2007). The germination boxes were arranged in a completely randomized design (CRD) in a walk-in germination chamber held at $30/20^0$ C with alternating 12 h fluorescent light and 12 hours darkness. Counts of germinating seeds were made daily, starting on the first day of imbibition and terminated 11 days after sowing, when maximum germination was obtained. Seeds were identified as germinated when 2mm of the radicals protruded (ISTA, 2007). Normal seedlings were recorded for calculating germination percentage (GP) at last count. The root and shoot length were measured on the 11th day after sowing by randomly sampling ten plants from each replicate of each treatment. After test time expiration, the following germination indices were evaluated: Germination percent (GP), Mean Germination Time (MGT), Germination Index (GI), Time to 50%

Germination (T50), Energy of Germination (EG), Seedling Emergence (SE) and Seedling Vigor Index (SVI).

a. **Germination percent (GP)** was calculated as follows:

$$\textbf{GP} = \frac{\text{Number of germinated seeds 11DAS} * 100\%}{\text{Total number of seeds sown}} \quad (1)$$

b. **Mean germination time (MGT)** was calculated according to the equation 2 (Dezfuli *et al*., 2008).

$$\mathbf{MGT = \Sigma Dn / \Sigma n} \quad \mathbf{(2)}$$

Where n is the number of seeds which were germinated on day D, and D is the number of days counted from the beginning of germination.

c. **Germination index (GI)**was calculated as described in the Association of Official Seed Analysts (AOSA, 1983) by following formula:

$$\mathbf{GI} = \frac{\textbf{No. of germinated seed}}{\text{Days of first count}} + \text{- -} + \frac{\textbf{No. of germinated seed}}{\text{Days of final count}} \quad (3)$$

d. **Time for 50% of germination (*t*1/2 or T50)**, is the point of the distribution in which the mean, median or mode (point at which the highest frequency of germinated seeds) is observed. It represents the peak of germination. The t**ime to 50% germination(T50)** was calculated according to the formula of Coolbear *et al*., (1984) modified by Farooq *et al*., (2005):

$$\mathbf{T50} = \mathbf{ti} + \frac{\{(N/2) - ni\}\,(ti - tj)}{ni - nj} \quad (4)$$

Where N is the final number of germination and ni, nj cumulative number of seeds germinated by adjacent counts at times ti and tj when ni<N/2< nj.

e. **Energy of emergence (EG)** – was recorded on the 4th day after planting. It is the percentage of germinating seeds 4 days after planting relative to the total number of seeds tested (Ruan, *et al*., 2002).

f. **Speed of emergence** was calculated using equation (5) (Dodlani *et al*., 1992).

$$\textbf{Speed of emergence} = \frac{\textbf{No. of seedlings emerged after 5 DAS x 100}}{\textbf{No of seedlings emerged after 11 DAS}} \quad \mathbf{(5)}$$

g. Seedling vigor index (SVI) - was calculated according to equation 6 (Orchard, 1977).

Seedling vigor index (SVI) = [seedling length (cm) × germination percent (6

3.2.3.3. Electrical Conductivity tests

Conductivity test is used to quantify the leakage of electrolytes from the seed coat with respect to age, storage life, and environmental factors such as temperature, humidity and mother plant nutrition.

Electrical conductivity tests were determined by weighing four replicate samples of 50 seeds per treatment and placing them in 250ml plastic cups containing 200mls of distilled water. The seeds were gently stirred to remove air bubbles. Any floating seeds were removed and the cups covered with aluminum foil. The seeds were then left to soak in the water for 24 hours at room temperature 20 ± 2^0C. Conductivity of seed leachates was measured using a Jenway 4020 conductivity meter and CRT-CAA- 515B electrode dip type cell (Fisons Scientific Equipment) (**Fig. 3.4**). The conductivity meter was standardized with 0.01N potassium Chloride (0.7456/74.56 = 0.01N KCl). The solution was prepared afresh by dissolving 0.7456g KCl in 1,000 ml of distilled water at room temperature. The cell constant (K) value at 1.000, and temperature coefficient per ^{0}C of 2 % rise at 25^0C was used to take the readings. The electrical conductivity of a control sample of an equivalent quantity of distilled water was also determined. Conductivity was expressed on a weight basis in micro Siemens per cm per gram (µs $cm^{-1}g^{-1}$) of seed (ISTA, 2007).

Plate 3.1: Jenway 4020 conductivity meter

3.2.3.4. Accelerated ageing test

For each treatment, seeds were first preconditioned by exposing them to humid environment, created by placing seeds in open trays, above a water pan at room temperature for 48 hours in order to raise the seed moisture content to between 10% and 14% (Plate 3.2). After allowing the seed moisture to equilibrate, 100 seed weight, adjusted to 13% moisture content was taken.

Plate 3.2: Preconditioning of seeds

Plate 3.3: Accelerated ageing box

Accelerated aging tests were conducted by placing four replicates of 100 seeds per treatment on a screen inside a 38 x 28 x 10 cm accelerated aging boxes (Hoffman Manufacturing Company, Albany, OR) into which 500 ml of distilled water had been added to the bottom of the box (Plate 3.3). The boxes were tightly sealed and placed in an oven set at 41^{0}C for a specific ageing period of 72, 96, 120,144,168, 196 and 216 hours. Immediately after each aging period, 100 seed weights were taken in order to determine whether the ageing process was successful. Thereafter, germination tests were done by planting four replicates of 50 seeds each on 1% water agar in 500 ml plastic germination boxes. The planted germination boxes were then placed in a walk-in germination chamber held at alternating temperature (20/30^{O}C) and 100% relative humidity with alternating light cycles (12-h on, 12-h off) for a total of 24-h per day for 11 days. Further, a sub-sample of 50 seeds per replicate for each treatment was subjected to electrical conductivity test according to the procedures described in section 3.2.3.3.

3.2.4. Statistical analysis

Data was analyzed using PROC GLM (GLM Procedure) model of the Statistical Analysis Systems software (SAS Institute, 2009). Parameters were subjected to Analysis of Variance (ANOVA) and means separated using Least Significance Difference (LSD) at P≤0.05 based on Tukey's Studentized Range (HSD) test at P≤0.05.

3.3. Objective 3: To determine the effect of osmo-priming and hydro-priming on soybean seed viability and vigor.

The experiment on the effects of osmo-priming and hydro-priming on soybean seed viability and vigor, was performed on stored seed of two soybean genotypes Gazelle and TGx 1740 2F(SB19) popularly grown by farmers in Meru South Sub-county. An on farm seed storage experiment was done and aging seed was sampled after four and eight month of storage. At the end of each storage period, seed was subjected to hydro and osmo-priming treatments.

3.3.1. Soybean seed storage experiment in Meru South

The seed of two soybean cultivars Gazelle and SB 19 from the 2013 harvest was obtained from two farmers in Meru south Sub-county and blended to make a uniform sample in February 2013. The seed was sundried dried and cleaned to remove debris then packed in 2.5 kg in synthetic gunny bags without any seed dressing. The experiment was set in a completely randomized design, with three replicates giving a total of 6 experimental units and stored in a farmer's in-house store. The seed storage site was at Igambatuntu village (00^0 06'19.4"N, 037^0 54' 49.7''E; Altitude 1129 m a.s.l.) at Lower Midlands 4 (LM4) with temperatures of 21^0C to 23.5^0C (Jaetzold *et al*., 2006b) (Figure 3.2). The site was chosen to simulate the environmental conditions that soybean seed would be subjected to in a typical farmer's storage facility and to determine influence of priming on quality of farm saved seed. The initial seed quality was determined by subjecting seed to germination and electrical conductivity tests and thereafter seed was stored for an eight months period and sampled at 4 months intervals and subjected to priming and seed quality tests.

3.3.2. Osmo and hydro-priming treatments

Priming treatments were performed using 2 priming agents (Polyethylene glycol 6000 and Distilled water), with Control (non-primed) and 4 solution osmotic potentials (0 - distilled water, -0.5, -1.0, -1.5 Mpa), 4 priming durations (6, 12, 24 and 48 hours) on two soybean genotypes - Gazelle and TGx 1740 -2F (SB 19). The osmotic potentials of priming agents were determined according to Michel and Kaufmann (1973) for polyethylene glycol 6000 (PEG).

For each treatment, samples of 420 seeds were soaked in distilled water for hydro-priming treatments and in PEG 6000 for osmo-priming treatments. (Plate 3.1)

(a) **(b)** **(c)**

Plate 3.4: Seed priming procedures (a) soaking seeds in priming agents (b) air drying primed seeds on shelves (c) seed drying in cloth bags.

The seeds in different osmotic potentials of priming agents were kept in an incubator at 25°C. At the end of each priming duration, seeds were rinsed with distilled water for 3 minutes, followed by air-drying on shelves in an air lock room for 24 hours to remove excess water. The seeds were then packaged in cloth bags and placed on open racks in a dehumidified walk in seed drying room, leaving enough space to allow the free circulation of air between the bags. The seeds were left in the seed drying room for 3 days at temperature of 20± 2°C and 15-23% RH in order to bring the seeds to their approximate original moisture content (Plate 3.1).

3.3.3. Post-priming seed storage

To study the effect of post-priming storage on soybean seed quality, seeds of two genotypes - Gazelle and TGx-1740-2F (SB19) were obtained from two soybean growing farmers in Meru South and Maara Sub-county respectively, from the crop harvested in February/March 2013. The seeds of each cultivar were blended to create a uniform sample and then hydro primed and osmo-primed in polyethylene glycol 6000 at osmotic potentials - 0.5, -1.0, -1.5 Mpa for 6, 12, 24 and 48 hours with dry seed as control using procedures described in section 3.3.2. After drying back to the original moisture content, primed and control treatment (unprimed seed) were then put in half kg khaki bags and stored in individual gunny bags under ambient temperature 20 ± 2^{0}C and RH 50% for 8 months at the Genetic Resource Research Institute seed testing laboratory (01^{0} 12' 57"S, 036^{0} 37' 52" E, 2098 M altitude), Muguga in Kiambu Ward, Limuru Sub-County, Kenya.

3.3.4. Seed Quality tests

Seed viability and vigor tests were conducted immediately after priming and at the expiry 8 months of post-priming storage. Seeds were tested for moisture content (fresh weight basis), germination potential, seedling growth and electrical conductivity using procedures described in section 3.2.3.

3.3.5. Statistical Analysis

Data was analyzed using PROC GLM (GLM Procedure) model of the Statistical Analysis Systems software (SAS Institute, 2009) Version 9.2 and the correlations were analysed by Pearson's correlation coefficient. The parameters were subjected to Analysis of Variance (ANOVA) and means were separated using Least Significance Difference (LSD) based on Tukey's Studentized Range (HSD) at $P \leq 0.05$.

3.4. Objective 4: To determine the influence of mother plant nutrition, genotype and agro-ecology on soybean productivity, seed longevity and vigor.

In order to determine the influence of mother plant nutrition, genotype and agro-ecology on soybean productivity, seed longevity and vigor, a field experiment was set up in two contrasting agro ecologies (Figure 3.4) during the short rains November 2013. Both experimental sites had no history of soybean cultivation, with KALRO-Muguga site having been fallow for 3 years while Nkoroi site had been fallow for one year, previously having been under maize cultivation. Data was collected during the crop growth followed by laboratory seed tests after harvest in April 2014.

3.4.1. Description of field research experimental sites

3.4.1.1. KALRO Muguga field experimental site

KALRO – Muguga field experimental site is located in Kikuyu Sub-county, Kiambu County within of the Central Region of Kenya (Figure 3.4). The Sub-county has a population of 125,402and occupies an area of 175 Km^2 (KNBS, 2009). It is divided into two main agro-ecological zones, namely the Lower Highland and Upper Midland zones (Jaetzold *et al*., 2011). The sub-county is divided into five wards Karai, Nachu, Sigona, Kikuyu and Kinoo wards. The research field site was located in the Kikuyu ward, at KALRO-Genetic Resource Research Institute - Muguga ($01^0$12’57’’ S $036^0$37’52’’ E, 2100m altitude). The site lies within semi-humid agro-ecological zone Lower Highlands III (LH3), which is a wheat, maize, barley zone with a short to medium and a (weak) very short to short cropping season.

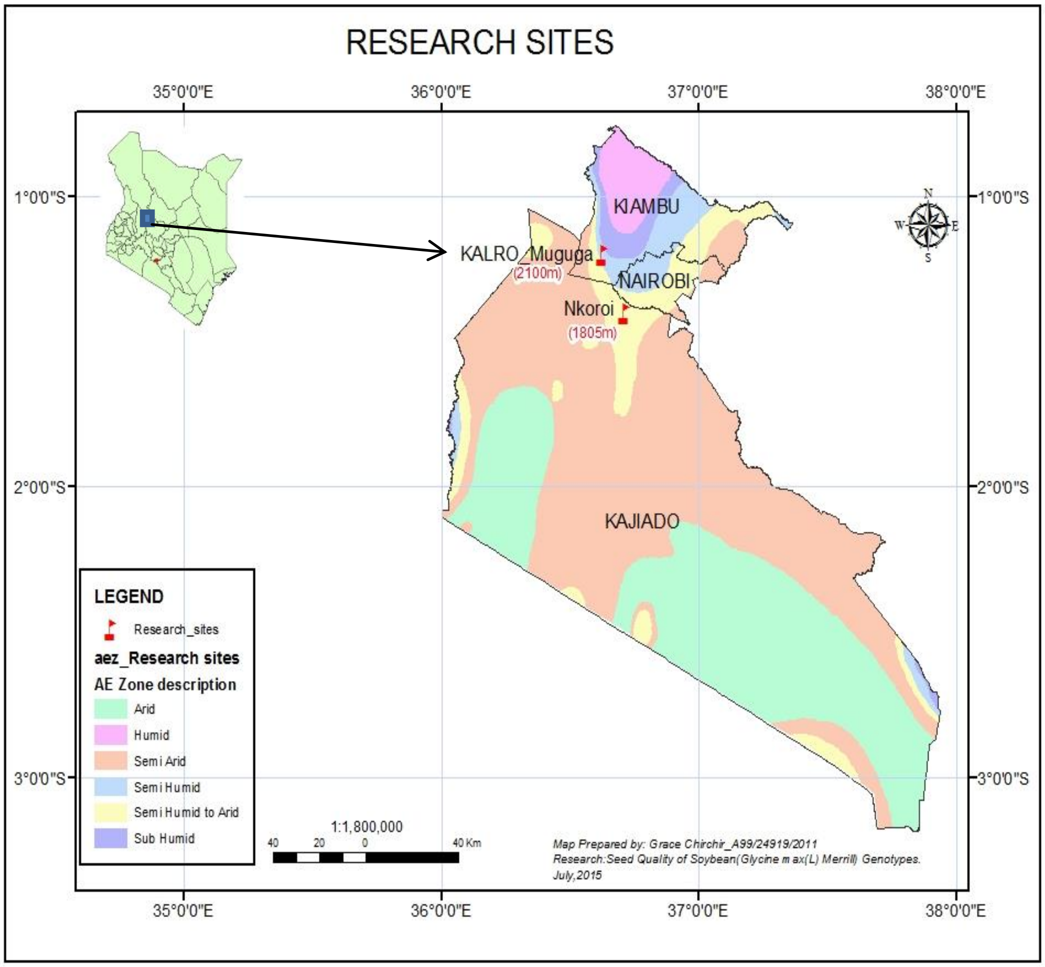

Figure 3.4: Soybean mother plant nutrition field research sites at KALRO-Muguga in Kiambu County and Nkoroi in Kajiado County of Kenya

The area receives average annual rainfall of 900-1200 mm bimodally. Long rains (LR) start from March to May and Short Rains (SR) from October to December. The annual mean maximum temperature is 20.9^0C; with a minimum of 10.8^0C; absolute minimum of 5.3^0C and with a mean of about 15.9^0C. The soils are humic Nitisols which are characteristically well drained, extremely deep, dark reddish brown and very friable clays with acidic humic top soils (Jaetzold *et al.*, 2006). Farmers in the area practice small-scale mixed farming with main crops being maize, beans, peas, potatoes and vegetables.

3.4.1.2. Nkoroi field experimental site

The Nkoroi experimental site is located within Kajiado North sub-county, in Kajiado County of the Rift Valley Region of Kenya (Figure 3.4). The sub-county has a population of 195,746 (KNBS, 2009) and occupies an area of 148 Km^2 and is divided into five wards namely Olkeri, Ongata Rongai, Nkaimurunya, Oloolua and Ngong wards. The sub-county is largely semi-arid and lies predominantly in agro-ecological zone III to VI with zone IV and V being the most predominant (Jaetzold *et al.,* 2011).

The research experimental site was located at a farmer's field in Olkeri ward, Upper Nkoroi Village ($01^0$24'296'' S; $036^0$42'606'' E), altitude 1805m*a.s.l*. The Olkeri ward lies within semi-humid to arid Agro-ecological zone classified as Upper Midland IV (UM4). It is a Maize-Sunflower Zone with a short to very short cropping season suitable only for early maturing varieties. Rainfall is unevenly distributed and unreliable. The mean annual rainfall ranges from 720 to 800 mm and rainfall is bimodal, with "short rains" starting from October to December and "long rains" from March to May. The temperature ranges from 13^0 to 25^0C but with a mean annual temperature of 18.0^0-18.4^0C. The soils are predominantly vertisols ("Black Cotton Soils") which are essentially dark montmorillonite-rich; poorly drained cracking clays (Jaetzold *et al.,* 2011).The main livelihood in the area is formal employment and mixed farming.

3.4.2. Soil sampling and analyses

Soil samples from the two experimental sites were taken on 8th and 9th October 2013 prior to the growing season. Random soil sampling (in a zigzag manner) was done from three blocks per site, six samples per block (30-cm in depth and 8 cm in diameter), totaling to 18 cores per site. For each core sampling was taken from 0-15 cm followed by 15 – 30 cm depth.

The samples were air dried on polythene sheets for five days and ground on a mortar to pass through a 2mm sieve for determining available P, exchangeable bases (K, Na, Mg and Ca) and micronutrients (Fe, Mn, Zn and Cu). A sub-sample was further ground to pass through 250 microns (60 mesh) sieve for analysis of total N, P and organic carbon.

For soil pH, 10 grams of sample was placed in a 50mls plastic beaker, into which 25ml distilled water was added and stirred with a policemen glass rod. The contents were left to stand for 1hr and then pH measurements were taken using pH meter

The Total Nitrogen and Phosphorous were determined by sampling 0.3 g of the 60 mesh soil sample which was transferred to a 75 ml digestion tube, added with 4.4mls of digestion mixture and placed in block digester heated to 330 ^{0}C until the solution became colorless and any remaining sand white (Okalebo *et al.*, 2002). The total Nitrogen was measured using the segmented flow analyzer equipment (Kjeldahl method). Phosphorus was measured using the Olsen for phosphorus test (Okalebo, *et al.* 2002). The optical densities were taken using a UV/visible spectrophotometer at 881nm wavelength and the final P levels were computed. Organic carbon was determined by the sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture. After complete oxidation, the residual $K_2Cr_2O_7$ was titrated against ferrous ammonium sulphate. The difference between the used and the unused $K_2Cr_2O_7$ gave the measure of the organic carbon content of the soil.

The EDTA-soluble copper, zinc, iron and manganese trace elements were measured using the ethylenediaminetetraacetic acid disodium salt (EDTA) method (Viro, 1955). Five grams of air dried soil was placed in 150ml plastic shaking bottle followed by 50ml 1% EDTA solution which is shaken for 1 hr., filtered with a Whitman no. 542 filter paper. Measurements were then taken using an atomic absorption spectrophotometer (Okalebo *et al.*, 2002).

The exchangeable cations (K, Na, Ca, and Mg) were measured by putting 2.5 g of air dried soil into a 150ml shaking bottle added with 50ml of 1.0N ammonium acetate solution, shaken for 30 minutes. The contents were filtered using whatman 42/542 and readings taken using atomic absorption spectrophotometer.

3.4.3. Experimental design

The experiment was conducted during the Short Rains Season (SR) of October-November year 2013. Field sowing was done from 10th to 12th November 2013, utilizing cultivar Gazelle and TGx 1740-2F (SB 19) sourced from farmers from Meru County and dressed with commercial seed dressing Apron star® before planting.

A randomized complete block design (RCBD) with six treatments, plus control, and three replications, separately for each experimental site was adopted (Figure 3.5). The treatments were arranged as a split plot. The two varieties (Gazelle and SB 19) constituted the main plots while phosphate in the form of (TSP) and nitrogen in the form of Calcium Ammonium Nitrate (CAN) plus the minus counter parts, as well as combination of both ($N_{25}P_{60}$) represented the sub-plot. The plots corresponding to the mineral Phosphate treatments received 60Kg ha^{-1} P_2O_5 at planting while the plots corresponding to mineral nitrogen treatments received 25kg ha^{-1} of N at beginning of flowering (R1) stage (Fehr and Caviness, 1977).

(a)	BLOCK 1	BLOCK 2	BLOCK 3
1.	V_2, N_0,P_0	V_1, P_1	V_1, N_0P_0
2.	V_2, N_1P_1	V_2,N_0,P_0	V_2, N_1P_1
3.	V_1, N_1	V_1, N_1P_1	V_1, P_1
4.	V_2, P_1	V_2, P_1	V_2, N_1
5.	V_2, N_1	V_1, N_0P_0	V_1, N_1
6.	V_1, N_1P_1	V_2, N_1P_1	V_2, P_1
7.	V_1, N_0P_0	V_2, N_1	V_2, N_0,P_0
8.	V_1, P_1	V_1, N_1	V_1, N_1P_1

(b)	BLOCK 1	BLOCK 2	BLOCK 3
1.	V1, N_1	V_1, N1	V2, N0,P0
2.	V1, N_1P_1	V_1, P1	V1, N1
3.	V_2, N_1P_1	V_2, N1P1	V1, P1
4.	V_2, N_1	V_2, N_0,P_0	V_2, N1
5.	V_1, P1	V_1, N1P1	V_2, N1P1
6.	V_1, N_0P_0	V1, N0P0	V2, P1
7.	V_2, N_0P_0	V_2, P1	V1, N0P0
8.	V2, P1	V2, N1	V1, N1P1

Figure 3.5: Experimental plots layouts at (a) GeRRI – Muguga and (b) Nkoroi –Kajiado North

KEY

V_1 – Soybean cultivar Gazelle
V_2 – Soybean cultivar TGx 1740-2F (SB 19)
N_0 – 0 Kg N ha^{-1}
N_1 – 25 kg Nha^{-1}
P_0 – 0 Kg P ha^{-1}
P_1 – 60 kg P ha^{-1}
N_1P_1 – 60kg P +25kg N

The plot size used was 4x4 m^2 (Muguga site) and 2.5 x 5 m^2 (Nkoroi site) with row to row distance of 45 cm and plant to plant distance of 10 cm with two seeds per hill. Using marked sisal twine, soybean was planted three seeds per hill and thinned to two seeds per hill at 4 leaf stage, giving a total plant population of 444,444 plants ha^{-1}.Two manual hoeing were done for the control of weeds and supplementary irrigation given when needed. No pesticides were applied except for rodenticide at GeRRI plots to control moles. All standard agronomic practices were adopted for all plots uniformly (Plate 3.5).

Harvesting was done in March/April 2014, when the crop attained physiological maturity, characterized by yellow leaves and leaf drop. At this stage, pods turn from brown to tan and seeds rattle in the pods.

(a) **(b).** **(c).** **(d)**

Plate 3.5: Experimental design RCBD (a); topdressing with N at R1 stage (b); supplementary irrigation (c) and harvesting when seeds rattle in pods (d).

3.4.4. Field data collection

Data was collected on stand count, days to 1st flower, days to onset of physiological maturity, plant height, number of branches per plant, number of pods per plant, number of seeds per pod, seed yields and 1000 seed weight. Stand count was recorded by counting number of plants that emerged in each plot and the data converted to number of plants per hectare. Plant height was determined by measuring the height of 10 randomly selected plants per plot in the stages corresponding R1 and R7 (Fehr & Caviness, 1977). Number of branches per plant, number of pods per plant and the number of seeds per pod were determined in 10 randomly selected plants per plot at harvest. For seed yield data, the crop bundles per plot were manually shelled separately; seed cleaned and weighed with an electronic balance to record seed yield. The data was then extrapolated to yield ha^{-1} and the weight of 1000 seeds was evaluated, with values corrected for 13% moisture content. All seeds were air dried to a constant moisture content of 13% and then kept in temporary storage at 20 °C during the initial testing. A determination of moisture content (fresh weight basis) was done using grain moisture meter (GMK-303RS, G-Won Hitech Co. Ltd).

3.4.5. Laboratory seed quality tests

The seed of two soybean varieties obtained from the field experiment at Genetic Resource Research Institute and Nkoroi in Kajiado North Sub-county were subjected to seed quality tests and the Genetic Resource Research Institute Seed testing laboratory. Tests of seed moisture, accelerated aging, germination and electric conductivity were performed.

3.4.5.1. Accelerated ageing tests

Accelerated ageing test was conducted to determine the longevity of soybean seeds from mother plants subjected to varying levels of Nitrogen and Phosphorous nutrition in two agro-ecological zones. Four hundred seeds per treatment were aged at 41 °C for 72h, 96h, 120h, 144 h, 168h, 192h and 216h using accelerated ageing boxes. Details of the procedure for accelerated ageing are described in section 3.2.3.4. At the end of each ageing period, 100 seed weights were taken and the seeds subjected to standard germination and electrical conductivity tests.

3.4.5.2. Germination tests

Fresh and artificially aged seed were subjected to standard germination tests (ISTA, 2007), using four replicates of 50 seeds per seed lot. Seeds of each replicate were sown in 1% water agar and placed in a walk in germination chamber at an alternating temperature of 20/30^{0}C and alternating 12h light and 12h darkness. Score of germinated seeds were taken on the 5th and 8th day and the data taken as described in section 3.2.3.2. The results of the aged seed were compared with the germinability of non-aged seeds (control treatment measured at the start of the experiment).

3.4.5.3. Electrical conductivity tests

Fresh and artificially aged seed were subjected to electrical conductivity (EC) tests in order to determine the effect of N and P fertilization, genotype and agro-ecology on soybean seed vigor at harvest, The EC tests were carried out according to the procedures as described in section 3.2.3.3

3.4.5.4. Determination of Potential seed longevity (p_{50})

A seed survival curve was created by plotting seed viability (percentage germination) against the ageing period (days). This equated to fitting the Ellis and Roberts (1980a) basic seed viability equation:

$$v = K\text{i} - p/\sigma$$

Where: v is the viability (germination) of the seed after p days in the ageing environment;

Ki is the y-intercept of seed survival curves and a measure of the initial seed viability,

σ (sigma) is the standard deviation of the frequency distribution of seed deaths in time.

The time for viability to decline to 50% (p_{50}) was read off the seed survival curve. P_{50} values were used to determine soybean seed longevity as influenced by seed production agro-ecology, soybean genotype (Gazelle and TGx 1740-2F (SB19) and fertilizer application (N_{25}; P_{60}; and N_{25}+P_{60}) to the mother-plants. The time for viability to fall by 50% is widely used as a measure of seed longevity (Ellis and Roberts 1980a, Mutegi *et al.*, 2001).

3.4.6. Statistical Analysis

The data was subjected to Analysis of variance (ANOVA) using PROC GLM (GLM Procedure) model of the Statistical Analysis Systems software (SAS Institute, 2009) Version 9.2 and the correlations were analyzed by Pearson's correlation coefficient. Means were separated using Least Significance Difference (LSD) based on Tukey's Studentized Range (HSD) test at $P \leq 0.05$.

CHAPTER FOUR

RESULTS AND DISCUSION

Overview

In this chapter, the results and discussions are presented chronologically for each study objective, which form the basis of the conclusions arrived at in this study. It starts with the findings of the household survey on soybean management practices, seed systems, processing and marketing. This is followed by evaluation of storage methods for farm-saved soybean seed experimental findings which involved monitoring of seed quality over an eight month storage period; and then investigation of seed invigoration techniques using osmo and hydro priming. Finally, the findings on the influence of mother plant nutrition, genotype and agro-ecology on soybean productivity and seed quality are presented and discussed.

4.1. Objective 1: Soybean production, seed handling and quality in key soybean production areas of Meru South, Eastern Kenya

Under this objective, the findings have been presented and discussed under; demographic characteristics of soybean producers; soybean production; seed sources and handling; soybean marketing and utilization; constraints faced in the enterprise as well as quality of farm saved seed sampled during the survey.

4.1.1. Demographic characteristics of soybean growing households

4.1.1.1. Farm household characteristics

The farm household characteristics of soybean growing households are presented on **(Table 4.1).**

The survey established that most of the household heads were male (79.6%) but the respondents were mostly female (70.2%) showing that females were the likely recipients of agricultural extension messages and to be engaged in farming.

Table 4.1 Characteristics of Farm Households Head and respondents

Parameters	**Frequency**	**(% of total respondents)**
Gender of the Household (HH) head		
Male	234	79.6
Female	60	20.4
Gender of Respondent		
Male	84	29.8
Female	198	70.2
Age of (HH) head (years)		
21-30	10	3.8
31-40	45	16.9
41-50	66	24.8
Above 50	145	54.5
Education Level HH head		
Primary School	177	59.4
Secondary School	98	32.9
None (Illiterate)	17	5.7
Tertiary (Colleges)	6	2.0
Occupation of HH Head		
Farmers	266	89.6
Teachers	13	4.4
Business persons	8	2.7
Casual Workers	3	1
Masons	1	0.3
Others	6	2.0

Ogunlela and Mukhtar (2009) showed that most farmers in rural areas were women who take the lead in agricultural activities, making up to 60-80 percent of labour force. Women are known to be more involved in agricultural activities than men in sub-Saharan African (SSA) countries, Kenya inclusive. In Nigeria, as much as 73 % were involved in cash crops, arable and vegetable gardening, while postharvest activities had 16 % and agroforestry, 15 percent (Ogunlela and Mukhtar 2009). Estimates of women's contribution to the production of food crops range from 30% in the Sudan to 80% in the Congo (FAO 1995).

Most household heads sampled were aged above 40 years (79.3%), which implied that soybean farming was mainly practiced by older farmers; hence youth were less engaged in the soybean farming. There may therefore be need to design strategies to engage youth in soybean production.

The distribution of farmer household heads' education showed that most (94%) were literate; with 59.1% having primary school education, 33% with secondary education, 2 % having tertiary education and only 6% being illiterate. This result generally shows that the educational level of most surveyed household heads was sufficient enough to adopt and to carry out good agricultural practices. The study further showed that most soybean growers (89.6%) relied only on farming as an occupation, but with other off farm activities being teaching (4.4%), business enterprises (2.7%) and casual labor (1%). These findings agree with the report by Anan (2014) that two thirds of Africans dependent on farming for their livelihoods, hence boosting Africa's agriculture can create economic opportunities, reduce malnutrition and poverty, and generate faster, fairer growth.

4.1.1.2. Dwelling houses of farm households

The type of dwellings owned by survey households was evaluated by observation of the main house, and used as an indicator of economic status of soybean growers (Table 4.2). The responses were classified into: Permanent (Stone/ Bricks) with iron sheet or tiled roof , wooden walled with iron sheet roof, Mud walled with iron sheet roof , mud walled with grass thatch roof , Others (e. g. Iron sheet structures etc.) in a decreasing order of quality and cost. Household assets such as acreage, access to household labor, types of domestic assets owned and types of houses dwelt in, have been used as an economic indicator in previous studies (Filmer and Pritchett, 2001; Muhammad *et al*, 2010; Langyintuo and Mungoma, 2008). In these studies households were ranked in a scale and the results used to determine their economic status.

Table 4.2: Type of dwelling structures owned by survey households

Quality Rank	Type	Frequency (%)
2nd	Wooden walled with iron sheet roof	205 (66.7)
1st	Permanent (stone/ bricks) with Iron sheet/tiled roof	66 (21.4)
3rd	Mud walled with Iron sheet roof	31 (10.2)
4th	Mud walled with grass thatched roof	4 (1.4)
5th	Others	1 (0.3)
	N	**308 (100)**

Values in parenthesis are percent figures.

Results of the present study revealed that the most common type of dwelling in the study area was wooden walled with iron sheet roof (66.7%), followed by Permanent (Stone/ Bricks) with iron sheet or tiled roof (21.4%). If we regard the first and second best quality type houses (Permanent (Stone/ Bricks) with iron sheet or tiled roof and wooden walled with iron sheet roof) to be inhabited by the relatively well to do in the survey, it implies that most soybean growing households about 271 out of 308 (or

88.1%) are relatively well to do economically. These results agree with the findings of Muhammad *et al.,* (2010) who reported from their study that 88 % of households in Machakos and Makueni districts had Block houses with asbestos/iron sheet roofs suggesting a fairly high standard of housing and living. The findings from the present study therefore suggest that most (88%) soybean growing households had a fairly high standard of living, and were unlikely to be economically constrained in obtaining the necessary inputs for the production of soybean.

4.1.1.3. Farm Size

The results indicated that soybean farmers had farm sizes ranging from 0.01 to 13.4 Ha but with a mean of 0.93 ha (Figure 4.1).

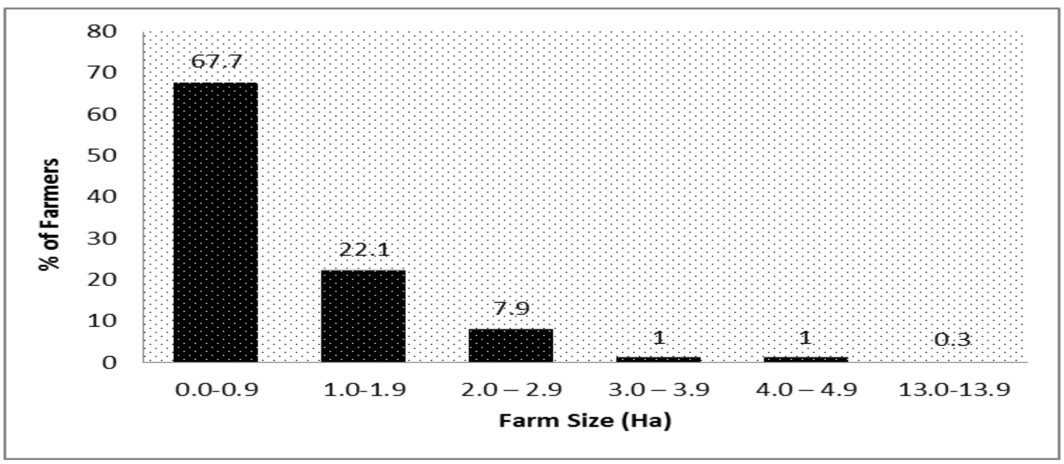

Figure 4.1: Farm Size distributions (ha.)

The distribution of farm sizes was skewed towards small sizes with the majority of soybean farmers (90%) having farm holdings of less than 2.0 Ha. This indicates that soybean crop will compete heavily for land resource allocation and is likely to be at a small scale level; hence difficulty in producing required volumes of soybean to meet industry demand. These findings are in agreement with the report by Chianu *et al.*,

(2008) that in Kenya, smallholder (usually non-commercial) farmers (with land holding ranging from 0.1 to 0.2 ha) almost wholly undertake soybean cultivation in Kenya.

4.1.2. Soybean production in Meru south

The soybean production in Meru south was audited by determining the competing crop enterprises, history of soybean cultivation, growing seasons, soybean varieties grown, land preparation and cropping systems, manure and fertilizer use, pests and diseases, hectarages under the crop and crop yields.

4.1.2.1. Crop production enterprises by soybean growing households

The prevalence of other crops in the farming system of the soybean growing farm households in the survey area was audited (Table 4.3).

Table 4.3 Other crops produced by soybean growing farm households in year 2013

Crop	Frequency	% of N (n=308)	% of total responses
Maize	295	95.8	28.9
Beans	284	92.2	27.8
Bananas	189	61.6	18.5
Coffee	119	38.6	11.6
Tea	38	12.3	3.7
Sorghum	21	6.8	2.1
Fruit crops	19	6.2	1.9
Pigeon Peas	17	5.5	1.7
Sweet potatoes	10	3.2	1.0
Vegetables	10	3.2	1.0
Climbing Beans	8	2.6	0.8
Cassava	7	2.3	0.7
Irish Potatoes	3	1	0.3
Cocoyams (Arrowroots)	2	0.6	0.2
Total	**1022**	**331.9**	**100.0**

Responses were not mutually exclusive.

The results showed that the major crops grown were Maize, beans, bananas, coffee and tea which accounted for about 90.5% of all the crops grown.

Other minor crops included sorghum, fruit crops (mangoes, avocadoes and passion fruits), and sweet potatoes, vegetables, climbing beans, cassava, Irish potatoes and cocoyam in decreasing order of prevalence. The prevalence of the crops by soybean growing farm households reflects their relative importance in their farming systems. In this respect maize (96%) was the most prevalent crop followed by beans (92%) and bananas (62%). These results indicate that soybean in Meru South Sub-county was grown by small scale mixed farmers, whose allocation of land and labor to soybean production competes with over 15 other enterprises.

These results agree with the findings of Garrity *et al* (2012) who reported that close to 70% of the rural poor in Sub-Saharan Africa reside in five farming systems: Highland Perennial, Maize-Mixed, Cereal Root and Tuber Crops, Agro-pastoral, and Highland Mixed Farming Systems. The study further found that the Highland Mixed Farming System is characterized by interaction between population growth, declining farm sizes, and the intensification of farming systems; and that the decrease in farm sizes poses a challenge in sustainable intensification and limits farming systems commercialization (Garrity *et al.*, 2012). The results of the present study therefore suggests that since the area can be categorized as highland mixed farming system, commercialization of the soybean crop in the study area is likely to be limited by small farm sizes and competing enterprises.

4.1.2.2. History of soybean cultivation in Meru South

The history of soybean cultivation and the scale of the enterprise was determined by evaluating crop introduction, soybean farming experience (years), soybean growing seasons, planting and harvesting dates as well as acreage and yields during the last cropping season (2012/2013). The study established that soybean cultivation in Meru South was a newly introduced enterprise as most (88.5%) of the sampled farmers had 1 to 4 years' experience in soybean farming with a mean of 2.5 years (Table 4.4).

Table 4.4 Experience of farmers in soybean cultivation

Factor	**Frequency**	**Percent of N**
Number of years of soybean farming (n=285)		
1-2years	208	68.4
3-4 years	61	20.1
5-6 years	10	3.3
7-8 years	3	1
9-10 years	1	0.3
11-30 years	21	6.9
Total	**285 (N)**	**100**

Soybean crop was mainly introduced by the Ministry of Agriculture (70%) followed by farmer to farmer introduction (12.3%), with others institutions being TSBF, SDA Church, Kenyatta University, KARI, Catholic Church and GTZ in descending order of influence (Figure 4.2)

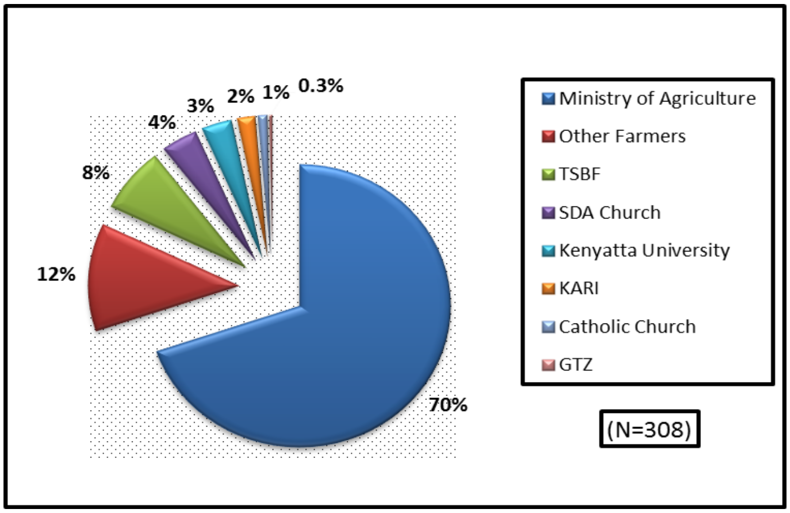

Figure 4.2: Institutions that introduced soybean farming

These results show that Government as well as non-governmental organizations have shown keen interest in introduction of soybean in the survey area in recent years. Hence being a new crop, farmers may still require greater support in the development of the soybean value chain.

4.1.2.3. Soybean growing seasons

Soybean in Meru South was reported to be grown in both the Long rains (LR) (Mid-March to June) and Short rains (SR) (October to January). Most farm households (54%) grew soybean only in the SR, with 15% growing only in the LR while 32 % grew in both seasons (**Table 4.5**).

Table 4.5 Proportion of farmers growing soybean in different seasons

Season	Frequency (%)	% of N
Long rains (March-April-May)	45	14.8
Short Rains (Oct-Nov-Dec)	163	53.6
Both seasons	96	31.6
Total	304	100

Responses were not mutually exclusive.

.

The bimodal rainfall pattern in Meru South Sub county determines cropping seasonality with the Short rains being more reliable than the Long rains (MOA, 2009), consequently most farmers grew soybean in the SR season.

According to **Table 4.6**, during the LR season, most farm households (94%) planted soybean crop in the month of March with only 6% planting in April. Harvesting however was spread almost equally between June (34%), July (32%) and August (33%). During the SR season however, most farm households (97.6%) planted soybean crop in October with only 6% planting in November. SR harvesting however was mostly done in February (57.4%), with 38% harvesting in January and 4.6% in March.

Table 4.6 Distribution of soybean planting and harvesting seasons during the (2012/2013) growing season

Rainy Season	**Planting**		**Harvesting**	
1st - Long Rains (LR)	**Months**	**Frequency (%)**	**Months**	**Frequency (%)**
	March	133 (93.7)	June	49 (34.2)
	April	9 (6.3)	July	46 (32.5)
			August	47 (33.3)
Total LR		**142 (100)**		**142 (100)**
2nd -Short rains (SR)	October	252 (97.6)	January	98 (38.0)
	November	6(2.4)	February	148 (57.4)
			March	12 (4.6)
Total SR		**258 (100)**		**258 (100)**

Responses were not mutually exclusive.

Therefore Soybean crop in Meru South Sub-County was reported to take approximately 3 to 5 months to harvest depending on genotype and agro ecology. Soybean maturity period was reported to be shorter in the lower hotter agro ecologies than in the higher cooler elevations. Moreover, the soybean cultivar SB 19 (TGX 1740-2F) was reported to have a longer maturity period than Gazelle. Soybean can be grouped into early, medium to late maturing varieties and farmers prefer high yielding, early maturing varieties that ensure food security (Mahasi *et. al* 2011). Since cultivar TGx 1740-2F (SB19) was reported to take longer to mature, leading to its susceptibility to mid-season droughts, its adoption was not preferred by soybean growing farm households in Meru South Sub-county.

4.1.2.4. Soybean varieties grown and preference

Survey households identified the soybean varieties that they grew; their variety preferences and the reasons thereof (Table 4.7.). The results showed that the four soybean cultivars ever grown by survey farm-households in Meru South were Gazelle (66% of total respondents), SB 19 (26.3%), and SB3 (4%), SB13 (2.6%) and Nyala (1.1%). However, during the last cropping season of 2012/13, the most popularly grown soybean variety was Gazelle (82.2%), with the remainder growing SB19 (14%), SB3 (1.9%), SB 13(1.9%) but with none growing Nyala. The most preferred variety was Gazelle (80.6% of respondents), liked by farmers because of large grains, high yields and early maturity hence easily escaping drought.

Table 4.7 Soybean varieties grown and farmer preferences

Variety name	Varieties ever grown	Variety - Last Crop	Variety preference	Reasons for preference
	****Frequency (% total responses)**	**Frequency (% of N)**	**Frequency (% of N)**	
Gazelle	231 (66)	212(82.2)	175 (80.6)	Early maturing , good yields and large grains
SB 19(TGx 1740-2F)	92 (26.3)	36 (14)	34 (15.7)	Late maturing, high yielding when rains are adequate
SB3 (TGx 1835-10E)	14(4.0)	5 (1.9)	5 (2.3)	Early maturing, high yields when rains are adequate.
SB 13	9 (2.6)	5 (1.9)	3 (1.4)	Early maturing, reasonable yields, drought tolerance
SB23 (Nyala)	4(1.1)	0 (0)	0 (0)	Not preferred
Total	**350 (100)**	**258 (100)**	**217(100)**	

** Responses were not mutually exclusive, figures in parenthesis are percentages.

Although 17% of respondents preferred SB 19 (TGx 1740-2F) because of high yields, farmers reported that the variety was disadvantaged by late maturity hence requiring more rain and may not escape mid-season droughts, which were a common feature in the study area. The 2.3% that preferred SB3 said that it was early maturing and produced high yields when rains were adequate. The 1.4% respondents that preferred SB13 cited early maturity, reasonable yields and drought tolerance as its advantages. These findings revealed that farmers preferred high yielding, early maturing soybean varieties that escape drought.

These results agree with the findings of Mahasi *et al*., (2011) that under western Kenyan conditions, farmers preferred early maturing varieties that escape off-season dry spells and ensure food security. This analysis further recommended cv. TGx 1740- 2F across locations but that breeding for earliness was necessary. The current study therefore recommends such breeding for early maturity for TGX 1740-2F (SB 19) because of its potential benefits in producing large biomass and its ability to improve soil fertility through Biological Nitrogen Fixation. This is likely to enhance its adoption by farmers in Meru South Sub-county. .

4.1.2.5. Land preparation and cropping system for soybean

The most commonly used land preparation method for soybean cultivation was hand hoeing (98.4%), but with 1% using oxen ploughs and 0.6% tractor ploughs (Table 4.8). Soybean was grown mainly as a pure crop (78.2%). The 23.3 % that intercrop, maize (91.5 %) was the main intercrop, followed by sunflowers (2.8%), bananas (2.8%) and coffee (2.8%).

Table 4.8: Land preparation and cropping system for soybean

Agronomic practices	Frequency	% of N
Land preparation method(N=308)		
Hand hoeing	303	98.4
Oxen ploughing	3	1.0
Tractor ploughing	2	0.6
Cropping system (N=304)		
Pure cropping	233	76.6
Intercropping	66	21.7
Pure cropping + Intercropping	5	1.6
Soybean intercrops (N=71)		
Maize	65	91.5
Bananas	2	2.8
Sunflowers	2	2.8
Coffee	2	2.8

Numbers in parenthesis are percentage farmers sampled; responses were not mutually exclusive.

These results show that soybean production in Meru South was mostly non-mechanized, grown as a pure stand (78%) and where intercropping (23%) is practiced, soya bean/maize intercropping is most common system.

Different findings however were reported by Karuga and Gachanja, (2004) that in Western and Nyanza regions of Kenya, soybeans was mostly intercropped (75 %) with maize and sugarcane, with 25% not intercropped. Land scarcity has been reported to be the major reason for soybean production under intercropping system and where land is not limiting, pure stands is the preferred production system (Karuga and Gachanja, 2004). In adition, soybean yields under each production system may also influence the type of farming system used by farmers (Karuga and Gachanja, 2004). In Meru South therefore, soybean crop may have been produced as a pure stand probably due to soybean yields inspite of the land scarcity.

The prevalence of non-mechanized soybean farming in Meru South Sub-county may be a constraint in the expansion of soybean enterprise. Improved access to mechanization has been found to be one realistic solution to enhancing the resources available for land management leading to expedition of crop establishment and allowing more land to be cultivated (Tinsley 2009). Hence mechanized farming should be promoted as one intervention that will lead for increased soybean production in the study area.

4.1.2.6. Manure and fertilizer use.

Nutrients were applied in the form of inorganic fertilizers (37%), manure (31%) and rhizobium (13%) while only about 20% applied no fertilizers (Table 4.9).

The most commonly used inorganic fertilizers was di-ammonium phosphate (DAP) with 80% of respondents using it. Although the majority of farm households (80%) reported application of nutrients on soybean, rates were sub-optimal (Tables 4.10 and 4.11). Application rates for inorganic fertilizers were however reported to be low averaging 79Kg ha^{-1}. In addition, 30% of households applied manure on soybean but most of them (70%) applied at rates of between 0.1 to 4.0 Mt ha^{-1}, which are considerably low, compared to what has been reported elsewhere. Hence low fertilizer and manure use characterized soybean cultivation in Meru South Sub-county. However, fertilizer and manure use at higher rates has been reported to increase productivity of soybean in Kenya. For example, application of Phosphate fertilizers such as di-ammonium phosphate at rates of 125Kg ha^{-1} (Mathu *et al.,* 2010) and 250 kg ha^{-1} (Mahasi *et al.*, 2011) was found to increased soybean yields.

Table 4.9: Types of nutrients applied to soybean in Meru South Sub-county

Soil Nutrient used (N=298)	Frequency	(% of total responses)
Manure	119	29.9
Inorganic fertilizer	151	38.0
Rhizobium	49	12.3
None	78	19.6
Type of inorganic fertilizer used (N=151)		
DAP	120	79.5
CAN	9	6.0
17:17:17	6	4.0
Mavuno	5	3.3
Foliar Feed	3	2.0
20:20:0	3	2.0
23:23:0	3	2.0
25:5:5	2	1.3

Numbers in parenthesis are percentage farmers sampled; responses were not mutually exclusive.

Table 4.10: Inorganic fertilizer application rates on soybean in Meru South Sub-County during the short rains October/November 2013**.**

Inorganic fertilizer (DAP) Kgha-1	**Frequency**	**% of N**
1-20	25	18.8
21-40	20	15.0
41-60	21	15.8
61-80	14	10.5
81-100	21	15.8
101-120	5	3.8
121-140	3	2.3
141-160	2	1.5
161-180	3	2.3
181-200	5	3.8
201-220	14	10.5
Mean 79 kg ha^{-1}	**133(N)**	**100**

Table 4.11: Manure application rates on soybean crop by survey households in Meru South Sub-county during the short rains October/November 2013.

MANURE		
Manure (tons ha-1)	**Frequency**	**% of N**
0.1-1	30	30.3
1.1-2	22	22.2
2.1-3	12	12.1
3.1-4	5	5.1
4.1-5	7	7.1
>5.1	23	23.2
Total	**99 (N)**	**100**

Increased grain yield has been reported to be due to increased nodulation and biomass production (Vanlauwe *et al.*, 2003). Similarly, soil amendments with phosphate, potassium and sculpture fertilizers have been found to increase soybean productivity in Meru South (Mugendi *et* al., 2010). In addition, manure application at higher rates of 10 $t \cdot ha^{-1}$ or 5 $t \cdot ha^{-1}$ combined with lime or mineral P fertilizer has been reported to improve soil conditions, increase nitrogen uptake and soybean grain yields in Eastern Kenya (Verde *et al.*, 2013).

Farm input use in Africa has been reported to be low. A World Bank study by Lele *et al*., (1989) showed that a huge diversity in farm input use in Africa was related to the cost to benefit ratio of farm input use in relation to the crops grown and differences in performance. Many respondents in the present study identified low farm incomes against high farm input costs as the reason for low utilization of manure and inorganic fertilizers in soybean cultivation. Consequently the low fertilizer and manure use observed in soybean in Meru South may be related to the low benefit: cost ratio that farmers attach to farm input use in relation to soybean cultivation. Consequently, this has led to poor soil fertility management which may be the likely cause of the depressed yields of soybean of 283 kg ha^{-1} (Table 4.14) in the study area.

4.1.2.7. Soybean Pests and Diseases

Table 4.12 shows the prevalence of soybean pests and diseases among survey households. Most farmers sampled (60%) experienced pest or disease problems in soybean production. The most prevalent pests were bollworms (31%); aphids (30%) and whiteflies (15%) while diseases were mainly powdery mildew (54%) and root rot (33%).

Table 4.12: Soybean pests and diseases prevalent in Meru South Sub-county

Pest or disease	**Frequency (%)**
Existence of pest or disease problem (n=304)	**Frequency (% of N)**
Yes	183 (60)
No	121 (40)
Total	**304(100)**
Use of crop protection chemicals (n=295)	**Frequency (% of N)**
Yes	134 (45)
No	161(55)
Total	**295(100)**
Pest prevalence (n=169)	**Frequency (% of total responses)**
Bollworms	53 (31.4)
Aphids	51 (30.2)
White flies	26 (15.4)
Cutworms	14(8.3)
Caterpillars	6 (3.6)
Weevils	5 (3.0)
Bean fly	5 (3.0)
Poultry	4 (2.4)
Grasshoppers	3 (1.8)
Crickets	1 (0.6)
Scales	1 (0.6)
Total	**169 (100)**
Disease prevalence (n=24)	**Frequency (% of total responses)**
Powdery Mildew	13 (54.2)
Root Rot	8 (33.3)
Flower abortion	3 (12.5)
Total	**24 (100)**

In spite of these pests and diseases, only 45% of survey respondents used crop protection chemicals. This observation showed that most soybeans in Meru South was affected by various pests and diseases, which require due attention in research and management. This is contrary to the conclusion by Misiko *et al.*, (2008) that soybean being a recent introduction in much of Africa, has fewer disease and insect problems than other grain legumes.

Various pests and diseases in soybean have been reported to be of economic importance in Africa. The diseases include rust, red leaf blotch, frog-eye leaf spot, bacterial pustule, bacterial blight, and soybean mosaic virus, while pests include pod (stink bugs) and foliage feeders, bean flies and nematodes (IITA, 2009)

Consequently due attention should be given to soybean pest and disease control and management in Meru South as they impact on soybean productivity and hence profitability of the soybean enterprise.

4.1.2.8. Hectarage under Soybean per farm-household

The area under which farm households planted their soybean crop during the long rains (LR) and short rains (SR) in last cropping season (2012/13) was evaluated (Table **4.13).**

Table 4.13: Hectarage under soybean during the 2012/2013 cropping season in Meru South Sub-County

Hectarage (ha)	**Short rains(SR)**	**Long Rains (LR)**
	Frequency (%)	**Frequency (%)**
0.00 - 0.04	104(40.9)	33(27.5)
0.05 - 0.09	110(43.3)	52(43.3)
0.10 - 0.14	34(3.4)	30(25.0)
0.20 - 0.24	5(2.0)	4(3.3)
0.25 - 0.29	0(0.0)	0(0.0)
0.40 - 0.44	1(0.4)	1(0.8)
Total	**254(100)**	**120(100)**
Mean SR+LR = 0.055ha	**Mean SR =** 0.049ha	**Mean LR = 0**.063ha

The results show that soybean was grown in small parcels ranging from 0.0004 - 0.4 Ha with a mean of 0.05Ha. The area under the crop was skewed towards smaller hectarage with 84 % (SR) and 71% (LR) being grown on less than 0.09Ha.

From these findings, it can be inferred that soybean was not given preference as a crop in allocation of land to its production in both the SR and LR, probably due to lack of assured markets. These results agree with Chianu *et al*., (2008) who reported that soybean cultivation in Kenya is almost wholly undertaken by smallholder (usually non-commercial) farmers. Karuga and Gachanja (2004) similarly reported that Soybeans cultivation in Kenya is almost wholly undertaken by small-scale producers on non-commercial basis and on ¼ to ½ of an acre. Hence the present study similarly shows that soybean cultivation in Meru South was small scale and non-commercial in nature.

4.1.2.9. Soybean yields of survey farm households

The kind of yields farm households got from their soybean crop during the last cropping season (2012/13) was evaluated (Table 4.14).

Table 4.14: Average yields (Kg ha^{-1}) of soybean produced by farm households during the 2012/2013 cropping year in Meru South Sub-County

Grain yield (Kgha-1)	Short Rains (SR)		Long Rains (LR)	
	Frequency	%	Frequency	%
0-199	162	62.8	72	50.4
200-399	37	14.2	46	32.6
400-599	19	7.3	2	1.6
600-799	11	4.5	6	3.9
800-999	29	11.3	17	11.6
Total	**258**	**100**	**142**	**100**
Mean SR+LR= 283	**Mean yield SR = 287 kg ha^{-1}**		**Mean yield LR = 279 kg ha^{-1}**	

Responses were not mutually exclusive

Very low soybean yields of about 283 Kg ha^{-1} were reported by farmers in the study area. Most households (77% of short rains crop and 83% of long rains crop) had yields of below 400 kg ha^{-1}. In spite of the low yields reported, it has been demonstrated that it is possible to obtain soybean yields of 3000 –3600 kg $ha^{-1}$from improved varieties of soybean and with good management practices (Mahasi *et al* ., 2011). In addition, variability in soybean yields has been reported in Kenya, with year to year variation ranging from 715 to 1010 kg ha^{-}1 from the year 2000 to 2010 (**FAOSTAT, 2011**), but with regional variability. Mahasi *et al.*, (2011) while conducting soybean variety trials in Lare, Menegai and Bureti areas of Kenya, obtained yields that varied with site and season ranging from 312 kg ha^{-1} to 1833 kg ha^{-1} for cultivar Gazelle. These observations are in agreement with the report by IITA, (2009) that soybean yields in Tropical Africa are low (<1 t ha^{-1}) and that shortage of fertilizer constrains the ability of some countries to increase production.

The low yields of soybean reported by farmers during the present study in Meru South may be attributed to their farms' low soil fertility status (Abuli *et. al.,* 2012). The major nutrient depletion causes have been found to be nutrient mining through crop harvests and residue removal (Mugendi *et al*., 2003) which is worsened by lack of or inadequate replenishment (Mugendi *et al.,* 2010). .

4.1.3. Soybean seed sources and handling

Soybean producing farm households reported on their sources of soybean seed, how they managed their soybean seed from field to storage, perceived soybean seed viability and how long they stored seed before next planting season.

4.1.3.1. Soybean seed sources

There was no established source of certified soybean seed in Meru South Sub-county; hence seed was sourced mainly from the Ministry of Agriculture (46 %); with farm saved seed being used by 25 % of farmers while 15 % exchanged seed with other farmers. Other soybean seed sources were identified as local markets, KARI, TSBF, KU, ICIPE, KTDA and Catholic Diocese **(**Figure **4.3**).

The Ministry of Agriculture was reported to have initially supplied soybean through the AGRAs Soya and climbing beans project (SOCO) Project and as food relief. SOCO was a three-year project starting from year 2010, and implemented by MOA (agronomy) in partnership with KALRO formerly called KARI (seed production), Farm

Concern International (trading blocs through commercial villages) and Kenyatta University as the lead partner (research).

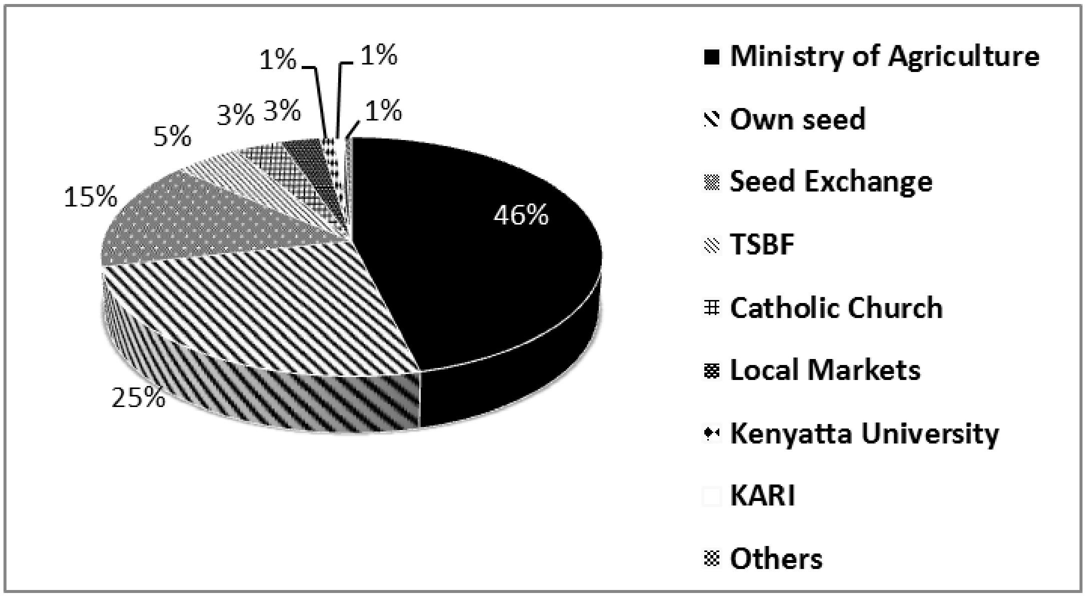

Figure 4.3: Sources of soybean Seed in Meru South Sub-county

The initial soybean seed was supplied by KALRO (KARI) Embu to farmers in ½ to 1 kg seed packs with farmers expected to return double the amount. Soya production being a relatively new enterprise in the Sub-County depended on availability of seed for planting and markets for the produce (MOA report 2013). These findings suggest that although the Ministry of Agriculture was the most important seed source, it was not a reliable source since the SOCO project ended after three years. Consequently, farmers in Meru south solely relied on farm saved seed, seed sourced from markets and seed exchange of uncertified seeds, which may lead to low germination and consequently reduced yields. These results agree with the findings of (Monyo, 2013) who reported that more than 60% of soybean seed in Mozambique is farmers' own-saved seed mainly because seed companies don't show interest in producing self-pollinated crops such as soybean.

4.1.3.2. Soybean Seed management

The study showed that most farmers (99%) did not manage soybean seed crop differently from grain crop (Table. 4.15).

Table 4.15: Seed production and processing in Meru South sub-county

Parameter	Frequency (% of total N)
Seed crop managed separately from grain crop? (N=308)	
Yes	3 (1.0)
No	305 (99.0)
Harvesting stage (N=295)	
At maturity (yellow leaves, leaf drop)	70 (23.7)
When totally dry	225 (76.3)
Threshing methods (N=297)	
Beating with sticks	279 (93.9)
Manually by hand shelling	18 (6.1)
Mechanical threshing	0 (0.0)
Seed/grain drying after threshing (N=296)	
Yes	201 (67.9)
No	95 (32.1)
Drying methods (N=201)	
Sun-drying	201 (100)
Mechanical drying	0 (0.0)
Use of seed dressing (N=300)	
None	265 (88.3)
Commercial seed treatment	29 (9.7)
Herbs	5 (1.7)
Ash	1 (0.3)

The 3 % that indicated some difference in management did so only by selecting vigorous healthy plants for seed. Farmers reported that soybean was mostly harvested when totally dry (76 %) but with 24 % harvesting when leaves are yellow and there is leaf drop. Threshing was done mainly by beating with sticks (94%) and followed by sun drying (100%). Most farmers (88%) did not seed dress before storage but with 10% treat seed with commercial chemicals and 3% using traditional methods such as ash and herbs (mostly Neem leaves).

These findings suggest that failure of farmers to separate grain crop from seed crop meant that maintenance of seed quality by seed field cleaning was not done.

Deterioration of seed due to high temperature and relative humidity prior to harvest (during maturation) in the field is known as field weathering (TeKrony *et al.*, 1980). Hence the common practice of harvesting when totally dry causes seed to be exposed to field weathering leading to loss in seed quality. Moreover, the structure of a soybean seed makes it susceptible to splitting and breakage during mechanical handling, with the extent of breakage varying with the impact force imposed on each individual seed. Undamaged soybean kernels store better than damaged ones hence a grain handling system that minimizes cracking and splitting of soybeans is preferred (Acklin, 1998). Hence threshing with sticks if not done gently leads to mechanical damage of seeds and sun-drying as opposed to drying under shade leads to further loss in seed quality.

Sun drying of soybean after harvest was practiced by most respondents in the study area. Babiker *et al.* (2010) reported that sun drying of seeds greatly reduces seed quality by affecting seedling radicle length, seedling dry weight and speed of germination. The high temperature and ultraviolet radiation from the sun accelerates respiration rate and impose stress to the seed causing ageing which adversely reduce the stored food for use in germination and vigor. Moreover, over heating of seeds caused by sun drying has been reported to cause seed breakage, bleaching, scorching, and discoloration, damage to seed coat and loss of nutritional quality (Desai *et al.*, 1997). Consequently, the sun drying of soybean seeds practiced by farmers in Meru South predisposes seed to ageing.

Although most households in Meru South did not apply seed dressing to soybean the effectiveness of seed dressing undertaken by some households in soybean is debatable and depends on several factors. Kleczewski, (2013), reported that fungicide seed treatments can increase the germination of poor quality seed if the low quality is due to the activity of a fungal pathogen or if seeds are planted into an environment that may delay germination (e.g. cold, wet soils) but not due to seed age or mechanical damage. Moreover, seed treatments with fungicides have also been known to significantly reduce soybean nodulation, hence limiting biological nitrogen fixation (Zilli *et al*., 2009). These reports suggest that if farmers in the study area use good quality seed at planting, it may not be advisable to apply seed treatments due to the negative effect of reducing biological nitrogen fixation.

4.1.3.3. Seed storage and Viability

Majority of farmers (87%) in the study area stored their soybeans within their houses as opposed to 13 % that stored in granaries; mainly due to security related issues (Table 4.16). Seed was mostly stored in synthetic gunny bags (91%), with the other storage materials used being gourds (3.2%), plastic cans (2.4%), khaki bags (2.0%), earthen pots (0.8%) and polythene bags (0.8%). Increases in seed moisture has been known to reduce the longevity of seeds since it is generally known that for every 1% increase in seed moisture content or 10% in eRH reduces the storage life of seeds by approximately 50% (Harrington, 1972). Hence once seeds have been dried to safe moisture levels, it is important to store them in leak-proof containers.

Table 4.16: Soybean seed storage methods in Meru South Sub-county

Parameter	Frequency (% of N)
Seed storage (N=292)	
Within the house	253 (86.6)
Granary	39 (13.4)
Type of storage materials/containers (N=248)	
Gunny bags	225 (90.7)
Gourds	8 (3.2)
Plastic cans	6 (2.4)
Khaki paper bags	5 (2.0)
Earthen pots	2 (0.8)
Polythene bags	2 (0.8)
Type of gunny bags used (N=275)	
Synthetic	270 (98.2)
Sisal	5 (1.8)
Type of plastic container used (N=13)	
Unsealed	10 (76.9)
Sealed	3 (23.1)

Numbers in Parenthesis are Percentages of N

The farmers' seed storage methods in the study area however was mainly in non-air-tight containers, exposing seeds to storage pests and increases in moisture content, leading to reduction in seed longevity.

4.1.3.4. Seed storage period and household perception on farm saved soybean seed viability

The seed storage period before the next planting varied with the number seasons soybean was grown in a year and the growing season whether seed was for short rains planting (SR-October) or long rains planting (LR-March) (Table **4.17**).

Sampled farmers that grew soybean in two seasons in a year (LR+SR) (31.6%) stored their farm saved seed for shorter periods of 1 to 4 months. The farmers that grew soybean only in one season, that is SR (53.6%) and LR (14.8%) stored their seed for longer periods of between 7 to 9 months.

Table 4.17: Soybean seed storage period before next planting season in Meru South Sub-county (N=304)

Seed storage period (months)	With only Short rains (SR) planting	With only Long rains (LR) planting	With both SR+ LR planting (Two seasons per year)	
	Frequency (% of total responses)	Frequency(% of total responses))	SR	LR
1	0(0)	0(0)	3 (0.98)	66(21.71)
2	0(0)	0(0)	32(10.53)	28(9.21)
3	0(0)	0(0)	28(9.21)	1(0.32)
4	0(0)	0(0)	33(10.85)	1(0.32)
5	0(0)	0(0)	0(0)	0(0)
6	0(0)	0(0)	0(0)	0(0)
7	5 (1.6)	6 (1.97)	0(0)	0(0)
8	95 (31.3)	25 (8.22)	0(0)	0(0)
9	63 (20.7)	14 (4.61)	0(0)	0(0)
Total	**163 (53.6)**	**45 (14.8)**	**96 (31.6)**	**96 (31.6)**

Consequently, the longer the seed storage period under ambient conditions, the greater risk of loss in seed viability. Sampled farmers that grew soybean in two seasons in a year (LR+SR) (31.6%) stored their farm saved seed for shorter periods of 1 to 4 months. The farmers that grew soybean only in one season, that is SR (53.6%) and LR (14.8%) stored their seed for longer periods of between 7 to 9 months. Consequently, the longer the seed storage period under ambient conditions, the greater risk of loss in seed viability. Field storage conditions of high humidity and temperature have been known to synergistically accelerate physiological deterioration and pathological damage of soybean seed leading to loss in seed viability and vigor (Dornbos *et al.,* 1989).). This study therefore recommends growing soybeans in the two seasons in a year, as this in addition to proper seed management, would reduce seed storage duration under ambient conditions hence almost eliminating the problem of high seed viability loss in the study area.

The interviewed households reported that the level of soybean seed germination at planting was variable, with most (57 %) reporting good germination, 38 % - average germination and only about 5% having experienced poor soybean germination (Table 4.18).

Table 4.18: Level of field germination of soybean reported by survey households

Field germination (n=300)	Frequency (%)
0-50% (Poor)	14 (4.7)
51-70% (Average)	115 (38.3)
71-100% (Good)	171(57)
Total	**300(100)**

The results obtained in the study shows that there was great variability in the level of germination of soybean seed reported by farmers. The likely reason for this is the wide range of climatic conditions present in Meru South Sub county (MOA, 2013), which may have led to the great variability in seed viability in the survey area due to changes in environmental conditions of temperature and relative humidity as well as differences in seed management practices during production (like mother plant nutrient levels, pest and diseases, mechanical damage as well as exposure to field weathering) and storage conditions.

4.1.4. Soybean marketing and uses

Soybean was reported to be grown mostly for domestic uses (71%); hence soybean was not grown for commercial purposes in the study area. Of the soybean sold, marketing was done mainly in the local markets (12%) with the rest being sold to local consumers (8%), Projects such as SOCO and TSBF (5%) and 4% to brokers. The selling price of soybean mainly (71%) ranged between 41-80 Ksh kg^{-1} (Table 4.19).

Table 4.19: Soybean marketing by farm-households in Meru South Sub-county

Factor	**Frequency (% of total responses)**
Soybean Markets (N=308)	
Domestic use (Not Sold)	220(71)
Local Markets	37 (12)
Local Consumers	24 (8)
Projects	15 (5)
Brokers	12 (4)
Selling Price (Ksh/kg) (N=97)	
1-20	3 (3.1)
21-40	7 (7.2)
41-60	52 (53.6)
61-80	17 (17.5)
81-100	8 (8.2)
101-120	4 (4.1)
121-140	1 (1.0)
141-160	4 (4.1)
181-200	1(1.0)

It has been reported that the farm gate and factory delivery prices for soybeans in Kenya are generally rather low, standing at about 24 and 26kshper kg respectively compared to the common bean prices of 100 Ksh. /kg (MOA,2009). Given that farmers in the study area priced their soybeans at over 40ksh per kg, they may have limited access to the huge vegetable oil and animal feeds industry market in Kenya whose prices are below the market prices in Meru South. Such processors are likely to continue depending on importation of soybean which is cheaper in the international market. Secondly, the soybean prices were considerably lower than the common bean prices hence farmers may opt to grow beans instead of soybean. Therefore there is need for concerted efforts to discourage importation of soybean by enhancing production and development of local markets.

4.1.5. Soybean utilization by farm-households in Meru South

Soybean utilization was assessed in the study. Findings indicated that soybean was mostly used for domestic purposes, with most households (56%) using it in composite flours, 40% for making beverages and only 4% for making soymilk (Fig.4.4).

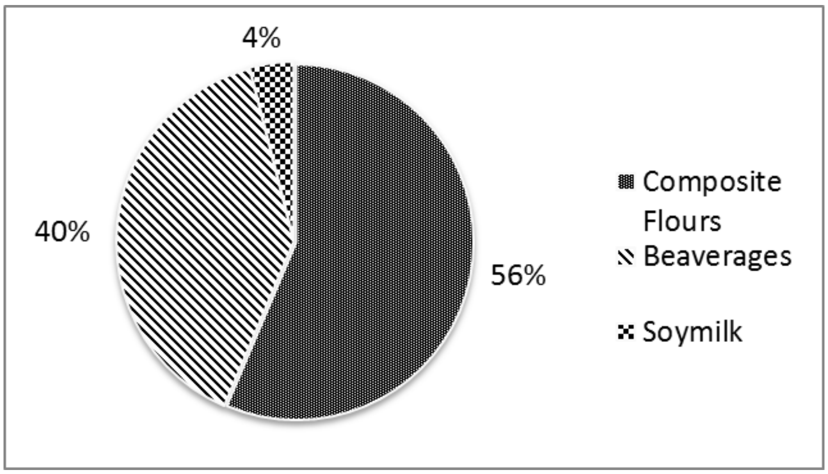

Figure 4.4: Soybean utilization by farm households in Meru South

Soybean has potential for other uses as it is a multipurpose crop grown for edible oil, industrial use, human food, livestock feed and as a source of bio-energy (Myaka *et al*., 2005). Soybean is a crop of a high commercial value as it contains about 40-45% protein, 20-22% oil, 20-26% carbohydrate, a high amount of Ca, P and vitamins (Rahman *et al.*, 2011). Therefore, there were limited uses of soybean in the study area given the multiplicity of uses of soybean; hence there was untapped potential for locally produced soybean which requires concerted development.

4.1.6. Constraints to soybean production

Constraints to soybean cultivation were identified by the survey households (Figure 4.5).

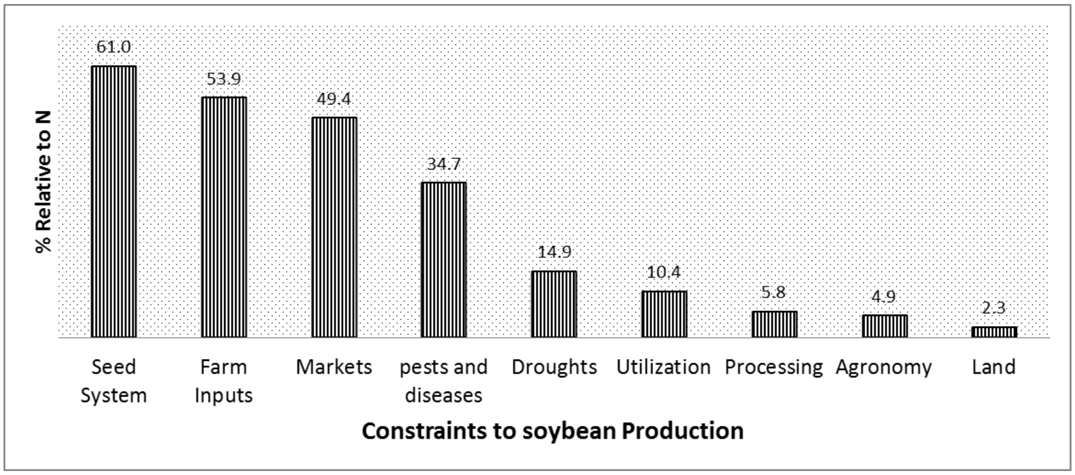

Figure 4.5: Soybean production constraints in Meru South Sub-County

The most critical problems was lack of seed and/or poor quality seed (61%), expensive farm inputs (54%), followed by lack guaranteed markets (49%), pests and diseases (34%), unreliable weather leading to crop failure (15%), lack of sufficient knowledge on utilization and nutritional benefits of soybean (10.4%), cumbersome and costly processing (6%); inadequate agronomic knowledge (5%) and land scarcity (2.3%). In addition soybean was found not to be well incorporated in household diets hence was the least popular among the pulses grown by farmers. These results agree with the findings of Tinsley (2009) on the soybean value chain analysis which described the constraints faced in soybean cultivation in Kenya. The presence of these constraints to a large extent contributes to the small and uneconomic nature of the soybean enterprise and low productivity in Meru south Sub-county. Hence in order to promote the soybean enterprise in the study area, these are the likely entry points, which if adequately addressed would enhance soybean production in Meru South sub-county.

4.1.7. Farm-saved soybean seed quality

The quality of farm saved soybean seed for the 2012/2013 short rains crop sampled from 30 farmers was assessed in this study (Fig. 4.6 and 4.7.)

The soybean seed sampled was mainly of cultivar Gazelle (93.3%), with only 3.3% being SB 19 and SB 13 (3.3%). Results from cultivar Gazelle only were used the subsequent discussion. The results indicated that seed quality components showed a normal distribution. In the four agro-ecological zones (UM2, UM3 LM3and LM4), seed moisture content increased in the higher agro-ecologies (UM2, UM3 LM3 than in the lower one (LM4) which showed the least variability. There was no significant difference in seed quality components (moisture content, percent germination and electrolyte leachate) in agro-ecological zones UM2, UM3 and LM3, with all the seeds showing high germination of between 87 to 99% and low seed leachates conductance averaging 40 µs/cm/g. Only soybean seed obtained from farmers in the lower zone LM4 showed significantly lower seed moisture content of (6.3%), lowest germination percent of (57%) and highest electrical conductivity of 79 µs/cm/g. This showed that seed viability and vigor reduced with increased temperatures in the lower agro-ecological zones LM4, as shown by the increase in leachate conductance hence reduction in seed viability and vigor with movement from higher cooler agro-ecological zone (UM2) to lower hotter zone (LM4).

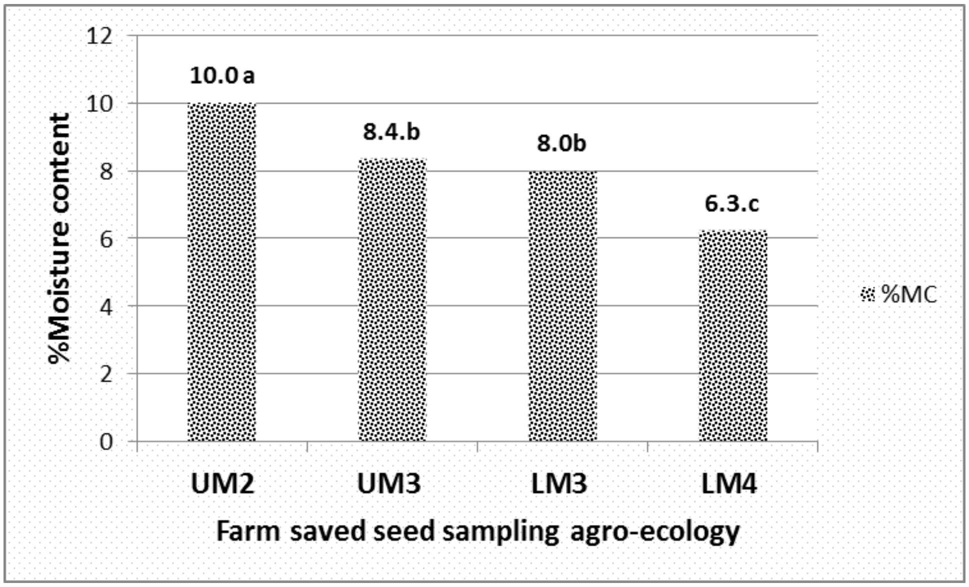

Figure 4.6: Changes in seed moisture content (fwb) of farm saved seed of soybean Gazelle sampled at Upper midland II(UM2), Upper Midlands III(UM3), Lower Midland III(LM3) and Lower Midland IV(LM4) agro-ecologies of Meru South.

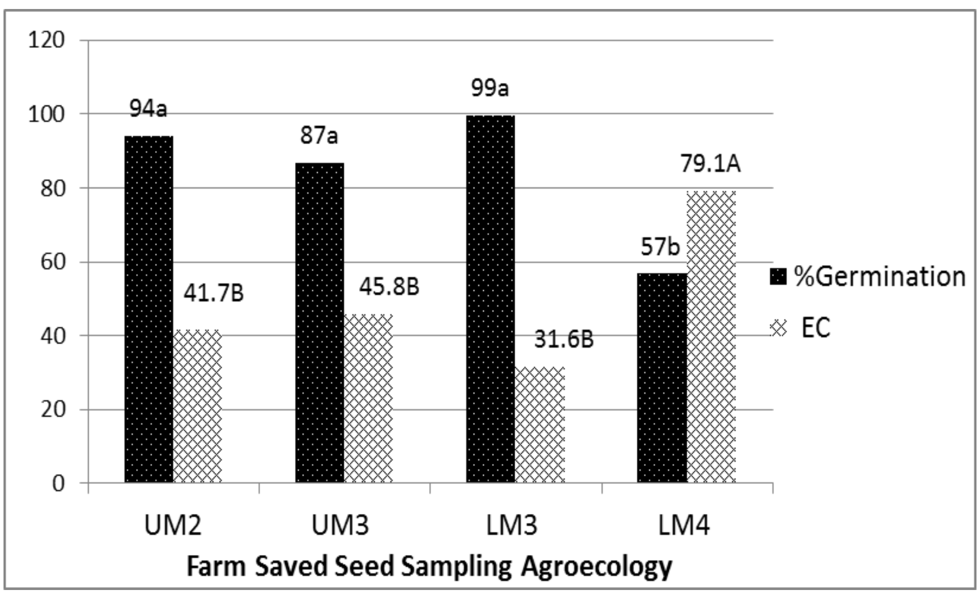

Figure 4.7: Seed leachate conductance (EC) and germination % of farm-saved seed genotype Gazelle sampled at UM2 (Upper midland II (UM2), Upper Midlands III (UM3, Lower Midland III (LM3) and Lower Midland IV (LM4) agro-ecologies of Meru South

These results agree with the report by Gold (2013) that the determinants of seed longevity are storage conditions, seed moisture status, storage temperature, initial seed quality and the species. Moreover, report made by Tinsley (2009), that producing seed in higher elevations of Meru where temperatures are cool enough is a solution to seed viability of soybean in Kenya is verified by these findings. Similar observations have been made in Malawi where soybeans are produced in high altitude above the Rift Valley Escarpment, while in Nigeria the crop is produced in higher altitudes around Jos where seed deterioration is reduced by the lower temperatures (Tinsley, 2009).

4.1.8. Summary of findings on Soybean farm household survey

The findings obtained from the study on soybean production, seed handling and quality in Meru South sub-county, showed that soybean was grown by small scale mixed farmers, with land parcels averaging 0.9 ha but whose major crops are mainly maize, beans, bananas and coffee. The crop was newly introduced mainly by the Ministry of Agriculture and through farmer to farmer extension, with most farmers having less than 4 years' experience in its production. The crop was mainly grown as a pure crop mainly in the short rains (64%) but with 36 % growing in the long rains. Soybean crop was grown on small uneconomic parcels averaging 0.05 ha, without mechanization, giving low yields of about 283 kg ha^{-1}. The most prevalent pests and diseases of soybean were reported as bollworms, aphids, whiteflies, powdery mildew and root rots but only 45% of farmers used crop protection chemicals. Soybean was reported to be grown principally for domestic consumption due to lack of established markets. Many farmers reported difficulties in processing, lack of sufficient knowledge on utilization and nutritional benefits of soybean as the reasons for limited incorporation of soybean in local diets. The main uses of soybean were limited to use in composite flours and beverages. The most commonly grown soybean variety was Gazelle, preferred because of its early maturity and large grains than the tall, small seeded and late maturing genotype TGX 1740 2F (SB19) which is susceptible to droughts leading to crop failure. Farmers relied on farm saved seed and seed exchange with other farmers because there was no established source of certified seed in Meru South Sub-county. Soybean was harvested by farmers when completely dry, threshed using sticks and sundried. The seed was then then stored mainly in synthetic gunny bags, principally without seed dressing, within farmers houses. This kind of seed handling exposes the seed to field weathering and mechanical damage leading to loss in seed quality. The farmers' seed storage methods being mainly in non-airtight containers, exposed seeds to storage pests and increases in seed moisture leading to reduced longevity. Farmers were found to store their seed for durations ranging from one to nine months before the next planting season depending on the number of seasons they grew soybean in a year. Quality analysis of seed randomly sampled from farmers showed that farm saved seed quality reduced with increased temperatures experienced in the lower altitude agro-ecologies of LM4, with the higher altitude agro-ecologies (UM2 UM3 and LM3) of Chuka and Magumoni Wards having better quality seed than the lower warmer Lower Midlands IV (LM4) of Igambang'ombe. Preferred attributes for soybean varieties included high yields, large grain size and earliness; consequently Gazelle was the most preferred variety as it matured in 3.5 months compared to TGx 1740 2F (SB19) maturing in 4 to 5 months. Farm input use in soybean production was low due to high cost and low commercialization of the crop, hence low yields.

4.2. Objective 2: Effects of storage agro-ecology, storage containers, seed dressing and genotype on soybean seed viability and vigor under ambient conditions.

Evaluation of seed storage under ambient conditions in Meru South Sub-county revealed that, agro-ecological conditions of storage, storage duration, genotypes, type of storage containers and seed dressing had a significant effect on the soybean seed viability and vigor during the 8 months of ambient storage.

4.2.1. Effect of storage duration in different agro-ecologies on germination and vigor of soybean

According to the results, the storage duration of soybean seed had significant influence on all of the studied seed germination and vigor traits ($p \leq 0.05$)

Effect of storage periods on seed leachate conductance (EC), germination percent (GP), Mean Germination time (MGT), Germination Index (GI), time to 50% germination (T50), energy of emergence (EG), speed of emergence (SE) seedling vigor index (SVI) and accelerated ageing -germination % of soybean seeds stored in two agro ecologies Upper Midlands II (UM2) Kirege and Lower Midlands IV (LM4) Igambatuntu are presented in Table 4.20.

Seed storage period showed significant effect on changes in seed moisture content, germination and vigor indices of soybean. Seed moisture content increase varied from 7.43 to as high as 9.36 with more changes in UM2 site than LM4. Germination (GP) being the most important indicator of viability showed significant changes at different storage periods and agro ecologies in the study. Seeds of genotype TGX 1740-2F (SB19) stored in the cooler agro ecology UM2 showed no significant decrease in germination but with Gazelle showing an increase from 93% to 97%.

However seeds stored in the warmer agro ecology - LM4, showed more changes in GP with genotype SB19 decreasing from 97.0 to 92.7%, while Gazelle increased from 93 to 97% and then decreasing to 93.25 by end of storage. This clearly showed a loss in viability with increase in storage period which was more pronounced in the warmer LM4 than in the cooler UM2 agro ecology. These results agree with the findings of Akter *et al*., 2014 that germination percentage (GP) of BARI Soybean-5 decreased with the increase of storage period and Heydecker, (1979) and Heatherly &Elmore, (2004) that the storability of seed is a function of initial seed quality and the storage conditions.

Seed vigor is a measure of the extent of damage that accumulates as viability declines and reveals subtle signs of damage, due to seed membrane deterioration, hence increased leachates. Results of this study showed a significant reduction in soybean seed vigor at LM4 site but not at UM2 as shown by the increased seed leachates (EC) (Table 4.20). The EC of soybean genotype Gazelle increased from 42.97 µs/cm/gat 0-days storage to 50.25 µs/cm/gat end of storage at LM4; while for genotype SB19 increased from 46.53 µs/cm/g to 51 µs/cm/g at LM4 at end of storage (246 days). Moreover, vigor test by germination% after accelerated ageing showed a reduction in vigor for both soybean genotypes at both UM2 and LM4 sites with increase in storage from 0 to 123 days after storage. High positive correlation has been found between field emergence and germination per cent after accelerated ageing in soybean (Usha and Dadlani, 2015)**.** Consequently, it can be inferred that field emergence with increased storage duration reduced in this study.

Table 4.20: Seed germination and vigor of soybean genotype Gazelle and SB19 at UM2 –Kirege and LM4-Igambatuntu as influenced by seed storage duration in Meru South sub-county

Days after storage	MC	EC	GP	MGT	GI	T50	EG	SE	SVI	AA 72h
Gazelle stored at UM2 site										
0	7.43c	42.97b	93.50b	4.71a	10.47c	4.13a	0.42b	84.19b	811.0c	45.66a
123	9.36a	47.84a	97.66a	3.08b	16.17b	2.55b	0.96a	100a	992.2b	24.50b
246	8.93b	44.96b	97.08a	2.37c	22.23a	1.89c	0.96a	99.19a	1186.2a	-
$LSD_{0.05}$	0.04	2.77	2.67	0.17	0.97	0.16	0.065	4.74	100.25	8.02
.r^2	0.99	0.81	0.44	0.95	0.95	0.95	0.91	0.66	0.69	0.81
SB19 stored at UM2 site										
0	7.46c	46.53a	97.00a	4.02a	13.03c	3.45a	0.70b	91.05b	703.85c	83.66a
123	9.35a	47.38a	97.41a	2.69b	18.85b	2.23b	0.97a	100a	1324.7b	34.66b
246	8.66b	47.37a	96.83a	1.90c	27.53a	1.42c	0.96a	100a	1498.4a	-
$LSD_{0.05}$	0.06	2.49	1.58	0.15	1.21	0.17	0.03	3.95	94.11	7.78
r^2	0.99	0.76	0.32	0.95	0.94	0.94	0.92	0.57	0.90	0.93
Gazelle stored at LM4 site										
0	7.43C	42.97b	93.10b	4.71a	10.47c	4.13a	0.42b	84.19b	811.0c	45.66a
123	8.23a	48.55a	97.0a	3.02b	16.57b	2.51b	0.96a	99.91a	933.9b	13.08b
246	7.61b	50.25a	93.25b	2.07c	24.37a	1.57c	0.93a	100a	1193.6a	-
$LSD_{0.05}$	0.08	2.61	3.31	0.17	1.18	0.15	0.07	4.73	104.82	8.02
r^2	0.94	0.78	0.45	0.96	0.93	0.96	0.89	0.66	0.72	0.89
SB 19 stored at LM4 site										
0	7.46c	46.53b	97.00a	4.02a	13.03c	3.45a	0.70c	91.05b	703.8b	83.66a
123	8.08a	51.75a	96.41a	2.46b	20.44b	1.93b	0.96a	100a	1362.3a	55.58b
246	7.71b	50.89a	92.75b	1.88c	26.95a	1.40c	0.92b	100a	1330.1a	-
$LSD_{0.05}$	0.06	2.45	2.07	0.16	1.32	0.18	0.03	3.95	117.38	5.78
r^2	0.97	0.80	0.47	0.95	0.92	0.94	0.92	0.57	0.82	0.95

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

EC-Electrical conductivity, GP-germination percent, Mean Germination time (MGT), Germination Index(GI), time to 50% germination (T50), energy of emergence(EG), speed of emergence (SE) seedling vigor index (SVI) andAA 72h-accelerated ageing germination %72h, 41^0C

Growth tests are based on the principle that vigorous seeds grow at a faster rate than poor vigor seeds even under favorable environments hence the rapidity of growth of the seedling will give an indication of seed vigor level (Gupta, 1993).Results of this study revealed that seedlings growth rate vigor indices increased with increase in seed storage duration, with mean germination time(MGT) and time to 50% germination (T50) significantly decreasing; while the germination index (GI), Energy of germination (EG), speed of emergence (SE) and Seedling Vigor Index (SVI) significantly increasing .

These results are contrary to the findings of Rastegar *et al*., (2011), who observed that under laboratory conditions, accelerated ageing of soybean significantly decreased germination indices. However, the degree of damage of soybean seed and the ability of seed to resist the negative consequences of aging during accelerated and natural aging has been found to be influenced by the duration of aging, type of storage and characteristics of soybean varieties (Balešević-Tubić *et al.,* 2011). It is probable then that in this present study, the degree of damage under natural aging in the study area may not have been high enough to show reduction seedling vigor. However, the biochemical vigor test of seed membrane leachate conductance (electrical conductivity) and accelerated ageing test positively showed a reduction in seed vigor with increase in storage duration.

4.2.2. Effects storage at different agro-ecologies on seed quality of soybean.

The influence seed storage agro-ecology of Meru South Sub-county on changes in seed germination and vigor of soybean genotypes with results of statistical significance are presented on Table 4.21 (Gazelle) and Table 4.22 (TGx 1740 2F).

Table 4.21: Effects of seed storage agro-ecology and storage period on studied seed quality traits of soybean Gazelle during storage at UM2 Kirege and LM4 Igambatuntu

	%Moisture Content at			**Electrical conductivity**			**Germination % at**		
Agro- ecology	**0 Day storage**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
UM2	7.43a	9.36a	8.93a	42.98a	47.84a	44.96b	93.50 a	97.66a	97.08a
LM4	7.43a	8.23b	7.61b	42.98a	48.55a	50.25a	93.50 a	97.00a	93.25b
$LSD_{0.05}$	2.871	0.02	0.02	2.119	2.076	1.957	2.567	2.048	2.123
r^2	1	0.99	0.99	0.69	0.9	0.81	0.46	0.2	0.53

	Mean Germination Time			**Germination Index at**			**Time to 50% Germination at**		
Agro- ecology	**0 Day storage**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
UM2	4.71a	3.08a	2.37a	10.48a	16.17a	22.23b	4.14a	2.55a	1.89a
LM4	4.71a	3.02a	2.07b	10.48a	16.57a	24.37a	4.14a	2.51a	1.57b
$LSD_{0.05}$	0.199	0.065	0.118	0.821	0.496	1.428	0.198	0.051	0.131
r^2	0.75	0.65	0.71	0.71	0.56	0.63	0.77	0.6	0.7

	Energy of Emergence at			**Speed of Emergence at**			**Seedling Vigor Index at**		
Agro- ecology	**0 Day storage**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246DAS**
UM2	0.42a	0.96a	0.96a	84.19 a	100.0a	99.91a	811.01a	992.24a	1186.26a
LM4	0.42a	0.96a	0.93b	84.19 a	99.91a	100.0a	811.01a	933.98a	1193.66a
$LSD_{0.05}$	0.06	0.02	0.02	5.99	0.17	0.17	34.08	81.42	117.69
r^2	0.82	0.34	0.54	0.47	0.25	0.25	0.76	0.67	0.43

	Accelerated ageing (72h, 41^0C) Germination percent at	
Agro ecology	**0 Days after storage**	**123 Days after storage**
UM2	45.66a	24.50a
LM4	45.66a	13.08b
$LSD_{0.05}$	10.27	9.493
r^2	0.69	0.64

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$);

DAS = Days after storage, UM2-Upper Midland 2 and LM4=Lower Midland 4

Table 4.22: Effects of seed storage agro-ecology and storage period on studied seed quality traits of soybean genotype SB19 (TGx 1740-2F) during storage at UM2 (Kirege) and LM4 (Igambatuntu)

	%Moisture Content at			**Electrical conductivity at**			**Germination % at**		
Agro- ecology	**0 Day storage**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
UM2	7.47a	9.35a	8.6a	46.53a	47.38b	47.37b	97.00a	97.41a	96.83a
LM4	7.47a	8.08b	7.71b	46.53a	51.75a	50.89a	97.00a	96.41a	92.75b
$LSD_{0.05}$	2.871	0.056	0.016	2.119	2.433	2.1434	2.567	1.23	2.061
r^2	1	0.99	0.99	0.69	0.84	0.64	0.46	0.3	0.46

	Mean Germination Time			**Germination Index at**			**Time to 50% Germination at**		
Agro- ecology	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
UM2	4.02a	2.69a	1.90a	13.04a	18.85b	27.53a	3.46a	2.23a	1.42a
LM4	4.02a	2.47b	1.88a	13.04a	20.44a	26.95a	3.46a	1.93b	1.40a
$LSD_{0.05}$	0.199	0.086	0.081	0.821	0.644	1.591	0.198	0.1089	0.055
r^2	0.75	0.55	0.29	0.71	0.57	0.34	0.77	0.55	0.35

	Energy of Emergence at			**Speed of Emergence at**			**Seedling Vigor Index at**		
Agro- ecology	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246DAS**
UM2	0.70a	0.97a	0.96a	91.06a	100.0a	100a	703.85a	1324.7 a	1498.39a
LM4	0.70a	0.96a	0.92b	91.06a	100.0a	100a	703.85a	1362.3a	1330.16b
$LSD_{0.05}$	0.067	0.013	0.0208	5.992	0	0	34.084	96.22	106.46
r^2	0.82	0.3	0.45	0.47	0	0	0.76	0.51	0.41

	Accelerated ageing (72h, 41^{0}C) Germination percent at	
Agro-ecology	**0 Days after storage**	**123 Days after storage**
UM2	83.66a	34.67b
LM4	83.66a	55.58a
$LSD_{0.05}$	3.558	7.622
r^2	0.48	0.85

Values followed by thesame letter(s) in each column are not significantly different ($p\leq0.05$)
DAS = Days after storage, UM2-Upper Midland 2 and LM4=Lower Midland 4

From the analysis of presented data it is clear that the analyzed seed quality traits varied amongst tested genotypes and storage agro ecologies with statistically highly significant differences ($P \leq 0.05$).

Changes in seed moisture in storage - Prior to storage, the seed moisture content means were 7.43% in Gazelle and 7.47% in TGx 1740 2F (SB19) in both UM2 and LM4 agro ecologies. At 123 and 246 days of storage, seed moisture content values at UM2 remained consistently higher than at LM4, with gazelle having seed moisture of 8.93% at UM2 but 7.61 at LM4, while SB19 had 8.6% (UM2) and 7.71% (LM4) at end of storage (246DAS). These observation suggested that soybean seeds gained more moisture in the cooler agro-ecology UM2 (18-21^{0}C) than in the warmer agro ecology of LM4 (21-24^{0}C) (r^2=0.99). In addition there was greater increase in seed moisture at UM2 in the large seeded soybean cv gazelle (increasing by 1.32%) than in the smaller seeded genotype TGx 1740 2F (increasing 0.89 %) in response to storage environments and duration. Moreover, the average annual temperature at LM4 was 3^{0}C higher than at UM2 on-farm seed storage sites. These observation suggested that soybean seeds gained more moisture in the cooler agro-ecology UM_2(18-21^{0}C) than in the warmer agro ecology of LM4 (21-24^{0}C) (r^2=0.99). In addition there was greater increase in seed moisture at UM2 in the large seeded soybean genotype Gazelle (increasing by 1.32% %) than in the small seeded TGx 1740 2F (increasing 0.89 %) in response to storage environments and duration. Moreover, the average annual temperature at LM4 was 3^{0}C higher than at UM2 on-farm seed storage sites. Germination is the most important function of a seed, being an indicator of its viability and seed worth. There was a significant difference in the percentage of germination due to different storage agro ecologies at 246 days storage (DAS) but not at 0 DAS and

123DAS. (Tables 4.21 and 4.22). Up to 123DAS, soybean seed retained a high germination ranging from 96.4% to 97.6%. However at 246 DAS seed stored in the cooler higher elevations of UM2 –97% (Gazelle) and 96.8% (SB19)) retained higher seed germination than seed stored in the warmer lower elevations of LM4 - 93.2% (Gazelle) and 92.7% (SB19)at the end of storage. This suggests that soybean seed can be stored up to 4 months (123DAS) in both agro-ecologies of Meru south sub county without significant loss in viability as seed germination remained above 96%

On the contrary, Seed vigor differences between UM2 and LM4 agro ecologies were evident at 123 DAS and 246DAS for both soybean genotypes. Seeds of soybean SB19 stored in LM4 had higher seed leachates (51.7 and 50.9µs/cm/g) than at UM2 (47.38 and 47.37µs/cm/g) at 123 DAS and 246 DAS respectively. This was collaborated by the higher SVI of 1498.4 at UM2 than at LM4 (1330.1). Gazelle on the other hand, only had increased seed leachates later at 246DAS at LM4 (50.25µs/cm/g) than UM2 (44.96µs/cm/g). These observations suggested greater decline of seed vigor, indicative of greater deterioration of seed membranes in LM4 than at UM2 and that the small seeded genotype SB19 deteriorated earlier by 123DAS than the large seeded genotype Gazelle. In addition, accelerated ageing germination % for Gazelle showed higher vigor of 24.5% at UM2 than LM4 (13.08%), as well as higher energy of emergence 0.96 (UM2) than at LM4 (0.93) indicating enhanced seed longevity and vigor of seeds stored at UM2 than LM4. On the contrary however at 123DAS, genotype SB19 showed a higher GI, shorter T50, shorter MGT and a higher AA germination% at LM4 than at UM2, indicating greater seedling vigor of this genotype at LM4 than UM2 site (Table 4.22). With regard to Gazelle at 246DAS, the MGT and T50 were also found to be shorter at LM4 than at UM2 (Tables 4.21), meaning soybean seedlings from LM4 were more vigorous as they took shorter time to germinate than those from UM2. Similarly GI indicated higher seedling vigor at LM4 than UM2 sites for Gazelle at 246DAS and for genotype SB19 at 123DAS. As regards SE there were no significant differences between the storage agro ecologies.

The evidence provided here indicates that greater soybean seed viability and integrity of seed membranes was achieved by storing soybean seed in the cooler Upper Midlands II (UM2) than at the warmer Lower Midlands IV(LM4) agro ecology, even though seedling growth rates appeared faster in LM4 than UM2. These results suggest that the changes in seed moisture during storage and the 3^0C higher temperature at LM4 agro-ecology may have caused accelerated seed deterioration than in seed stored in cooler UM2. The soybean seed stored in Upper Midlands II (UM2) - (Kirege) and Lower Midlands IV (LM4) - Igambatuntu were subjected to environmental conditions outside the acceptable limits for seed storage as reported by Harrington (1972) indicating that these on-farm storage environments were inadequate for long-term seed storage. Consequently, seed lots stored under these conditions would have deteriorated, with time but with the seed stored in the warmer LM4 deteriorating faster than seed stored in the cooler high elevation of Kirege (LH2). These results agree with those reported elsewhere that unfavorable storage conditions (high air temperature and high humidity of air) accelerate seed deterioration, leading to losses in seed germination and vigor of stored seed (Burris, 1980; Tewari and Gupta, 1981). Harrington (1972) revealed the three “rules of thumb” that describe seed deterioration in storage: (a) for each 1% decrease in seed moisture content, the life of the seed is doubled; (b) for each 10^OF

(5.5^{O}C) decrease in storage temperature, the life of the seed is doubled (Harrington, 1972); (c) the sum of temperature in degrees Fahrenheit and relative humidity in percentage should not exceed 100, and seeds should not be stored in temperatures above 50^{O} F (10^{O}C) (Harrington, 1960).

The biochemical changes occurring in stored soybean seed in this study may be have accelerated seed deterioration due to inadequate on-farm storage environments under ambient conditions in Meru South. Biochemical changes in the seed during storage have been found to affect seed storability (Smith and Berjak, 1995). Higher levels of lipid peroxidation (Buchvarov and Gantcheff, 1984) and enzymatic activity increases the permeability of seed membranes during storage in inadequate storage environments (Ching and Schoolcraft, 1968). These changes deplete stored food reserves and increase the potential for electrolyte leakage at germination, which can result in higher pathogen loads (Copeland and McDonald, 1995), and eventual death of the seed while in storage.

The results of this study therefore suggest that soybean seed can be stored for 4 months (123DAS) in both UM2 and LM4 without significant reduction in viability but by 8 months of storage, seed deterioration will have taken effect. Hence for quality seed farmers should store soybean seeds before next planting for shorter periods. Secondly, storing soybean seed in cooler higher elevations (UM2) of Kirege maintained seed of higher seed germination and vigor than in the lower warmer elevations (LM4) of Igambatuntu during 8months (246 DAS.) of on farm storage in Meru South Sub-county.

4.2.3. Influence of Genotype on storability of soybean seed

The genotypic differences in storability of soybean genotypes SB 19 (TGx1740- 2F) and Gazelle under ambient conditions were studied. Overall, the effect of genotype was significant ($P \leq 0.05$) for all studied traits over the 8 month storage period (Tables 4.23 and 4.24).

There were significant genotypic differences in storability of soybean seed, with the smaller seeded genotype SB19 (TGx-1740-2F) having significantly higher germination % and seedling vigor across sites and storage durations than the larger seeded genotype Gazelle. Genotype SB19 showed greater seedling growth rates as shown by the significantly shorter MGT and T_{50}, as well as higher germination index, energy of germination, speed of emergence and seedling vigor index than genotype Gazelle. The results of seed vigor test by accelerated ageing, further showed a higher seed vigor of the small seeded genotype SB19 (TGx-1740-2F) (34.7%and 55.6%) than the large seeded genotype Gazelle (24.5% and 13.1%) at the UM2 and LM4 respectively at 123DAS (4 months) of storage. On the contrary, seed vigor test by electrical conductivity (EC) of seed membrane leachates showed the small seeded genotype SB19 to have higher EC of 47.3 and 51.7 µs/cm/g, than Gazelle (44.9 and 48.5 µs/cm/g) at UM2 and LM4 respectively at the end of storage (246 DAS), indicating better integrity of seed membranes was maintained in genotype Gazelle than SB19 during storage (Tables 4.23 and 4.24).

Table 4.23: Comparison of means of studied traits in soybean as influenced by genotype and seed storage period at Upper Midlands II (UM2) Kirege site.

	%Moisture Content at			Electrical conductivity			Germination % at		
Genotype	**0 Day storage**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gazelle	7.43b	9.36a	8.93a	42.98b	47.85a	44.96b	93.5b	97.67a	97.08a
SB19	7.47a	9.35a	8.66b	46.53a	47.38a	47.37a	97.00a	97.42a	96.83a
LSD	2.87	0.07	0.07	2.119	2.736	1.86	2.567	1.271	1.59
r^2	1	0.99	0.99	0.69	0.82	0.82	0.46	0.24	0.22

	Mean Germination Time			Germination Index at			Time to 50% Germination at		
Genotype	**0 Day storage**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gazelle	4.71a	3.08a	2.37a	10.48b	16.17b	22.24b	4.14a	2.56a	1.89a
SB19	4.02b	2.69b	1.91b	13.04a	18.85a	27.53a	3.46b	2.23b	1.42b
$LSD_{0.05}$	0.199	0.061	0.095	0.821	0.414	1.36	0.198	0.072	0.0948
r^2	0.75	0.85	0.84	0.71	0.85	0.78	0.77	0.74	0.85

	Energy of Emergence at			Speed of Emergence at			Seedling Vigor Index at		
Genotype	**0 Day storage**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gazelle	0.42b	0.97a	0.96a	84.19b	100a	99.91a	811.01a	992.24b	1186.26b
SB19	0.70a	0.97a	0.96a	91.06a	100a	100.0a	703.85b	1324.73a	1498.40a
$LSD_{0.05}$	0.067	0.013	0.01	5.99	0	0.17	34.084	81.71	90.951
r^2	0.82	0.35	0.26	0.47	0	0.25	0.76	0.76	0.73

	Accelerated ageing (72h, 41^0C) Germination percent at	
Genotype	**0 Days after storage**	**123 Days after storage**
Gazelle	45.67b	24.5b
SB19 (TGx 1740 2F)	83.67a	34.67a
$LSD_{0.05}$	8.02	4.92
r^2	0.81	0.93

Values followed by thesame letter(s) in each column are not significantly different ($p\leq0.05$)
DAS = Days after storage, UM2-Upper Midland 2 and LM4=Lower Midland 4

Table 4.24: Comparison of means of studied traits in soybean as influenced by genotype and seed storage period at Lower Midlands IV (LM4) Igambatuntu site, Meru South Sub-county.

	%Moisture Content at			**Electrical conductivity**			**Germination % at**		
Genotype	**0 Day storage**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gazelle	7.43b	8.23a	7.61a	42.98b	48.55b	50.25a	93.5 b	97.0 a	93.25a
SB19	7.47a	8.08b	7.71a	46.53a	51.75a	50.89a	97.00 a	96.42a	92.75a
$LSD_{0.05}$	2.871	0.05	0.10	2.12	1.92	2.29	2.56	2.13	2.48
r^2	1	0.96	0.84	0.69	0.9	0.49	0.46	0.17	0.41

	Mean Germination Time			**Germination Index at**			**Time to 50% Germination at**		
Genotype	**0 Day storage**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gazelle	4.71a	3.02a	2.07a	10.48b	16.58b	24.38b	4.14a	2.52a	1.57a
SB19	4.02b	2.47b	1.88b	13.04a	20.48a	26.95a	3.46b	1.93b	1.40b
$LSD_{0.05}$	0.19	0.07	0.11	0.821	0.669	1.745	0.198	0.087	0.104
r^2	0.75	0.88	0.37	0.71	0.83	0.32	0.77	0.86	0.36

	Energy of Emergence at			**Speed of Emergence at**			**Seedling Vigor Index at**		
Genotype	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gazelle	0.42b	0.96a	0.93a	84.19b	99.91a	100a	811.01a	933.98b	1193.66b
SB19	0.70a	0.96a	0.92a	91.06a	100a	100a	703.85b	1362.31a	1330.16a
$LSD_{0.05}$	0.067	0.02	0.03	5.99	0.17	0	34.08	84.60	121.93
r^2	0.82	0.22	0.40	0.47	0.25	0	0.76	0.84	0.34

	Accelerated ageing (72h, 41^0C) Germination percent at	
Soybean Genotype	**0 Days after storage**	**123 Days after storage**
Gazelle	45.66b	13.08b
SB19 (TGx 1740 2F)	83.66a	55.58a
$LSD_{0.05}$	8.02	6.82
r^2	0.81	0.89

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)
DAS = Days after storage, LM4=Lower Midlands IV

These results suggest that the small seeded genotype SB19 resisted better the negative consequences of ageing during 8 months (246DAS) of storage than Genotype Gazelle as shown by the high germination and vigor. However, the higher seed leachates in SB19 may be indicative of permeable seed coat properties. These results are in agreement with the findings of various researchers. Horlings *et al.* (1991) found that the deterioration of soybean seed quality was associated with large seed size and permeable seed coats while Sung, (1992) showed that soybean seed size had a direct effect on seed germination and vigor. Wien and Kueneman (1981) found consistent differences in storability among soybean lines, with some small-seeded lines maintaining more than 50% germinability after 8 months of adverse ambient storage than large seeded ones; while Saranga *et al*., (1998) found that seed vigor was negatively correlated with embryo mass but that large seeds germinated and emerged later than small seeds. The differences observed in thecurrent study on soybean seed viability and vigor highlights variations in potential seed longevity of soybean genotypes. Results demonstrate that seed deterioration and eventual seed storage life may be dependent on genetic factors and seed chemical composition, since the small-seeded genotype TGx-1740-2F (SB19) maintained a higher germination and vigor than the larger seeded genotype Gazelle after 8 months of ambient storage in Meru South Sub-county..

4.2.4. Effect of storage container on storability of soybean seed

Effect of containers during storage on seed viability and vigor traits of soybean genotypes - Gazelle and TGx 1740 2F (SB19) stored at Upper Midlands II (UM2) and Lower Midlands IV (LM4) sites are presented in Table 4.25 (Gazelle at UM2); table 4.26 (SB19 at UM2); Table 4.27 (Gazelle at LM4) and Table 4.28 (SB19 at LM4). Storage containers showed significant effect on studied seed quality traits of soybean at different storage periods in the two agro ecologies. ($P \leq 0.05$).

The type of seed storage containers used significantly influenced seed moisture content at different storage periods in both agro-ecologies. Soybean seed stored in gunny bags gained significantly higher moisture (7.8 – 11.03 %) than seed stored in sealed plastic cans (7.2 – 8.0%) during storage. These results revealed that the sealed plastic cans were effective in maintenance of low seed moisture during 8 months of storage than gunny bags. The rate of absorbance was higher in gunny bag because it is not an air tight container but sealed plastic can is moisture proof. As seed is highly hygroscopic living material; it absorbs moisture from air if it is stored in an environment where relative humidity is higher than seed moisture content (Copeland, 1976). Once seeds have been dried to safe moisture levels, it is important to store them in leak-proof containers. Any increase in moisture content due to container leaks will greatly reduce useful storage life.

Table 4.25: Comparison of means of studied traits in soybean genotype Gazelle as influenced by storage containers and seed storage periods at Upper Midlands II – Kirege site

Storage Container	%Moisture Content at			Electrical conductivity			Germination % at		
	0 Day of storage	123 DAS	246 DAS	0 Day of storage	123 DAS	246 DAS	0 Dayof storage	123 DAS	246 DAS
Gunny Bag	7.43a	10.90a	10.40 a	42.97a	38.58 b	38.54b	93.5a	98.16a	97.33 a
Plastic Can	7.43a	7.83b	7.47 b	42.97a	57.11 a	51.4 a	93.5a	97.16a	96.83 a
$LSD_{0.05}$	0	0	0	2.11	3.40	2.61	2.56	1.90	2.35
r^2	1	1	1	0.59	0.91	0.89	0.49	0.15	0.34

Storage Container	Mean Germination Time			Germination Index at			Time to 50% Germination at		
	0 DAS	123 DAS	246 DAS	0 DAS	123 DAS	246 DAS	0 DAS	123 DAS	246 DAS
Gunny Bag	97.33 a	4.71a	3.10a	10.47a	16.18a	18.97 b	4.13a	2.58a	2.22 a
Plastic Can	96.83 a	4.71a	3.06a	10.47a	16.16a	25.50 a	4.13a	2.53a	1.57 b
$LSD_{0.05}$	2.35	0.19	0.08	0.82	0.52	1.403	0.19	0.077	0.16
r^2	0.34	0.21	0.69	0.45	0.61	0.89	0.36	0.61	0.85

Storage Container	Energy of Emergence at			Speed of Emergence at			Seedling Vigor Index at		
	0 DAS	123 DAS	246 DAS	0 DAS	123 DAS	246 DAS	0 DAS	123 DAS	246 DAS
Gunny Bag	0.42a	0.98 a	0.97 a	84.19a	100 a	99.83 a	811.01a	966.4a	1336.0 a
Plastic Can	0.42a	0.96 b	0.97 a	84.19a	100 a	100 a	811.01a	1018.1a	1036.4 b
$LSD_{0.05}$	0.06	0.01	0.02	5.99	0	0.35	34.08	132.67	104.44
r^2	0.52	0.58	0.44	0.35	0	0.34	0.65	0.35	0.25

	Accelerated ageing (72h, 41^0C) Germination percent at	
Storage Container	0 Days after storage	123 Days after storage
Gunny Bag	45.66a	9.16b
Plastic Can	45.66a	39.83a
$LSD_{0.05}$	16.471	4.727
r^2	0.69	0.97

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)
DAS = Days after storage, UM2-Upper Midland II Agro-ecology

Table 4.26: Comparison of means of studied traits in soybean genotype TGx 1740 2F (SB19) as influenced by storage containers and storage periods at UM2 - Kirege site

	%Moisture Content at			**Electrical conductivity**			**Germination % at**		
Container	**0 Day of storage**	**123 DAS**	**246 DAS**	**0 Day of storage**	**123 DAS**	**246 DAS**	**0 Dayof storage**	**123 DAS**	**246 DAS**
Gunny Bag	7.47a	11.03a	10.13 a	46.53a	40.28b	43.72b	97.0a	98.00a	96.83a
Plastic Can	7.47a	7.67b	7.20b	46.53a	54.48a	51.02a	97.0a	96.83a	96.83a
$LSD_{0.05}$	0	0	0	1.97	4.09	2.28	1.55	2.05	2.261
r^2	1	1	1	0.89	0.8	0.83	0.6	0.36	0.39

	Mean Germination Time			**Germination Index at**			**Time to 50% Germination at**		
Container	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gunny Bag	4.02a	2.67a	1.95 a	13.03a	19.13a	26.48b	3.45a	2.20a	1.46 a
Plastic Can	4.02a	2.71a	1.86 a	13.03a	18.57a	28.58a	3.45a	2.26a	1.40 a
$LSD_{0.05}$	0.23	0.08	0.09	1.43	0.63	1.89	0.28	0.12	0.07
r^2	0.85	0.58	0.58	0.68	0.54	0.53	0.83	0.43	0.55

	Energy of Emergence at			**Speed of Emergence at**			**Seedling Vigor Index at**		
Container	**0 DASe**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gunny Bag	0.70a	0.98a	0.97a	91.06a	100a	100a	703.85a	1323.9a	1491.0 a
Plastic Can	0.70a	0.96a	0.97 a	91.06a	100a	100 a	703.85a	1325.5a	1505.7 a
$LSD_{0.05}$	0.06	0.02	0.02	7.847	0	0	48.36	126.13	122.55
r^2	0.92	0.36	0.40	0.57	0	0	0.81	0.7	0.47

	Accelerated ageing (72h, 41^0C) – germination percent	
Container	**0 Days after storage**	**123 Days after storage**
Gunny Bag	83.66a	15.00b
Plastic Can	83.66a	54.33a
$LSD_{0.05}$	5.707	7.778
r^2	0.48	0.93

Values followed by thesame letter(s) in each column are not significantly different ($p\leq0.05$)
DAS = Days after storage, UM2-Upper Midland II Agro-ecology

Table 4.27: Comparison of means of studied traits in soybean genotype Gazelle as influenced by storage containers and storage periods at LM4 – Igambatuntu site

	%Moisture Content at			Electrical conductivity at			Germination % at		
Container	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gunny Bag	7.43a	8.46a	7.80a	42.97a	40.38b	48.87a	93.50a	96.67a	89.83 b
Plastic Can	7.43a	8.00b	7.4 b	42.97a	56.72a	51.63a	93.50a	97.33a	96.67 a
$LSD_{0.05}$	0	0	0	3.57	3.02	2.89	4.98	4.03	3.92
r^2	1	1	1	0.59	0.9	0.67	0.49	0.27	0.52

	Mean Germination Time at			Germination Index at			Time to 50% Germination at		
Container	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gunny Bag	4.71a	3.16a	2.02 a	10.47a	15.78b	24.50 a	4.13a	2.61a	1.57 a
Plastic Can	4.71a	2.89b	2.11 a	10.47a	17.37a	24.26 a	4.13a	2.42b	1.57 a
$LSD_{0.05}$	0.33	0.08	0.13	0.91	0.80	1.95	0.28	0.06	0.157
r^2	0.21	0.79	0.61	0.45	0.69	0.48	0.36	0.8	0.56

	Energy of Emergence at			Speed of Emergence at			Seedling Vigor Index at		
Container	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gunny Bag	0.42a	0.96a	0.89 b	84.19a	99.83a	100 a	811.01a	1104.0a	1198.19a
Plastic Can	0.42a	0.97a	0.96a	84.19a	100 a	100 a	811.01a	763.94 b	1189.13a
$LSD_{0.05}$	0.13	0.04	0.04	10.78	0.35	0	45.57	93.14	195.52
r^2	0.52	0.36	0.52	0.35	0.34	0	0.65	0.88	0.27

	Accelerated ageing (72h, 41^0C) Germination percent at	
Container	**0 Days after storage**	**123 Days after storage**
Gunny Bag	45.66a	3.16b
Plastic Can	45.66a	23.00a
$LSD_{0.05}$	16.47	3.05
r^2	0.69	0.97

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)
DAS = Days after storage, LM4=Lower Midland IV Agro-ecology

Table 4.28: Comparison of means of studied traits in soybean genotype TGx 1740-2F (SB19) as influenced by seed storage containers and storage periods at LM4 – Igambatuntu site

	%Moisture Content at			Electrical conductivity			Germination % at		
Container	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gunny Bag	7.46a	8.53a	8.10 a	46.53a	43.69b	48.44b	97.0a	97.33a	91.17 a
Plastic Can	7.46a	7.63b	7.33 b	46.53a	59.81 a	53.34a	97.0a	95.50a	94.33 a
$LSD_{0.05}$	0	0	0	1.97	2.319	3.65	1.55	1.97	3.76
r^2	1	1	1	0.89	0.94	0.5	0.6	0.3	0.36

	Mean Germination Time			Germination Index at			Time to 50% Germination at		
Container	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gunny Bag	4.02a	2.47a	1.84 a	13.03a	20.65a	27.31 a	3.45a	1.94a	1.37 b
Plastic Can	4.02a	2.47a	1.92 a	13.03a	20.24a	26.59 a	3.45a	1.92a	1.44 a
$LSD_{0.05}$	0.23	0.11	0.11	1.43	0.83	1.92	0.28	0.14	0.06
r^2	0.85	0.68	0.52	0.68	0.73	0.68	0.83	0.64	0.71

	Energy of Emergence at			Speed of Emergence at			Seedling Vigor Index at		
Container	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Gunny Bag	0.70a	0.97a	0.92 a	91.05a	100a	100 a	703.85a	1443.00a	1250.69a
Plastic Can	0.70a	0.96a	0.94 a	91.05a	100a	100a	703.85a	1281.63a	1409.62a
$LSD_{0.05}$	0.06	0.02	0.038	7.847	0	0.0	48.364	156.84	169.87
r^2	0.92	0.3	0.34	0.57	0	0.0	0.81	0.43	0.45

	Accelerated ageing (72h, 41^0C) Germination percent at	
Container	**0 Days after storage**	**123 Days after storage**
Gunny Bag	83.66a	37.66b
Plastic Can	83.66a	73.50a
LSD	5.707	5.785
r^2	0.48	0.95

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)
DAS = Days after storage, LM4=Lower Midland IV Agro-ecology

The germination percent of soybean seed Genotype Gazelle and SB19 showed no significant difference between storage containers at 4 months (123DAS) of storage in both agro-ecologies (LM4 and UM2), maintaining a high germination of between 95% to 98% . However after 8 months of storage, storage containers had significantly influenced the degree of deterioration in the warmer agro-ecology LM4 Igambatuntu (21.0- 23.5 ^{0}C) but had no significant difference in the cooler agro-ecology UM2 Kirege (18.2-20.6 ^{0}C). In LM4, sealed plastic cans maintained a significantly higher seed germination of 94-97% than gunny bags with 89.8 to 91% at the end of 8 months storage. These results suggest that storing soybean seed in the cooler Upper Midlands II, whether in Gunny bags or sealed plastic cans made no significant difference since germination was above 97% in both storage containers, however at LM4, sealed plastic cans retained higher germination than gunny bags. Vigor tests are known to provide a better estimation of field emergence than germination tests when sub-optimal conditions exist (McDonald Jr. 1980).

Seed storage containers had significant effect on seedling vigor of soybean during storage for some genotypes and sites but not in others. Seed Stored in plastic cans retained higher seedling vigor, as shown by the shorter Time to 50% germination (T50) for Gazelle at UM2 of 1.57 and then seed in gunny bags (2.22) and higher germination index of seed stored in plastic cans than gunny bags for genotype Gazelle at both UM2 and LM4 sites. Other indices EG, SE and SVI showed no significant difference over all treatments at end of storage. Seed vigor was significantly affected by seed storage containers. Seed vigor test by accelerated ageing - germination percent at 123DAS for both soybean genotypes showed that sealed plastic cans maintained significantly higher seed vigor than gunny bags in both storage agro-ecologies (Figure 4.8).

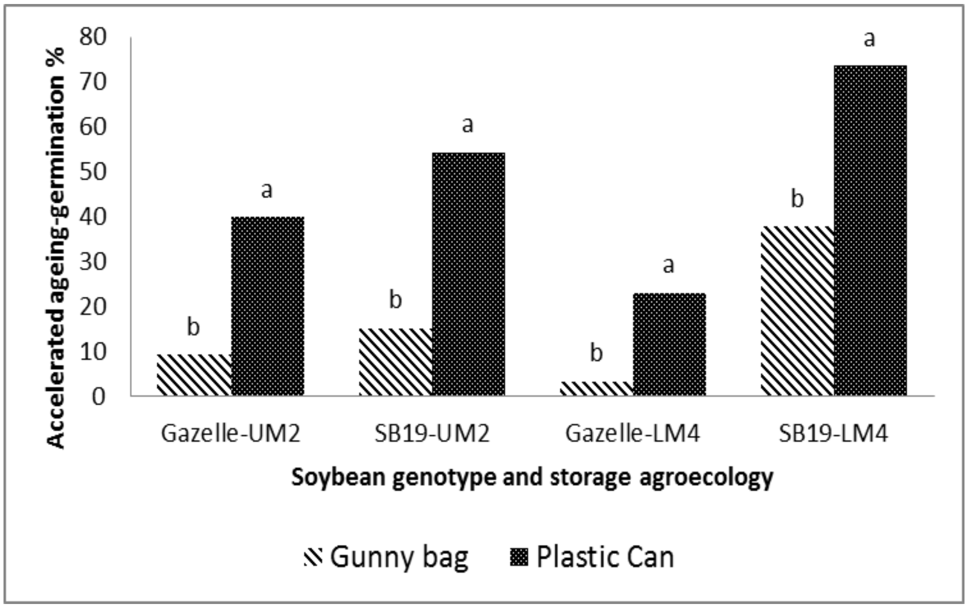

Figure 4.8 Influence of storage containers – sealed plastic cans and gunny bags on soybean genotypes Gazelle and SB19 seed vigor by accelerated ageing - germination percent at 123 days after storage at Upper Midland II (UM2) and Lower Midland IV (LM4) storage sites.

Electrical conductivity (EC) test of seed leachates provides a quick decision about seed vigor. High EC of seed is an indicator of seed membrane deterioration of lower quality seed. Storage containers had significant effect on EC of soybean seed (Tables 4.25, 4.26, 4.27 and 4.28). Initial EC of seed leachate was 42.9 µS/ cm/g for Gazelle and 46.5 µS/ cm/g for SB 19 for all containers in both storage agro ecologies at 0-day storage. During storage 123 and 246DAS, soybean seed stored in sealed plastic cans had significantly higher seed membrane leachate conductance of 51.0 - 59.8 µs/cm/g than seed stored in gunny bags with 38.5-48.9µs/cm/g. These results are contrary to the findings of Akter *et al.*, (2014) who found that seed stored in cloth bags, which had greater moisture absorption had higher leachates than seed stored in metal cans.

In the current study, the probable reasons for the higher seed leachates shown in plastic cans may have been due to higher temperature inside the sealed cans that could have caused increased leakiness as opposed to gunny bags which were likely to have had better aeration and cooler temperatures. However, because vigor stress test by accelerated ageing (Fig. 4.8), and seedling vigor tests showed that plastic cans retained higher vigor than seed stored in gunny bags it can be inferred that seed in gunny bags, having been exposed to fluctuations in seed moisture and temperature changes under ambient conditions eventually will deteriorate more than that stored in sealed plastic cans.

The results of this study are in agreement with the findings of Pessu *et al*., 2005; Monira *et al*., (2012) and Akter *et al.,* (2014) who found that storing soybean seed in sealed polythene bags and tin containers under ambient conditions preserved the seed better than storing in cloth bags or in bamboo bins and clay pots.

The results of the current study clearly show that sealed plastic cans had the effect of retaining seed of low moisture contents and higher seed germination and vigor than storing in gunny bags. Storing soybean seed in agro-ecologies with cooler temperatures as well as excluding seed moisture by using sealed plastic cans enhanced soybean seed longevity and vigor under ambient conditions of Meru South, Tharaka Nithi County, Kenya.

4.2.5. Effect of Seed dressing on germination and vigor of soybean.

The results show that there were significant effects of seed dressing with ash and Apron star on the studied traits of soybean genotypes during storage ($P \leq 0.05$) (Table 4.29 for Gazelle at UM2; Table 4.30 for SB19 at UM2; Table 4.31 for Gazelle at LM4 and Table 4.32 for SB 19 at LM4).

Seed dressing effect on soybean seed moisture during storage was significant but varied with site. Seed of genotype Gazelle and SB19 treated with Wood Ash (*Ash*) and stored at the warmer Lower Midlands IV (LM4) agro-ecology had the lowest seed moisture than control, followed by Apron star® 42 WS (*Apron Star*) at 246 days after storage (DAS) . At the cooler Upper Midlands II (UM2) seed storage site, *Ash* and *Apron Star* treated seeds of genotype Gazelle had lower moisture at 123 DAS, but higher moisture contents than control at 246 DAS in both soybean genotypes (Gazelle and SB19). *Ash* therefore lowered seed moisture more than *Apron star* in storage.

Seed treatment with *Ash a*nd *Apron star* had no significant effect on seed germination during the 246 days of storage. However, seed vigor test by electrical conductivity (EC) showed increased seed leachates for genotype Gazelle dressed with *Ash* and *Apron star* at LM4 (123DAS) and with seed dressed with Apron Star at LM4 and UM2 after 246 DAS. At LM4 ash had no effect on seed leachates for Gazelle at the end of storage (246DAS).

Table 4.29: Comparison of means of studied germination and vigor traits of soybean genotype Gazelle as influenced by seed dressing and storage periods at Upper Midlands II (UM2)-Kirege site

	%Moisture Content at			Electrical conductivity			Germination % at		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	7.4b	9.45a	8.8c	47.91a	45.79a	42.09b	97.0 a	97.75a	96.0a
Apron star	7.4b	9.25c	9.1a	41.44b	49.65a	48.33a	88.0b	97.75a	97.5a
Ash	7.5a	9.4b	8.9b	39.58b	48.09a	44.49ab	95.5a	97.50 a	97.5a
$LSD_{0.05}$	0	0	0	5.33	5.07	3.91	7.44	2.84	3.514
r^2	1	1	1	0.59	0.91	0.89	0.49	0.15	0.34

	Mean Germination Time			Germination Index at			Time to 50% Germination at		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	4.57a	3.22a	2.45a	11.20a	15.15b	20.86b	4.03a	2.65a	1.96a
Apron star	4.81a	3.02b	2.31a	9.63b	16.5a	22.73ab	4.07a	2.51b	1.83a
Ash	4.75a	2.99b	2.35a	10.60ab	16.52a	23.12a	4.31a	2.49b	1.88a
$LSD_{0.05}$	0.5056	0.126	0.193	1.3712	0.782	2.095	0.4203	0.114	0.24
r^2	0.21	0.69	0.88	0.45	0.61	0.89	0.36	0.61	0.85

	Energy of Emergence at			Speed of Emergence at			Seedling Vigor Index at		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	0.51a	0.95a	0.96a	81.59a	100.0a	100.0a	848.76a	893.83a	1162.2a
Apron star	0.47ab	0.98a	0.97a	78.34a	100.0a	100.0a	757.20b	1071.60a	1148.5a
Ash	0.29b	0.97a	0.97a	92.65a	100.0a	99.75a	827.06a	1011.29a	1248.2a
$LSD_{0.05}$	0.198	0.026	0.029	16.10	0	0.53	68.026	198.02	155.88
r^2	0.52	0.58	0.44	0.35	0	0.34	0.65	0.35	0.85

	Accelerated ageing (72h, 41^0C) Germination percent at	
Seed dressing	**0 Days after storage**	**123 Days after storage**
Control	70.50a	15.75b
Apron star®	58.50a	20.25b
Ash	48.00a	37.50a
$LSD_{0.05}$	24.58	7.055
r^2	0.69	0.97

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)
DAS = Days after storage, UM2=Upper Midlands II Agro-ecology

Table 4.30: Comparison of means of studied germination and vigor traits of soybean genotype TGx 1740-2F(SB19) as influenced by seed dressing and storage periods at Upper Midlands II (UM2)-Kirege site

	%Moisture Content at			**Electrical conductivity**			**Germination % at**		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	7.4b	9.4b	8.6c	53.40a	46.19a	45.50a	97.07a	96.5a	97.0a
Apron star	7.5a	9.2c	8.75a	43.05b	46.19a	48.91a	98.0a	97.0a	97.5a
Ash	7.5a	9.45a	8.65b	43.16b	49.77a	47.70a	96.0a	98.75a	96.0a
$LSD_{0.05}$	2.948	0	3.673	2.948	6.107	3.415	2.323	3.058	3.375
r^2	1	1	1	0.89	0.8	0.83	0.6	0.36	0.39

	Mean Germination Time			**Germination Index at**			**Time to 50% Germination at**		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	3.94b	2.68a	1.90a	13.03ab	18.73a	27.4a	3.29b	2.22a	1.43a
Apron star	3.54c	2.75a	1.97a	15.07a	18.42b	26.64a	2.93b	2.29a	1.47a
Ash	4.58a	2.66a	1.85a	11.01b	18.73ab	28.6a	4.15a	2.18a	1.38a
$LSD_{0.05}$	0.353	0.118	0.141	2.144	0.95	2.831	0.424	0.177	0.104
r^2	0.85	0.58	0.58	0.68	0.54	0.53	0.83	0.43	0.55

	Energy of Emergence at			**Speed of Emergence at**			**Seedling Vigor Index at**		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	0.84a	0.96a	0.97a	92.34ab	100a	100a	764.23a	1082.03b	1531.52a
Apron star	0.82a	0.97a	0.97a	97.47a	100a	100a	713.81a	1448.86a	1451.92a
Ash	0.44b	0.98a	0.96a	83.36b	100a	100a	633.51b	1443.29a	1511.76a
$LSD_{0.05}$	0.08	0.03	0.03	11.71	0	0	72.18	188.25	182.91
r^2	0.92	0.36	0.4	0.57	0	0	0.81	0.7	0.47

	Accelerated ageing (72h) – Germination percent at	
Seed dressing	**0 Days after storage**	**123 Days after storage**
Control	84.00ab	12.25c
Apron star®	78.00b	38.50b
Ash	89.00a	53.25a
$LSD_{0.05}$	8.51	11.61
r^2	0.48	0.93

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

DAS = Days after storage, LM4=Lower Midland IV Agro-ecology

Table 4.31: Comparison of means of studied germination and vigor traits of soybean genotype Gazelle as influenced by seed dressing and storage periods at Lower Midlands IV (LM4) - Igambatuntu site.

	%Moisture Content at			Electrical conductivity			Germination % at		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	7.4b	8.2b	7.9a	47.91a	47.28b	47.41b	97.0 a	95.0a	93.75a
Apron star	7.4b	8.25a	7.5b	41.44b	49.13a	52.05a	88.0b	97.5a	92.25a
Ash	7.5a	8.25a	7.4c	39.58b	49.24a	51.31ab	95.5a	98.3a	93.75a
$LSD_{0.05}$	0	0	0	5.33	4.51	4.32	7.43	6.02	5.86
r^2	1	1	1	0.59	0.9	0.67	0.49	0.27	0.52

	Mean Germination Time			Germination Index at			Time to 50% Germination at		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	458a	3.11a	2.12a	11.20a	15.73b	24.31a	4.03a	2.57a	1.67a
Apron star	4.81a	2.96b	20.5a	9.63b	16.96a	24.11a	4.07a	2.47b	1.52a
Ash	4.75a	3.00ab	20.5a	10.60ab	17.04a	24.72a	4.31a	2.5ab	1.53a
$LSD_{0.05}$	0.50	0.13	0.20	1.37	1.19	2.92	0.42	0.08	0.23
r^2	0.21	0.79	0.61	0.45	0.69	0.48	0.36	0.8	0.56

	Energy of Emergence at			Speed of Emergence at			Seedling Vigor Index at		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	0.51a	0.94a	0.93a	81.59a	99.75a	100a	848.76a	768.06c	1201.6a
Apron star	0.47ab	0.98a	092a	78.34a	100a	100a	757.20b	943.37b	1092.3a
Ash	0.29b	0.97a	0.93a	92.65a	100a	100a	827.06a	1090.52a	1287.0a
$LSD_{0.05}$	0.19	0.06	0.05	16.1	0.53	0	68.02	139.02	291.82
r^2	0.52	0.36	0.52	0.35	0.34	0	0.65	0.88	0.27

	Accelerated ageing (72h) – Germination percent at	
Seed dressing	**0 Days after storage**	**123 Days after storage**
Control	70.50a	31.50b
Apron star®	58.50a	26.96b
Ash	48.00a	43.25a
$LSD_{0.05}$	24.58	4.55
r^2	0.69	0.97

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)
DAS = Days after storage, LM4=Lower Midland IV Agro-ecology

Table 4.32: Comparison of means of studied germination and vigor traits of soybean genotype TGx 1740-2F (SB19) as influenced by seed dressing and storage periods at Lower Midlands IV - Igambatuntu site.

	%Moisture Content at			Electrical conductivity at			Germination % at		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	7.4b	8.05b	7.85a	53.40a	51.7a	49.32a	97.07a	96.5a	94.75a
Apron star	7.5a	8.05b	7.7b	43.05b	51.7a	53.47a	98.0a	96.5a	92.00a
Ash	7.5a	8.15a	7.6c	43.16b	51.84a	49.86a	96.0a	96.25a	91.50a
$LSD_{0.05}$	0	0	0	2.94	3.46	5.46	2.32	2.94	5.61
r^2	1	1	1	0.89	0.94	0.5	0.6	0.3	0.36

	Mean Germination Time at			Germination Index at			Time to 50% Germination at		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	3.94b	2.51a	1.81a	13.03ab	20.10a	29.07a	3.29b	1.98a	1.33b
Apron star	3.54c	2.39a	1.95a	15.07a	21.06a	25.52b	2.93b	1.87a	1.45a
Ash	4.58a	2.50a	1.89a	11.01b	20.18a	26.25ab	4.15a	1.94a	1.42ab
$LSD_{0.05}$	0.35	0.16	0.16	2.14	1.23	2.86	0.42	0.21	0.09
r^2	0.85	0.68	0.52	0.68	0.73	0.68	0.83	0.64	0.71

	Energy of Emergence at			Speed of Emergence at			Seedling Vigor Index at		
Seed dressing	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**	**0 DAS**	**123 DAS**	**246 DAS**
Control	0.84a	0.97a	0.94a	92.34ab	100a	100a	764.23a	1411.23a	1331.92a
Apron star	0.82a	0.96a	0.92a	97.47a	100a	100a	713.81a	1337.17a	1342.59a
Ash	0.44b	0.96a	0.91a	83.36b	100a	100a	633.51b	1338.54a	1315.97a
$LSD_{0.05}$	0.08	0.029	0.05	11.71	0	0	72.18	234.09	253.54
r^2	0.92	0.3	0.34	0.57	0	0	0.81	0.43	0.45

	Accelerated ageing (72h) – Germination percent at	
Genotype	**0 Days after storage**	**123 Days after storage**
Control	84.00ab	42.75b
Apron star®	78.00b	50.25b
Ash	89.00a	73.75a
$LSD_{0.05}$	8.51	8.63
r^2	0.48	0.95

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)
DAS = Days after storage, LM4=Lower Midland IV Agro-ecology

The EC of SB 19 however was not affected by seed dressing with *Ash* and *Apron Star* in both storage sites at 123 and 246DAS. This means that the effect of seed dressing with *Ash* and *Apron star* on seed membrane integrity as indicated by the EC values, varied with genotype, storage environment and length of storage. Seed dressing increased seed membrane leachates, suggesting increased deterioration of seed membranes for cv. Gazelle but not for SB19 (TGx 1740 2F) during storage.

Seedling vigor indices of Mean Germination Time, Energy of Emergence and Speed of Emergence were not significantly affected by seed dressing. However, results revealed that Germination Index (GI) of soybean Gazelle was equally increased when treated with *Ash* and *Apron Star* at UM2 site at 123 and 246DAS, as well as at LM4 site at 123DAS but not at 246DAS. For soybean genotype SB 19, *Ash* treatment had no effect on GI but *Apron Star* increased it at UM2 (123DAS) and at LM4 (246DAS). Seedling vigor was enhanced by *Ash* and *Apron Star* as shown by the shorter time to 50% germination (T50) at 123DAS for soybean Gazelle at UM2 and LM4 but had no effect at 246DAS. Seed dressing SB19 with *Ash* and *Apron Star* had no effect on T50 at 123DAS and 246DAS at UM2. However at LM4, at the end of storage (246DAS) *Apron Star* reduced seedling vigor of SB 19 as shown by increased T50 but ash had no effect during this period.

The seedling vigor Index (SVI) was increased by *Ash* on genotype Gazelle at LM4 more than by *Apron Star* at 123DAS but both had no effect at 246DAS. However, SVI of SB19 was equally increased by *Ash* and *Apron Star* at UM2 storage site after 123DAS but had no effect at end of storage (246DAS) and at LM4 site at 123 and 246DAS. From these findings, seed treatment with wood *Ash* and *Apron Star* had no effect on seed germination but significantly improved seedling vigor mainly up to 4 months (123DAS), however their effectiveness was reduced by 8 months of storage (246DAS). Seed membranes leachates were leakier by application of both ash and Apron star, for genotype Gazelle but not SB 19. These results are contrary to the findings of Wambugu *et al.,* (2009) who found that seed treatment with either Mortein Doom® or cow dung ash in airtight containers equally improved seed vigor in maize as shown by reduction in seed leachates. The results of Seed vigor stress test by accelerated ageing germination percent at 4 months of storage (123DAS) are shown on Figure 4.9.

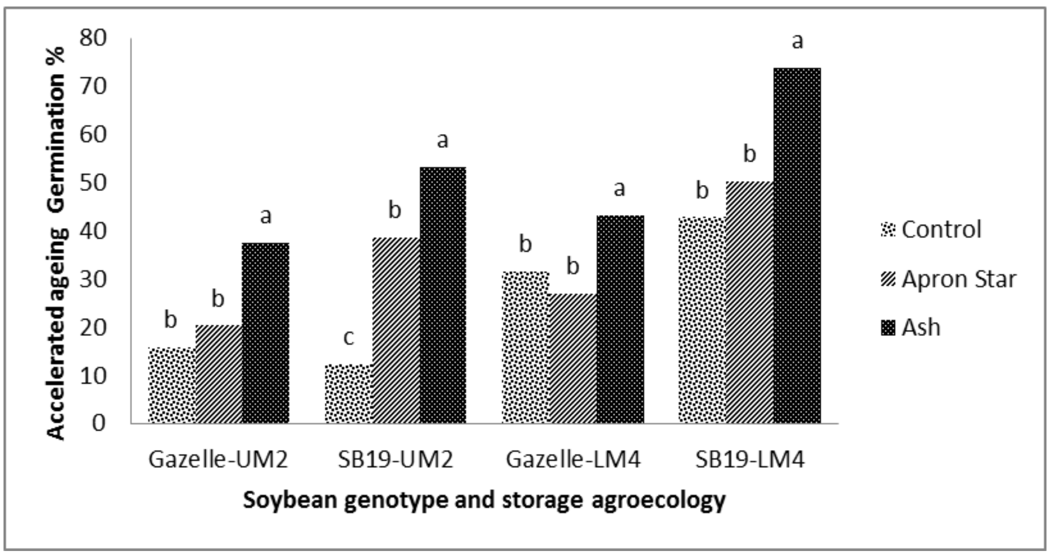

Figure 4.9: Influence of seed dressing with Ash and Apron Star® on soybean genotype Gazelle and SB19 accelerated ageing germination percent at 123 days after storage at Upper Midland II (UM2) and Lower Midland IV (LM4) storage sites in Meru South.

Accelerated ageing germination percent at 123 DAS clearly indicated that seed dressing with *wood Ash* enhanced seed vigor across sites for both genotypes than the commercial seed protectant *Apron star* and control. In addition, seed dressing with Apron star had no effect on seed vigor across sites except for SB19 at UM2 where it enhanced vigor than the control treatment. These results suggest that that seed treatment with *wood Ash* was more effective than Apron Star in enhancing seed vigor of soybean genotype

Gazelle and SB 19 (TGx 1740 2F). These results are in agreement with the findings of Adebisi *et al*., (2004) who showed that soybean seed dressed with fungicides and/or insecticides (Apron Plus, Almithio and Aldrex T) had significantly longer storage life under ambient tropical conditions. In addition, Ash has been found effective in preservation of seeds from storage pests in in cowpea and maize (Adebayo and Ibikunle, 2015) and in soybean (Naito, 1999) and to improve seed longevity and vigor in Maize (Wambugu *et al.,* 2009). However, fungicide seed dressing have been found to increase germination of poor quality seed if the low quality is due to the activity of a fungal pathogen but not due to seed age or mechanical damage (Kleczewski, 2013).

In this present study soybean seed was not attacked by storage pests during storage hence the likely reason for improved seed vigor with Ash treatment, was due to its effect of lowering seed moisture contents. It is probable then that soybean vigor was enhanced by the fungicide seed treatment - Apron star through inhibition of fungal growth and by Ash through its effect of lowering seed moisture during storage at UM2 and LM4 agro ecologies of Meru South sub-county.

4.2.6. Summary of findings on soybean seed storage experiment

Evaluation of soybean seed storage methods for enhancing soybean seed viability, longevity and vigor under ambient conditions in Meru south sub-county revealed that there was a significant reduction in soybean seed viability and vigor during 8 months of ambient storage in Meru South Sub-county. The degree of seed deterioration was affected by seed storage agro-ecology, type of storage containers used and seed dressing applied at storage. The soybean seed stored in the higher and cooler elevations of Kirege (UM2, 1529 m a.s.l.) had higher germination and vigor than the seed stored in the warmer lower elevations of Igambatuntu (LM4,1129 m a.s.l.) at the end of 8 months storage. In addition, storing soybean seed using what farmers commonly use - the synthetic gunny bags, exposed the seed to fluctuations in seed moisture and eventually led to greater reduction in germination and vigor than seed stored in sealed plastic cans. This indicated that any changes in seed viability and vigor may have been due to changes in seed moisture contents, temperature and duration of storage. In addition, genotypic differences in storability of soybean seed was observed, with the small seeded TGx1740-2F exhibiting greater seed longevity and vigor than the larger seeded genotype Gazelle. Seed dressing had no effect on viability but enhanced soybean vigor most probably by inhibiting fungal growth (Apron star®) and by lowering seed moisture (wood ash), with ash being the best treatment in maintenance of vigor by the end of storage. Therefore hermetic storage in sealed plastic cans, seed dressing with wood ash and storage in cooler agro-ecologies was found effective for enhancing soybean seed viability and vigor in Meru South Sub-county.

4.3. Objective 3: Influence of osmo-priming and hydro-priming on soybean seed quality and storability.

The influence of osmo-priming with Polyethylene Glycol 6000 (PEG) and hydro-priming on two soybean genotypes - Gazelle and TGx 1740-2F (SB 19) seed quality and storability was determined. Evaluation of seed priming was done on soybean seed stored for 4 and 8 months in Igambatuntu (LM_4), Meru South Sub-county. In a subsequent experiment, storability of primed seed was evaluated at the Genetic Resource Research Institute Seed Laboratory. Polyethylene glycol (PEG) has large molecular weight hence cannot pass through the cell walls, therefore it can be used for water potential adjustment in germination experiments (Emmerich and Hardgree, 1990) such as priming.

4.3.1. Effect of priming on germination percent of soybean

Data regarding the influence of priming on germination percent of soybean genotype Gazelle and SB 19 (TGx 1740 2F after 4 and 8 months of on-farm storage at Lower Midlands IV, Igambatuntu in Meru South sub-county is reported on (Table 4.33). Analysis of the data revealed that the effects of priming duration and priming concentration on seed germination of soybean after were significant ($p \leq 0.05$). Osmo priming with polyethylene 6000 at -0.5, -1.0 and -1.5 Mpa and hydro-priming with distilled water for 6, 12, 24 and 48 hour durations after both 4 and 8 months storage significantly decreased germination of soybean genotype Gazelle and SB 19. However, priming with PEG -1.5 Mpa on soybean genotype SB19 had no effect compared with control.

Table 4.33: Germination Percent (GP) of soybean genotypes as affected by seed priming Concentration and Priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South

Treatment	**Soybean Cv. Gazelle Germination Percent after**		**Soybean Cv.SB19 Germination Percent after**	
Priming Concentration	4 months storage	8 months storage	4 months storage	8 months storage
Control (Unprimed seed)	95.50a	91.50a	97.50a	94.00a
Distilled water (0Mpa)	81.00b	48.75d	89.62b	86.00b
PEG -0.5 Mpa	57.37d	58.37cd	87.75bc	75.87c
PEG -1.0 Mpa	65.25c	60.87c	87.0bc	84.87b
PEG -1.5 Mpa	66.37c	71.37b	84.37c	88.75ab
LSD $_{0.05}$	**7.77**	**10.00**	**4.88**	**6.97**
Priming Duration hours				
0 h (Unprimed Control)	95.50a	91.50a	97.50a	94.00a
6 h	74.75b	68.87b	84.62c	84.00bc
12 h	81.12b	72.00b	91.00b	85.37bc
24 h	82.37b	71.75b	90.75b	86.75b
48 h	31.75c	26.75c	79.37d	79.37c
LSD $_{0.05}$	**7.77**	**10.00**	**4.88**	**6.97**

Comparison of Germination Percent of primed soybean genotypes

Genotype	**GP mean - 4 months storage**	**GP mean - 8 months storage**
Gazelle	73.10b	66.17b
SB 19 (TGx1740 2 F)	88.65a	85.90a
LSD $_{0.05}$	2.614	3.098

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance or P values

Factors	Gazelle GP after		SB 19 GP after	
	4 months storage	8 months storage	4 months storage	8 months storage
Concentration (C)	`**	`**	`**	`**
Duration (D)	**	**	**	**
C x D	**	**	**	**
Storage Period x C	**	**	**	**
Storage Period x D	NS	NS	NS	NS

NS = Not significant, ** = Significant at ($p \leq 0.05$), PEG=Polyethylene glycol 6000. Mpa=Megapascals, LM4 – Lower Midlands IV Agro-ecology

Priming concentrations reduced germination percent from non-primed control from 92% - 96 % to between 58 and 69% for genotype Gazelle, while SB19 (TGx-1740 2F) was reduced from non-primed control (94-96 %) to between 80 and 88% germination. All priming durations significantly reduced germination percent of soybean genotypes but with 48 h being the most detrimental as it reduced germination percent of genotype Gazelle from 92-96% (control) to 27-32% (primed seed) and for genotype TGx 1740-2F from 94-98% (control) to 76-90% (primed seed). Significant genotypic differences in response to priming was observed with the germination percent of genotype Gazelle being reduced more by priming than genotypeSB19 (TGx 1740 2F).

The results of this study agree with the findings of Ghassemi-Golezani *et al.*, (2011) who found that priming decreased germination percentage of soybean (cv. 'Zan'). Similar findings havealso been reported for barley and corn (Sharif *et al.*, 2006). Contrary findings, however, were reported by Arif *et al.*, (2014) that priming with either water or polyethylene glycol increased germination percent of soybean cv. William-82. Improved germination has also been reported with osmo-priming on soybean cv. Sari, (Rouhi *et al*., (2011), on canola (Basra *et al.*, 2003a) and on Milk thistle seeds (Ghasem *et al*., 2013). The different effects of priming on germination have been attributed to factors such as plant species, water potential from priming factor, priming duration, temperature, vigor and primed seed storage conditions (Mubshar et *al.,* 2006).

4.3.2. Effect of priming on seed leachate conductance (Electrical Conductivity) of soybean.

Influence of priming on seed leachate conductance of soybean genotypes is reported on Table 4.34 and Figure 4.10.

Table 4.34: Electrical conductivity (µs/cm/g) of soybean genotypes as affected by seed priming Concentration and Priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South

Treatment	**Soybean Gazelle Electrical Conductivity (µs/cm/g) after**		**Soybean SB19 Electrical Conductivity (µs/cm/g) after**	
Priming Concentration	4 months storage	8 months storage	4 months storage	8 months storage
Control (Unprimed seed)	38.56 d	44.56 b	45.72 a	45.54 a
Distilled water (0Mpa)	46.39 c	63.57 a	37.77 b	44.76 a
PEG -0.5 Mpa	68.58 a	61.35 a	46.76a	43.24 a
PEG -1.0 Mpa	51.10 b	65.44 a	38.60 b	38.35 b
PEG -1.5 Mpa	53.39 b	61.36 a	35.84 b	42.97 ab
LSD $_{0.05}$	**3.527**	**4.911**	**3.518**	**4.846**
Priming Duration - hours				
0 h (Unprimed Control)	38.56 d	44.56c	45.72 b	45.54 b
6 h	36.31 d	44.83 c	36.37c	36.57 c
12 h	55.30 b	59.84 b	38.58 c	43.58 b
24 h	44.11 c	56.34 b	32.66 d	38.62 c
48 h	83.74 a	90.71 a	51.35 a	50.55 a
LSD $_{0.05}$	**3.527**	**4.911**	**3.518**	**4.846**

Comparison of EC means of primed soybean Genotypes

Genotype	**EC mean -4 months storage**	**EC mean - 8 months storage**
Gazelle	50.98a	59.26a
TGx1740 2 F (SB 19)	40.94b	42.97b
LSD $_{0.05}$	**1.481**	**1.929**

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance or P values

Factors	Gazelle EC after		SB 19 EC after	
	4 months storage	**8 months storage**	**4 months storage**	**8 months storage**
Concentration (C)	**	**	**	**
Duration (D)	**	**	**	**
C x D	**	**	**	**
Storage Period x C	**	**	**	**
Storage Period x D	NS	NS	NS	NS

NS= Not significant, ** = Significant at ($p \leq 0.05$), PEG=Polyethylene glycol 6000; Mpa=Megapascals, LM4 – Lower Midlands IV Agro-ecology.

Electrical Conductivity test (EC) is used to quantify the leakage of electrolytes from the seed coat with respect to age, storage life and other factors i.e. temperature, humidity, soil and water stress (Sadeghi *et al.*, 2011). Priming presumably allows some repairs of damaged seed membrane caused by deterioration (Ruan *et al*., 2002). Moreover, the EC of soybean seed has been found to be a more efficient indicator of field emergence than germination test (Salinas *et al.*, 2010).

The results of this study indicated that different osmotic potentials and priming durations had significant effect on soybean seed electrical conductivity ($p \leq 0.05$).

The effect of priming on seed leachate conductance varied with genotype, pre-priming seed storage duration, priming agent osmotic potential and priming duration.

There were significant genotypic differences on the effect of priming on integrity of seed membranes as shown by the seed leachate conductance. For genotype Gazelle, after both 4 and 8 months of pre-priming seed storage, all priming concentrations and durations (except for 6 hours which was same as control) significantly increased seed membrane leachate conductance, suggesting a reduction in seed vigor (Table 4.34 and figure 4.10).

For soybean genotype TGx 1740-2F (SB 19) however, the response to priming varied with pre-priming seed storage period, priming agent osmotic potential and duration of priming (Table 4.34 and Fig. 4.10). For SB19 after 4 months of seed storage, hydro-priming (0 Mpa) and osmo-priming with PEG -1.0 Mpa and PEG -1.5Mpa as well as for 6h, 12 and 24h priming durations significantly reduced seed membrane leachates, while 48h duration increased it. After 8 months of storage, however, priming of genotype SB 19 with PEG -1.0Mpa and for 6 and 24 h duration significantly reduced seed membrane leachates compared with the control, while 48h duration increased it.

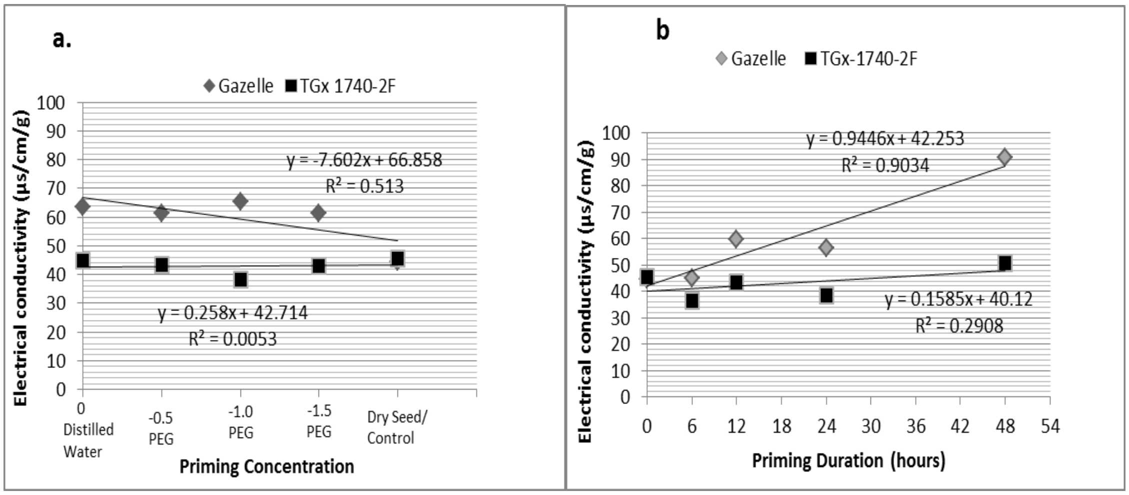

Figure 4.10: Relationship between priming concentration (Fig. a) and priming duration (Fig. b) on electrical conductivity of soybean Gazelle and TGx 1740 2F (SB 19) after 8 months of seed storage.

Moreover, the interactions between C x D for electrical conductivity in both soybean genotypes were highly significant (**$p \leq 0.05$**) and were positively correlated(r = 0.50).

This study revealed significant genotypic differences in response to priming with (a) genotype TGx 1740-2F (SB 19) exhibiting lower EC (40-43µs/cm/g) hence higher seed vigor than Gazelle(51 - 59µs/cm/g); (b) priming was detrimental to genotype Gazelle as it increased seed membrane leachate conductance in all treatments (c) while for genotype SB19, priming for 6 h or 24h (with water , PEG -1.0 and -1.5 Mpa) were the most beneficial treatments as they reduced seed membrane leachates conductance suggesting increased seed vigor. These findings suggest that osmo priming with Polyethylene 6000 and hydro priming improved seed vigor of soybean genotype TGx 17402F (SB19) but not for Gazelle.

The results of this study, with regard to soybean genotype SB19 agree with the findings of Sadeghi *et al.* (2011) who reported the lowest EC of soybean from -1.2 osmotic potential and 12 h seed priming duration treatments. Similarly in rice, Ruan *et al.*, (2002) reported that primed seeds showed better germination and higher vigor level than non- primed. The integrity of seed membranes was sustained more and even improved in genotype SB 19 than Gazelle which appeared more susceptible to damage upon priming. Probably, uncontrolled water uptake, causes seed coat weakening and vital electrolyte may leak which results, in germination interference (Jet *et al.*, 1996). There is a likelihood that genotype Gazelle has a weaker seed coat than SB19 hence increased susceptibility to damage upon priming leading to increased leakage of electrolytes.

4.3.3. Effect of priming on Mean Germination Time of soybean

The results of this study revealed that different osmotic potentials and priming durations had significant effect on mean germination time (MGT)of soybean seeds ($P \leq 0.05$) (Table 4.35).

There were significant genotypic differences between primed and non-primed seed in mean germination time (MGT). After 4 months of storage, priming seeds of genotype Gazelle with -0.5Mpa, -1.0Mpa and for 6h and 24h reduced MGT; while -1.5 Mpa and 12h duration increased it; but hydro-priming had no effect. After seed storage for 8 months, hydro priming genotype Gazelle and osmo-priming with PEG -1.0Mpa, -1.5 Mpa and for 6 and 12h durations increased MGT; while PEG - 0.5Mpa reduced it but with 24 and 48h durations having no effect.

Table 4.35: Mean Germination Time (MGT) of soybean seed as affected by genotype, seed priming Concentration and Priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South

Treatment	**Soybean Gazelle Mean Germination Time (MGT) after**		**Soybean SB19 Mean Germination Time (MGT) after**	
Priming Concentration	4 months storage	8 months storage	4 months storage	8 months storage
Control (Unprimed seed)	3.20b	2.23c	2.20c	1.71c
Distilled water (0Mpa)	3.07bc	2.95a	2.33c	2.37a
PEG -0.5 Mpa	3.00cd	1.42d	2.88a	1.71c
PEG -1.0 Mpa	2.89d	2.61a	2.20c	2.00b
PEG -1.5 Mpa	3.54a	2.79a	2.58b	2.06b
LSD $_{0.05}$	**0.242**	**0.497**	**0.159**	**0.139**
PrimingDuration -hours				
0 h (Unprimed Control)	3.21b	2.23b	2.57ab	1.70b
6 h	2.88c	2.63a	2.24b	2.06a
12 h	3.43a	2.88a	2.64a	1.95a
24 h	2.91c	2.24b	2.41b	2.05a
48 h	3.38ab	2.03b	2.51ab	2.07a
LSD $_{0.05}$	**0.242**	**0.497**	**0.159**	**0.139**

Comparison of MGT of primed soybean genotypes

Genotype	MGT mean - 4 months storage	MGT mean - 8 months storage	Mean
Gazelle	3.12a	2.41a	2.76a
SB 19 (TGx1740 2 F)	2.52b	1.97b	2.24b
LSD $_{0.05}$	0.0718	0.114	0.095

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance

Factors	MGT of soybean Gazelle after		MGT of soybean SB 19 after	
	4 months storage	8 months storage	4 months storage	8 months storage
Concentration (C)	**	**	**	**
Duration (D)	**	**	**	NS
C x D	**	**	**	**
Storage Period x C	**	**	**	**
Storage Period x D	**	**	**	NS

NS= Not significant, ** = Significant at ($p \leq 0.05$); PEG=Polyethylene glycol 6000; Mpa=Megapascals, LM4 – Lower Midlands IV Agro-ecology

For soybean genotype TGx-1740-2F (SB19), after 4 months of storage, PEG -0.5 Mpa and PEG -1.5 Mpa significantly increased MGT, while hydro priming (0Mpa), PEG -1.0Mpa and all priming durations were same as control hence no effect. After 8 months of storage however, all priming durations and concentrations except -0.5MPa (which was same as control) significantly increased MGT of soybean genotype SB19. This meant that priming reduced seed vigor of SB19 at the end of storage than non-primed control. Moreover, the interactions between C x D for MGT in both genotypes were highly significant at ($p<.0001$) for genotype Gazelle and (p = 0.0122) for SB19. The results of this study clearly revealed that the effects of hydro priming and osmo-priming with polyethylene 6000 varied with soybean genotype, priming duration and seed age in storage. Osmo-priming of soybean genotype Gazelle with PEG 6000 at -0.5Mpa, -1.0 Mpa and for 6h and 24h decreased MGT, while for TGX 1740-2F (SB19) hydro priming, PEG 0.5Mpa, -1.0Mpa and -1.5Mpa increased MGT.

These results agree with what has been reported elsewhere that priming treatments can have a negative effect on subsequent germination responses (Hardegree, 1998; Carlos and Cantliffe, 1992) as well as a positive effect. Sadeghi *et al*., (2011) showed that the MGT of soybean cv. 033 decreased when primed with polyethylene glycol 6000 at -1.2Mpa and 12 h duration but not in other treatments. Similarly, Arif *et al*., (2008) reported that priming at osmotic potential of -1.1 MPa and 6 h priming duration resulted in faster and improved emergence and higher grain yield of soybean. In mountain rye, osmo priming with PEG -15 bar for 24h at 15◦C was found to decrease MGT (Ansari and Sharif-Zadeh, 2012). Gharib and Hegazi (2010) for Bean (Phaseolus vulgaris L.) and Rouhi *et al*., (2011) for four grass species showed that priming reduced mean time to germination. The higher germination speed as a result of priming has been attributed to increment in antioxidants in the form of glutathione and ascorbate in seed. These enzymes increase germination speed through reduction of lipid peroxidation activity (Sung and Chiu, 1995).

4.3.4. Effect of priming on Germination Index (GI) of soybean.

The effect of priming on germination index of soybean genotype Gazelle and TGx 1740-2F (SB 19) are reported on Table 4.36.

The results of this study revealed. That different, seed storage duration (seed age), osmotic potentials and priming durations had significant effect on Germination Index (GI) of soybean seeds ($P \leq 0.05$).

Results after 4 months storage showed that osmo-priming of Gazelle with PEG -0.5, -1.0 and -1.5Mpa and for 12h and 48h durations reduced germination index. In addition, hydro-priming and for 6 and 24h duration had no effect on Gazelle. Different effects of priming on GI of soybean genotype SB19 at 4 months seed storage was observed. While hydro-priming increased GI , PEG -0.5Mpa, -1.5Mpa and 48h duration reduced it, but with PEG -1.0Mpa and priming for 6,12,and 24h having no significant effect. However, when seeds were primed after 8 months of ambient storage, hydro priming and osmo-priming in all osmotic potentials and priming durations decreased germination index of both genotype Gazelle and TGx 1740 2F(SB 19). These findings suggest that priming older seeds was detrimental as it reduced index of germination of both soybean genotypes. Comparison of the genotypic differences in response to priming showed that soybean genotype SB 19 (21.57) retained a higher germination index, indicative of higher vigor than Gazelle (13.04). In addition, the interactions between C x D for GI in both genotypes were highly significant gazelle ($p<.0001$) and SB19 ($p= 0.0010$).

Table 4.36: Germination Index (GI) of soybean genotypes as affected by seed priming concentration and priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South.

Treatment	**Soybean Gazelle Germination Index (GI) after**		**Soybean SB19 Germination Index (GI) after**	
Priming Concentration	4 months storage	8 months storage	4 months storage	8 months storage
Control (Unprimed seed)	15.39a	23.41a	19.83b	31.31a
Distilled water (0Mpa)	14.70ab	7.92c	21.62 a	20.07c
PEG -0.5 Mpa	10.38d	9.12c	16.09c	22.44bc
PEG -1.0 Mpa	12.71bc	12.43b	21.24ab	22.70b
PEG -1.5 Mpa	10.59cd	13.68b	17.60c	22.72b
LSD $_{0.05}$	**2.1483**	**3.1941**	**1.6968**	**2.3806**
Priming Duration hours				
0 h (Unprimed Control)	15.39a	23.41a	19.83ab	31.31a
6 h	14.76a	14.04b	19.35abc	21.87bc
12 h	12.59b	13.16b	18.76bc	24.01b
24 h	16.10a	9.55c	20.69a	21.55c
48 h	4.92c	6.40c	17.75c	20.50c
LSD $_{0.05}$	**2.148**	**3.194**	**1.696**	**2.380**

Comparison of GI means of soybean genotypes

Genotype	**GI mean - 4 months storage**	**GI mean - 8 months storage**
Gazelle	12.75b	13.31b
SB 19 (TGx1740 2 F)	19.28a	23.85a
LSD $_{0.05}$	1.92	2.787

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance

Factors	Gazelle GI after		SB 19 GI after	
	4 months storage	8 months storage	4 months storage	8 months storage
Concentration (C)	**	**	**	**
Duration (D)	**	**	**	**
C x D	**	**	**	**
Storage Period x C	**	**	**	**
Storage Period x D	**	**	**	**

NS= Not significant, ** = Significant at ($p \leq 0.05$); PEG=Polyethylene glycol 6000; Mpa=Megapascals, LM4 – Lower midlands IV Agro-ecology

The different effects of priming on GI revealed in this study are in agreement with the findings of Dezfuli *et al.,* (2008) who found that osmo-priming using PEG 6000 for 96h reduced GI in maize inbred lines (M017 and B73), and Sadeghi *et al*., (2011) who found an increase in GI of soybean after priming, as well as Yari *et al.*, (2010) who showed that priming did not improve GI of wheat.

Even though hydro priming (0Mpa) and osmo-priming with PEG 6000 at -1.0Mpa osmotic potential only gave promising results by increasing GI of soybean TGx 1740-2F (SB19) after 4 months of seed storage, these effects were not sustained with increased ageing of seeds to 8 months. The present experiments are consistent with the concept that seed aging may be associated with deteriorative changes in membranes, which increased with soybean seed ambient on-farm storage in Meru South. These results suggest that priming may have damaged the seed hence was not successful in invigorating aged soybean seed as shown by the decreased germination index.

4.3.5. Effect of priming on Time to 50% Germination of soybean

The effect of priming on T50 varied with genotype, seed age in storage, priming concentration and duration (Table-4.37).According to the results, time to 50% germination (T50) was affected by the experimental factors as there were significant differences between control (non-primed seeds) and primed seeds of soybean genotypes Gazelle and TGx 1740-2F(SB19) ($P \leq 0.05$).

Table 4.37: Time to 50% germination (T50) of soybean genotypes as affected by seed priming Concentration and Priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South

Treatment	**Soybean Gazelle Time to 50 % Germination (T50) after**		**Soybean SB19 Time to 50 % Germination (T50) after**	
Priming Concentration	4 months storage	8 months storage	4 months storage	8 months storage
Control (Unprimed seed)	2.64b	1.83c	2.07b	1.24c
Distilled water (0Mpa)	2.50b	2.44a	1.82c	1.91a
PEG -0.5 Mpa	2.49bc	1.99bc	2.36a	1.44b
PEG -1.0 Mpa	2.33c	2.10bc	1.63d	1.50b
PEG -1.5 Mpa	3.01a	2.26ab	2.03b	1.53b
$LSD_{0.05}$	**0.288**	**0.45**	**0.1713**	**0.1242**
Priming Duration - hours				
0 h (Unprimed Control)	2.65b	1.83c	2.07a	1.24d
6 h	2.33c	2.27b	1.93ab	1.56bc
12 h	2.93a	2.60a	2.08a	1.44c
24 h	2.96c	2.45ab	1.90b	1.80a
48 h	2.80ab	1.48d	1.94ab	1.58b
$LSD_{0.05}$	**0.288**	**0.45**	**0.1713**	**0.1242**

Comparison of T50 means of soybean genotypes

Genotype	**T50 mean - 4 months storage**	**T50 mean - 8 months storage**
Gazelle	2.58a	2.13a
SB 19 (TGx1740 2 F)	1.99b	1.53b
$LSD_{0.05}$	0.074	0.094

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance or P values

Factors	**Gazelle T50 after**		**SB 19 T50 after**	
	4 months storage	8 months storage	4 months storage	8 months storage
Concentration (C)	**	**	**	**
Duration (D)	**	**	**	**
C x D	**	**	**	**
Storage Period x C	**	**	**	**
Storage Period x D	**	**	**	**

** = Significant at ($p \leq 0.05$); PEG=Polyethylene glycol 6000; Mpa=Megapascals.
LM4 – Lower Midlands IV Agro-ecology

Results revealed that at 4 months of seed storage, osmo-priming soybean genotype Gazelle with PEG -1.0 Mpa and for 6h and 24h priming duration reduced T50 hence was beneficial as it increased vigor. However all other priming agents and durations did not improve T50 of Gazelle with PEG -1.5Mpa and 12h duration increasing it , while hydro-priming (0 Mpa), PEG -0.5 Mpa and 48h duration was no different from non-primed control.

With regard to soybean genotype TGx 1740-2F (SB19) seeds primed after 4 months of storage showed that hydro-priming, PEG -1.0Mpa and 24h duration reduced T50, hence were beneficial treatments However, SB 19 seed primed with PEG -1.5 and for 6h, 12h, and 48h had no effect as they were same as non-primed seeds.

After 8 months of seed storage of Soybean Gazelle, priming with PEG -0.5Mpa, -1.0Mpa and 48h duration was beneficial as it reduced T50 but hydro priming (0Mpa), PEG -1.5Mpa and for 6h, 12h and 24h increased it. However, priming soybean genotype SB 19 seed after 8 months of ambient storage increased T50 in all priming treatments and durations meaning primed seed took longer to germinate than non-primed seed.

Genotypic differences in T50 were evident, with SB19 (1.76) having a shorter T50 indicative of higher vigor than Gazelle (2.36) during 8 months storage. Moreover, the interactions between C x D and their interactions with seed storage period for T_{50} for both soybean genotypes were highly significant. ($p \leq 0.05$)

In Summary, priming enhanced vigor of soybean as shown by shorter time to 50% germination, when Gazelle was primed with PEG -0.5Mpa, -1.0Mpa and for 6h, 24h and 48h durations and when SB19 was primed with water (0Mpa), PEG -1.0 Mpa and for 24h duration. The observed improvements in germination rate of primed seed may be attributed to the induced quantitative changes in biochemical content of the seed and improved membrane integrity and enhanced physiological activities at seed germination (Sung and Chang, 1993).

These results are in agreement with findings of various researchers. Sadeghi *et al*., (2011) and Arif *et al.*, (2008) reported shorter T50 of primed soybean seed. Dezfuli, *et al*., (2008) revealed that maize seeds hydro primed for 36 hours had the lowest values of T50 and Mean Germination Time (MGT), followed by 24 h and 48 h seed treatments. In the current study, osmo and hydro-priming was found to improve time to 50% germination of soybean.

4.3.6. Effect of priming on Energy of Emergence (EE) of soybean

Energy of Emergence (EE) is the percentage of germinating seeds 4 days after planting relative to the total number of seeds tested (Ruan *et al.*, 2002).The findings of this study revealed that different osmotic potentials and priming durations had significant effect on energy of emergence of soybean genotypes ($P \leq 0.05$) (**Table 4.38**).

There were significant differences between primed and non-primed seed in energy of emergence (EE). All priming concentrations and durations significantly reduced the EE for genotypes Gazelle and SB 19 at both 4 and 8 months of seed storage, except 48h priming which was same as control for SB19 at 4 months storage. However, in both genotypes, PEG -0.5Mpa as well as 48h priming duration had the most adverse effect in reducing energy of emergence. Genotypic differences in EE were evident, with small seeded genotypeSB19 (0.86) having a higher EG with priming than larger seeded Gazelle (0.65). The interactions between C x D and their interactions with seed storage period for Energy of emergence in both soybean genotypes were highly significant ($p \leq 0.05$).

Table 4.38: Energy of Emergence (EG) of soybean genotypes as affected by seed priming concentration and priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South

Treatment	**Soybean Gazelle Energy of Emergence (EG) after**		**Soybean SB19 Energy of Emergence (EG) after**	
Priming Concentration	4 months storage	8 months storage	4 months storage	8 months storage
Control (Unprimed seed)	0.94a	0.91a	0.97a	0.94a
Distilled water (0Mpa)	0.72b	0.44d	0.87b	0.86b
PEG -0.5 Mpa	0.56d	0.58c	0.81c	0.75c
PEG -1.0 Mpa	0.64c	0.59c	0.86b	0.84b
PEG -1.5 Mpa	0.60cd	0.70b	0.83bc	0.88ab
LSD $_{0.05}$	**0.0784**	**0.0937**	**0.0484**	**0.0699**
Priming Duration - hours				
0 h (Unprimed Control)	0.94a	0.91a	0.97a	0.94a
6 h	0.72b	0.65b	0.84c	0.83bc
12 h	0.72b	0.71b	0.89b	0.85b
24 h	0.79b	0.70b	0.77d	0.86b
48 h	0.29c	0.26c	0.97a	0.79c
LSD $_{0.05}$	**0.0784**	**0.0937**	**0.0484**	**0.0699**

Comparison of EG means of soybean genotypes

Genotype	**EG mean - 4 months storage**	**EG mean - 8 months storage**
Gazelle	0.71b	0.65b
SB 19 (TGx1740 2 F)	0.87a	0.86a
LSD $_{0.05}$	**0.027**	**0.030**

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance or P values

Factors	Gazelle EG after		SB 19 EG after	
	4 months storage	8 months storage	4 months storage	8 months storage
Concentration (C)	**	**	**	**
Duration (D)	**	**	**	**
C x D	**	**	**	**
Storage Period x C	**	**	**	**
Storage Period x D	**	**	NS	NS

NS= Not significant, ** = Significant at ($p \leq 0.05$) PEG=Polyethylene glycol 6000; Mpa=Megapascals, LM4= Lower midlands IV Agro-ecology.

The present study showed that osmo-priming and hydro priming techniques reduced energy of emergence of soybean Gazelle and SB19. These results are contrary to the findings of Sadeghi *et al*., (2011) working on soybean seed (cv.033) and Farooq *et al.*, (2007), working on muskmelon, who reported an increase in energy of emergence after priming. Similarly, work by Gray *et al.* (1984) revealed that osmo priming of a slowly germinating stock improved the percentage seedling emergence compared with untreated seeds. It has been suggested that low vigor seeds will benefit more from priming because of a requirement for repair before germination advancement occurs, whereas, in high vigor seeds, advancement in germination occurs rapidly when primed and progresses to a stage where seeds become susceptible to more rapid deterioration (Powell *et al*.,2000). In the current study non-primed soybean seed retained a high EE of between 91-97% throughout the 8 months of ambient storage in Meru South (Table 4.39), hence are likely to have been susceptible to rapid deterioration with priming.

4.3.7. Effect of priming on Speed of Emergence (SE) of soybean

Data regarding the effect of priming on the Speed of Emergence (SE) of soybean are presented on Table 4.39. The study revealed that seed storage periods, genotypes , osmotic potentials and priming durations had significant effect on SE of soybean ($p \leq 0.05$).

Table 4.39: Speed of Emergence (SE) of soybean genotypes as affected by seed priming concentration and priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South

Treatment	**Soybean Gazelle Speed of Emergence (SE) after**		**Soybean .SB19 Speed of Emergence (SE) after**	
Priming Concentration	4 months storage	8 months storage	4 months storage	8 months storage
Control (Unprimed seed)	100a	100a	100a	100a
Distilled water (0Mpa)	96.88a	93.75a	99.05a	100a
PEG -0.5 Mpa	75.00c	100a	99.11a	100a
PEG -1.0 Mpa	100a	100a	100a	100a
PEG -1.5 Mpa	87.94b	99.85a	99.70a	100a
LSD $_{0.05}$	**8.4368**	**10.826**	**1.0252**	**0**
Priming Duration - hours				
0 h (Unprimed Control)	100a	100a	100a	100a
6 h	99.15a	100a	99.87ab	100a
12 h	97.49a	100a	99.05ab	100a
24 h	99.11a	99.85a	100a	100a
48 h	64.06b	93.75a	98.95b	100a
LSD $_{0.05}$	**8.4368**	**10.826**	**1.0252**	**0**

Comparison of SE means of soybean genotypes

Genotype	**SE mean - 4 months storage**	**SE mean - 8 months storage**
Gazelle	92.34b	98.72a
SB 19 (TGx1740 2 F)	99.57a	100.00a
LSD $_{0.05}$	3.165	2.437

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance or P values

Factors	Gazelle SE after		SB 19 SE after	
	4 months storage	8 months storage	4 months storage	8 months storage
Concentration (C)	**	NS	**	NS
Duration (D)	**	NS	**	NS
C x D	**	NS	**	NS
Storage Period x C	NS	NS	**	NS
Storage Period x D	**	**	**	**

NS= Not significant, ** = Significant at ($p \leq 0.05$); PEG=Polyethylene glycol 6000; Mpa=Megapascals; LM4=Loer Midlands IV Agro-ecology.

Priming significantly reduced the speed of emergence of soybean seed Gazelle after 4 months seed storage when primed for 48 hours and with PEG -0.5 Mpa , while priming with osmotic potentials 0(water), -1.0MPa Mpa and for 6, 12 and 24 hours made no significant difference than the control treatment. However, with SB19 (TGx 1740-2F), hydro-priming, and osmo-priming as well as priming durations (6, 12, and 24h) had no effect but priming for 48h reduced SE. After 8 months of seed storage for both soybean genotypes all priming durations and concentrations had no effect as their speed of emergence was same as the unprimed control. Genotypic differences in SE were evident, with SB19 (99.8) having a higher SE than Gazelle (95.9). Increased speed of germination (and hence emergence) is the primary purpose for priming. Faster emergence results in a longer growing season and hence larger yields.

From the results of this study, it was clear priming reduced or had no effect on the speed of emergence of soybean genotype Gazelle and TGx-1740 2F(SB19) seed after 4 and 8 months of storage under ambient conditions in Meru South.

It has been reported that in the germination process, Phase I and II (lag phase) represents the most delicate phases for the process of germination and are crucial for a successful seed priming (Bewley, 1997) and beyond this stage (phase III) germination is too advanced to allow a drying-back without seed damage (Taylor et al., 1998). In the current study, the likely reason for the reduced soybean SE was that the unprimed controls seed had a high SE (100) hence with priming, germination may have progressed beyond the lag phase hence the subsequent loss in vigor after drying back.

Results of this study are contrary to the findings of Bittencourt *et al.*, (2005) that showed asparagus seeds primed with Polyethylene glycol 6000 to have higher germination speed, but agrees with the observation that the beneficial effects of priming on asparagus seeds was were more pronounced in the seed lot of low physiological quality.

4.3.8. Effect of Priming on Seedling Vigor Index of soybean

The effect of priming on seedling vigor index was significant ($P \leq 0.05$) (**Table 4.40).**

Priming significantly reduced Seedling Vigor Index (SVI) of both soybean genotypes with genotype Gazelle reducing from 1038-1183 (control) to 241-567 (primed seed) and in SB19 (TGx 1740 2F) reducing from 1329-1592(control) to 618-975(primed seed). In addition, there were significant genotypic differences in seedling vigor index of soybean with TGx 1740 2F (SB19) having a higher SVI (976) than variety Gazelle (543).

These results are contrary to the findings of Sadeghi *et al*., (2011) who reported that -1.2 osmotic potential and 12 h seed priming duration increased SVI of soybean. Similarly, Ruan *et al.*, (2002), while working on rice reported increased SVI with priming. The improvement in germination and vigor of normal/low-vigor seed might be due to reserve mobilization of food material, activation and re-synthesis of some enzymes DNA and RNA synthesis start during priming (Basra *et al*., 2003). However, the negative effects of priming have been reported to be as a consequence of germination *stricto sensu* having advanced to a state where seeds have lost desiccation tolerance (Sliwin´ska and Jendrzejczak, 2002). This is likely to have occurred in the present study since the unprimed control seeds had high seedling vigor Index (1038 – 1183 (Gazelle) and 1329 -1592(TGx 1740 2F), hence are likely have lost desiccation tolerance upon drying back after priming.

Table 4.40: Comparison of means of Seedling Vigor Index (SVI) of soybean genotypes as affected by seed priming concentration and priming duration after 4 and 8 months of on-farm seed storage at Igambatuntu (LM4) in Meru South

Treatment	**Soybean Gazelle Seedling Vigor Index (SVI). after**		**Soybean SB19 Seedling Vigor Index (SVI). after**	
Priming Concentration	4 months storage	8 months storage	4 months storage	8 months storage
Control (Unprimed seed)	1038.68a	1183.15a	1592.72a	1329.36a
Distilled water (0Mpa)	566.53b	240.74c	975.23b	852.42b
PEG -0.5 Mpa	420.90c	378.04bc	768.63c	617.71c
PEG -1.0 Mpa	278.93d	253.48c	906.93bc	950.54b
PEG -1.5 Mpa	406.68c	547.02b	823.52c	943.01b
LSD $_{0.05}$	**107.06**	**175.09**	**143.45**	**177.08**
Priming Duration - hours				
0 h (Unprimed Control)	1038.68a	1183.15a	1592.7a	1329.36a
6 h	502.22c	446.94bc	777.43c	801.41bc
12 h	419.55c	299.42cd	1008.75b	737.18c
24 h	615.16b	514.15b	901.22bc	969.80b
48 h	136.11d	158.49d	786.92c	855.29bc
LSD $_{0.05}$	**107.06**	**175.09**	**143.45**	**177.08**

Comparison of SVI means of primed soybean genotypes

Genotype	**SVI mean - 4 months storage**	**SVI mean - 8 months storage**	**Mean**
Gazelle	565.98b	520.43b	543.21b
SB 19 (TGx1740 2 F)	1013.41a	938.61a	976.01a
LSD $_{0.05}$	**45.52**	**64.4**	**45.49**

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance

Factors	. Gazelle SVI after		SB 19 SVI after	
	4 months storage	8 months storage	4 months storage	8 months storage
Concentration (C)	**	**	**	**
Duration (D)	**	**	**	**
C x D	**	**	**	**
Storage Period x C	**	**	**	**
Storage Period x D	NS	NS	**	**

NS= Not significant, ** = Significant at ($p \leq 0.05$); PEG=Polyethylene glycol 6000; Mpa=Megapascals; LM4=Lower midlands IV Agro-ecology.

4.3.9. Effect priming on storability of soybean.

Data on the effects of priming and post-priming storage on soybean TGx 1740-2F (SB 19) seed viability and vigor are reported on Tables 4.41 and 4.42 for soybean genotype Gazelle and Tables 4.43 and 4.44 for soybean TGx 1740-2F (SB19). The effect of Priming concentration and duration on seed germination and vigor characteristics of soybean after priming and 8 months of post priming storage was found to be highly significant ($p \leq 0.05$)

4.3.9.1. Effect of post-priming storage on germination and vigor of soybean genotype Gazelle

The effects of priming concentration and duration on seed germination and vigor of soybean genotype Gazelle at priming (Table 4.41) and after post-priming storage (Table 4.42) was found significant ($p \leq 0.05$). For Gazelle, seed moisture increased during post priming storage in all treatments. After 8 months of post priming storage, seed primed with with-1.5 and -0.5 Mpa and for 12h, 24h and 48h priming durations increasing seed moisture , while hydro primed seed reduced and osmo-primed seed with PEG -1.0 MPa and 6h was same as control.

The level of seed membrane leachates (EC) are indicative of the integrity of seed membranes which deteriorate with seed ageing, but priming essentially helps in the repair of membranes but with variable outcomes. Priming has been shown to be both beneficial (Georghiou et al., 1987; Wechsberg, 1994) and detrimental (Argerich *et al.*, 1989; Tarquis and Bradford, 1992) to subsequent longevity.

In this study, priming of soybean Genotype Gazelle with PEG -1.0 Mpa reduced seed membrane leachates, but PEG -0.5Mpa and 12h duration increased it, while with -1.5 Mpa, hydro priming (0Mpa)as well as for 6h, 24h and 48h having no effect.

Germination percent (GP) was reduced significantly by all priming concentrations and durations, except 12h and 48h duration which had no effect. After 8 months post priming storage primed soybean seed had the lowest germination ranging from 69% -77% compared with the control (87%). The negative effects of priming on germination have been reported on maize (Dezfuli *et al.*, 2008) and in wheat (Sharifzadeh *et al.*, 2006). Contrary findings, however was reported by Abnavi and Ghobadi, (2012) who showed that storing of primed improved germination in wheat.

Table 4.41: Comparison of means of studied traits in soybean Gazelle after 0- months of post-priming storage as influenced by priming concentration and duration

Treatment	**% MC**	**EC**	**GP**	**MGT**	**T50**	**SVI**
Priming agent	**after 0 - months post priming storage of cultivar Gazelle**					
Unprimed (control)	7.43 b	42.97bc	93.50a	4.71a	4.13 a	811.01 bc
Distilled water 0Mpa	7.43 b	39.66cd	81.33 c	3.56 b	2.94 b	772.15 c
PEG -0.5 Mpa	7.36c	57.98 a	82.16bc	2.39 d	1.71 d	889.81 ab
PEG -1.0 Mpa	7.36 c	37.24 d	86.83 b	2.68 c	2.13 c	848.73a bc
PEG -1.5 Mpa	7.53 a	46.37 b	85.50 bc	2.37 d	1.87 d	938.15 a
$LSD_{0.05}$	0.059	5.613	5.202	0.236	0.253	109.35
Priming duration (hours)						
Unprimed Control (0h)	7.43a	42.97bc	93.50a	4.71a	4.14a	811.01b
6 h (1)	7.42 a	38.67c	82.58cd	2.92b	2.32bc	920.72a
12 h (2)	7.42 a	55.79a	88.33ab	2.96b	2.44b	767.32b
24 h (3)	7.42 a	39.58c	78.50d	2.76b	2.14c	957.91 a
48 h (4)	7.42 a	47.22b	93.50a	2.35c	1.74d	802.89 b
$LSD_{0.05}$	**0.059**	**5.61**	**5.20**	**0.23**	**0.25**	**109.35**

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance

Source	**ANOVA**					
Priming concentration (C)	*	*	*	*	*	*
Priming Duration (D)	NS	*	*	*	*	*
C x D	NS	*	*	*	*	*

NS=Not significant; *Significant at p≤ 0.05 probability level.

PEG=Polyethylene 6000; %MC-Moisture content; EC-Electrical conductivity; GP-Germination %; MGT-Mean germination time; T50-Time to 50% germination; SVI-Seedling vigor Index.

Table 4.42: Comparison of means of studied traits in soybean seed Gazelle after 8 - months of post-priming storage as influenced by priming concentration and duration.

Treatment	% MC	EC	GP	MGT	T50	SVI
Priming agent	**after 8 months post priming storage of Gazelle**					
Unprimed (control)	9.03 b	51.30 a	87.33 a	3.33 a	2.82a	710.02 a
Distilled water 0Mpa	8.84 c	45.37 b	73.33 b	2.85 b	2.33 b	471.63b
PEG -0.5 Mpa	9.43 a	53.71 a	72 .01b	2.61 c	2.08 c	582.91 ab
PEG -1.0 Mpa	9.04 b	44.52 b	76 .41b	2.43 d	1.91 d	607.67ab
PEG -1.5 Mpa	9.43 a	45.73 b	77.21b	2.39 d	1.84 d	539.06b
$LSD_{0.05}$	0.096	4.682	5.303	0.158	0.157	160.47
Priming duration (hours)						
Unprimed Control (0h)	9.03c	51.31ab	87.33a	3.33a	2.82a	710.02a
6 h (1)	8.53 c	45.55cd	77.43b	2.62b	2.11b	642.70ab
12 h (2)	9.34 b	54.64 a	75.94b	2.61 b	2.06b	460.74c
24 h (3)	9.41ab	41.14d	76.25b	2.35 c	1.77 c	591.88abc
48 h (4)	9.47a	48.01bc	69.35c	2.72 b	2.21b	523.95bc
$LSD_{0.05}$	0.096	4.682	5.303	0.158	0.157	160.47

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance

Source	ANOVA Table					
Priming concentration (C)	*	*	*	*	*	*
Priming Duration (D)	*	*	*	*	*	*
C x D	*	*	*	*	*	*

NS=Not significant; *Significant at $p \leq 0.05$ probability level.

%MC-Moisture content; EC-Electrical conductivity; GP-Germination %; MGT-Mean germination time; T50-Time to 50% germination; SVI-Seedling vigor Index.

With post-priming storage the seed membrane leachates (.EC) increased significantly in all treatments from an average of 45 to 48 µs/cm/g. However, the lowest seed leachates was achieved by hydro-priming, PEG -1.0 Mpa -1.5 Mpa, as well as 6 and 24h duration , suggesting better integrity of seed membranes was achieved by these treatments and even improved after 8 months of post- priming storage under ambient conditions. Seed primed with PEG -0.5Mpa and for 12h and 48h however were not different from the control treatment . Measurement of seedling vigor index showed that PEG -1.5 Mpa, 6 and 24h priming duration increased vigor which collaborate with the EC results. However, by end of storage, seeds that had been hydro-primed and osmo-primed with PEG -1.5Mpa and for 12h and 48h had lower SVI than control, while priming with PEG -0.5, -1.0 Mpa, 6 and 24h had no effect. Osmo and hydro-priming however increased the rate of germination as shown by the reduced MGT, T50 and these enhanced vigor effects, were consistent by end of post priming storage of soybean genotype Gazelle. The increased seed and seedling vigor with priming in this study agrees with the report that seed priming can enhance rapid and uniform seed emergence (Farooq *et al.*,2007; Farooq *et al.*, 2008), and Abnavi and Ghobadi., (2012) who reported that storing of primed wheat seeds improved shoot and radicle length, shoot and radicle dry weight and speed of germination.

The study revealed that post-priming storage of genotype Gazelle, was beneficial in terms of enhanced vigor but with a loss in final germination percent and these effects were retained after 8 months post priming storage under ambient conditions at Muguga, Kiambu County . Priming with polyethylene glycol 6000 at -1.0 Mpa for 6 and 24h gave the best germination and vigor indices of all the primed seed of Gazelle. This priming procedure therefore may be applied for invigorating low vigor seeds before storage.

4.3.9.2. Effect of post-priming storage on germination and vigor of soybean Genotype TGX 1740-2F (SB19).

The effect of priming concentration on seed quality traits of soybean genotype TGx 1740 2F (SB19) at priming and after post-priming storage was found significant ($p \leq 0.05$(Tables 4.43 and 4.44). During the 8 months of post-priming storage of genotype

SB19, seed moisture increased significantly with primed seed having the lowest seed moisture at the onset of storage but having the highest at the end of storage.

Table 4.43: Comparison of means of studied traits in soybean genotype SB19 after 0-months of post-priming storage as influenced by priming Concentration and Duration .

Treatment	**% MC**	**EC**	**GP**	**MGT**	**T50**	**SVI**
Priming agent	**after 0- months post priming storage - SB19**					
Unprimed (control)	7.46 a	46.53 ab	97.00a	4.02 a	3.45 a	703.85 b
Distilled water 0Mpa	7.23 c	43.09 b	91.00b b	2.88 b	2.25 b	1014.12 a
PEG -0.5 Mpa	7.13 d	47.75 a	88.58b b	1.96d	1.35 d	1029.68 a
PEG -1.0 Mpa	7.36 b	37.23 c	91.00 b	2.29 c	1.70 c	1054.49 a
PEG -1.5 Mpa	7.20 c	45.83 ab	89.33b	2.09cd	1.55cd	1033.37 a
$LSD_{0.05}$	**0.05**	**4.12**	**2.91**	**0.20**	**0.22**	**92.73**
Priming duration (hours)						
Unprimed Control (0h)	7.46a	46.53b	97.00a	4.02a	3.45a	703.85c
6 h (1)	7.23b	40.05c	92.41b	2.56b	1.88b	1107.68a
12 h (2)	7.23b	58.61a	88.08c	2.40bc	1.80b	1030.27ab
24 h (3)	7.23b	37.84c	90.83bc	2.32c	1.79b	998.70b
48 h (4)	7.23b	37.41c	88.58c	1.95d	1.38c	995.01b
$LSD_{0.05}$	**0.053**	**4.125**	**2.910**	**0.204**	**0.225**	**92.735**

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance

Source	ANOVA					
Priming concentration (C)	*	*	*	*	*	*
Priming Duration (D)	NS	*	*	*	*	*
C x D	NS	*	*	*	*	*

NS=Not significant; *Significant at the $p \leq 0.05$ probability level.

%MC-Moisture content; EC-Electrical conductivity; GP-Germination %; MGT-Mean germination time; T50-Time to 50% germination; SVI-Seedling vigor Index.

When genotype SB19 was osmo-primed with PEG 6000 at - 1.0 Mpa concentration and for 6h, 24h and 48h duration seed membrane leachates were reduced, while 12h increased it, but with PEG -0.5, -1.5 and hydro-priming treatments having no effect.

However, at the end 8 months of of post-priming storage, seed hydro primed and that osmo-primed with -1.0Mpa and -1.5 Mpa and for 6, 24 and 48h had significantly lower seed leachates than non-primed control. However, priming with PEG -0.5Mpa had no effect. Final germination percent of genotype TGX-1740-2F (SB19) was reduced with priming in all treatments and this loss was consistent at the end of post-priming storage.

Table 4.44: Comparison of means of seed quality traits in soybean genotype SB19 after 8 - months of post-priming storage as influenced by priming Concentration and Duration

Treatment	**% MC**	**EC**	**GP**	**MGT**	**T50**	**SVI**
Priming agent	**after 8 months post priming storage - SB19**					
Unprimed (control)	8.93d	47.86a	92.00a	2.59a	2.12a	1051.05a
Distilled water 0Mpa	8.75e	40.93bc	81.83bc	2.36b	1.80b	681.42b
PEG -0.5 Mpa	9.40b	48.01a	81.16bc	2.33b	1.72b	678.48b
PEG -1.0 Mpa	9.22c	40.46c	77.83c	2.15c	1.59c	733.97b
PEG -1.5 Mpa	9.80a	43.69b	82.66b	2.21c	1.72b	740.59b
$LSD_{0.05}$	0.148	3.036	4.133	0.112	0.121	132.14
Priming duration (hours)						
Unprimed Control (0h)	8.93c	47.86b	92.00a	2.59a	2.12a	1051.05a
6 h (1)	8.92c	43.73c	82.29b	2.23cd	1.76b	722.55bc
12 h (2)	9.52a	53.82a	77.61c	2.31bc	1.70bc	613.83c
24 h (3)	9.44a	38.56d	85.75b	2.17d	1.59c	782.68b
48 h (4)	9.29b	36.96d	77.83c	2.35b	1.78b	715.40bc
$LSD_{0.05}$	0.148	3.036	4.133	0.112	0.121	132.14

Values followed by thesame letter(s) in each column are not significantly different ($p \leq 0.05$)

Factors and their interactions with statistical significance

Source	ANOVA					
Priming concentration (C)	*	*	*	*	*	*
Priming Duration (D)	*	*	*	*	*	*
C x D	*	*	*	*	*	*

NS=Not significant; *Significant at the $p \leq 0.05$ probability level.

%MC-Moisture content; EC-Electrical conductivity; GP-Germination %; MGT-Mean germination time; T50-Time to 50% germination; SVI-Seedling vigor Index.

Osmo and hydro-priming increased the rate of germination as shown by the shorter MGT and T50, with PEG 1.0 and 24h duration having the lowest values and these effects remained consistent with post priming storage of SB19.

Seedling vigor Index increased with priming, but after post-priming storage, non-primed control had higher seedling vigor than primed seed. In addition, osmo and hydro-priming significantly increased speed of germination as shown by the shorter MGT and T50 but reduced germination percent for genotype TGx 1740-2F (SB19) and these effects were consistent after 8 months post-priming storage. On average, soybean seeds germinated faster at the end of storage as shown by the reductions in MGT from 2.7 to 2.3 days and T50 from 2.1 to 1.8 days although germination percent was reduced from 91% to 83%.

The study revealed that priming reduced final germination percent but increased seedling vigor as shown by the reduced seed leachates, shortened germination time and time to 50% germination for genotype TGx-1740-2F (SB19) and these effects were consistent after 8 months post-priming storage. Although priming reduced germination percent, primed seed for any length of time was more vigorous than non-primed seed. Osmo-priming of SB19 with PEG -1.0 and 24h was the most beneficial treatment in terms of vigor improvement, and these effects were similar to the preceding findings on genotype Gazelle

Although priming is one of the physiological methods, for improving seed performance (Sivritepe and Dourado, 1995) reported that the longevity of primed seeds in storage is often reduced (Van Pijlen *et al.*, 1996; Taylor *et al.*, 1998) or improved (Abnavi and Ghobadi, (2012). There are many examples of priming increasing the rate of germination (Argerich and Bradford, 1989; Argerich *et al.*, 1989; Lanteri *et al.*, 1993; Powell *et al*, (2000) and some of increasing germination (Georghiou *et al.*, 1987; Demir, 2003). However, when combined with subsequent desiccation, the effect of priming is not consistently positive. In some cases, the benefit to germination is lost on desiccation, or only partly retained on desiccation but lost rapidly in storage (Heydecker and Gibbins, 1978). Seed priming has been found to both decrease or increase viability and vigor of soybean. Arif *et al.,* (2008) reported better seedling emergence and yield improvement, while Ghassemi-Golezani *et al.*, (2011) reported a decrease in germination percentage, seedling dry weight and field emergence percentage and rate of soybean. Rouhi *et al.*, (2011) showed that hydro-priming decreased rate of germination, while osmo-priming (-12 bar, for 12 hours) improved germination and vigor of soybean seed lots cv. 'Sari'. Sadeghi *et al*., (2011) on the other hand found that osmo-priming of soybean (cultivar 033) at -1.2 Mpa osmotic potential and 12 h priming duration increased germination percentages, germination index and seed vigor, but decreased mean germination time, the time to get 50% germination and electrical conductivity of seeds.

The present study revealed beneficial effects of priming, which was retained during post-priming storage in terms of vigor improvements but with subsequent reduction in germination percent. Osmo-priming with Polyethylene glycol 6000 was better than hydro-priming in all studied traits. Osmotic potential of -1.0 Mpa and 24 h priming duration had the most beneficial effect of enhancing soybean seed vigor of genotype TGx 1740 -2F and Gazelle.

4.3.9.3. Effects of genotype on post priming storage of soybean

Data regarding genotypic influence on storability of primed soybean is reported on **Table 4.45.** The genotypic differences on the effect of priming and post priming storage on germination and vigor traits of soybean was highly significant ($p \leq 0.05$)

Table 4.45: Means comparison of seed quality traits as influenced by soybean genotype after 8 months postpriming storage.

Genotype	%MC	EC	GP	MGT	GI	T50	EG	SE	SVI
Gazelle	9.15b	48.12a	77.26b	2.72b	7.71b	2.19a	0.76b	99.77b	582.26b
SB19	9.22a	44.19b	83.09a	2.33b	9.72a	1.79b	0.83a	99.93a	777.10a
$LSD_{0.05}$	0.04	1.29	1.58	0.04	0.25	0.04	0.015	0.158	47.85

Means with the same letter along a column are not significantly different at $p \leq 0.05$

Statistical analysis of 8 months post-priming storage revealed significant genotypic differences in studied traits. Averaged over all treatments, the small seeded genotype SB19 (TGx 1740-2F) showed a significantly higher germination and vigor compared to large seeded genotype Gazelle as shown by the lower seed leachate conductance (ECµs/cm/g); higher germination percent(GP); shorter mean germination time (MGT); higher Germination Index (GI); shorter time to 50% germination (T50), higher energy of emergence (EG), higher speed of emergence (SE) and a higher seedling Vigor Index (SVI). Significant genotypic differences in soybean were shown with smaller seeded genotype SB19 (TGx-1740-2F) showing better seed longevity and vigor than the larger seeded genotype Gazelle after 8 months of post-priming storage The results revealed that benefits of priming on seed performance were maintained during dry storage but the degree of enhancement was genetically determined .

Seed longevity and vigor has been reported to be in part genetically determined (Priestley, 1986). These results are in agreement with the findings of Singh *et al.*, (1978), which revealed a strong negative association of germination and seed weights of six soybean genotypes.

4.3.10. Summary of findings on priming and post-priming storage

The findings on the effect of osmo-priming with Polyethylene Glycol 6000 and hydro-priming on soybean viability and vigor revealed that priming decreased germination percentage, germination index and seedling vigor index of both soybean genotypes - Gazelle and TGx 1740-2F (SB 19), but enhanced seed vigor of soybean SB19 when hydro primed and osmo primed with PEG -1.0 Mpa and for 6 h or 24h, as shown by the reduced seed membrane leachates. For genotype Gazelle however, priming reduced seed vigor in all treatments as shown by the increased seed membrane leachates although -0.5Mpa osmotic potential was beneficial as it decreased MGT. Priming however had had variable outcomes on the speed of emergence of soybean seed, as it reduced or had no effect. Genotypic differences in response to priming were evident with TGx 1740-2F (SB19) showing high viability and vigor than Gazelle in all priming durations and concentrations. From these findings, it can be concluded that since the soybean seed lots used in this study were of high vigor even after 8 months of ambient storage at Igambatuntu, germination may have progressed beyond the lag phase hence the subsequent loss in viability and vigor after drying back.

Results from post priming storage experiment revealed that primed seed had improved seed vigor as shown by the reduction in seed leachate conductance and increased rate of germination as shown by the reduced MGT and T50 than non-primed seed. Primed seed however, had reduced final germination percent than non-primed control seed and these effects were retained during post-priming storage. Of the primed treatments, priming for 24 h and/or with PEG -1.0 MPa was the most beneficial. These improvements were retained during the 8 months post-priming storage. There were significant genotypic differences in storability of primed seed, with SB19 (TGX 1740F) maintaining higher seed germination and vigor in all studied traits than Gazelle.

This study revealed that the quality of primed seed was improved in terms of increased soybean seed vigor traits but compromised in terms reduced germination.

4.4. Objective 4: Influence of mother plant nutrition, genotype and agro-ecology on soybean productivity and seed quality.

4.4.1. Soil type and average initial soil fertility level for experimental sites

The initial soil properties at field experimental sites are described in Table 4.46.

Table 4.46: Initial soil properties at field experimental sites

SITE	Soil Classification	pH	Organic C (%)	Total N (%)	Available Nutrients (ppm)							
					P	K	Ca	Mg	Fe	Mn	Zn	Cu
Muguga (LH3)	Humic Nitosols	5.5	3.18	0.34	58.7	1150.5	2143.5	343.3	583.3	3138.9	29.8	1.8
Nkoroi (UM4)	Vertisols	6.2	2.86	0.3	70.8	1130.3	5679.3	1019.6	700.0	3055.6	4.9	9.4

The pH levels in the experimental sites were 5.5 at Muguga (LH3) and 6.2 at Nkoroi (UM4) site. These levels are within the suitable pH range of 5.5 to 7.0 for maximum P availability to plants (Tisdale and Rucker 1964). The levels of total Nitrogen in soils in Nkoroi (0.3%) and Muguga (0.34%) were high as they were more than 0.25 (Tekalign, 1991). In addition, the Olsen P levels were also very high, with Muguga site registering 58.7ppm while Nkoroi site had 70.8ppm. Crop response to phosphate fertilizer has been observed in soils where P test levels are below 10 ppm when routine Bray 2 and Olsen and Truog extractants are used (Roche *et al.,* 1980; Okalebo 1987 and Okalebo *et al.,* 1989). The soil organic matter levels were moderate at Nkoroi site (2.86) but high at Muguga site (3.18), hence the soils were in good condition (Tekalign, 1991).

4.4.2. Growth and yield of soybean genotypes in response to N and P fertilization and agro-ecology.

The results of the study on the effect of Nitrogen and phosphorous fertilization, agro-ecology and genotype on soybean productivity are discussed under this section.

4.4.2.1. Effects of Nitrogen and Phosphorous fertilization on growth and yield of soybean.

Data on the effect of Nitrogen (N) and Phosphorous (P) fertilization on growth and yield components of soybean genotype Gazelle and TGx 1740 2F (SB19) grown at Lower Highlands III (LH3) Muguga site are presented on Table 4.47 and for Upper Midlands IV (UM4)-Nkoroi site on Table 4.48 as well as Figure 4.11.

The effect of fertilization with Phosphorous (60 kg ha^{-1}), Nitrogen (25 kg ha^{-1}), as well as and N + P (25 kg ha^{-1} + 60 kg ha^{-1}) on soybean growth and yield components was not significant, except in some components for genotype Gazelle at UM4 ($p \leq 0.05$).

These results revealed that there was no growth and yield response to N and P fertilizers for TGx 1740 2F (SB19) at both Lower highlands III (LH3) and Upper Midlands IV (UM4) sites. However Gazelle responded to N and P fertilizers at both sites but only in some growth and yield components but not in others. At UM4, application Nitrogen fertilizers at 25kg ha^{-1} to Gazelle significantly reduced both plant height at maturity (R7 stage) and the number of pods per plant, while combined application of P 60 kg ha^{-1} + N 25 kg ha^{-1} caused a significant increase in seed yield to 3,717 kg ha^{-1} compared to control (2972kg ha^{-1})

Table 4.47: Effect of Nitrogen (N) and Phosphorous (P) fertilization on growth and yield components of soybean Gazelle and TGx 1740 2F grown at LH3 agro-ecology.

Fertilizer Treatment (Kg ha^{-1})	Plant height R7 stage (cm)	Branches /plant	Pods / Plant	Seeds /pod	1000 seed wt. (g)	Seed yield (kg ha^{-1})
	Gazelle (LH3-Muguga)					
N_0P_0 (Control)	31.66ab	1.20b	14.90b	2.13a	183.64a	1463.2a
N 25	30.26b	1.66ab	15.70b	2.08a	188.58a	1869.5a
P 60	36.00a	1.93a	22.56a	2.15a	175.63a	2441.5a
N 25 + P 60	31.46ab	1.43ab	17.20ab	2.08a	174.01a	1683.5a
LSD $_{0.05}$	4.74	0.67	6.76	0.23	17.69	1486.4
	TGx 1740 2F (LH3-Muguga)					
N0P0 (Control)	42.30a	2.40a	29.16a	2.00a	124.52ab	1612.2a
N 25	36.91a	2.20a	22.86a	2.05a	124.76ab	1106.2a
P 60	37.18a	1.93a	23.13a	1.95a	117.55b	1282.0a
N 25 + P 60	38.91a	2.00a	26.07a	2.01a	124.91a	1453.4a
LSD 0.05	9.27	1.48	15.41	0.15	7.24	882.33

Values with same letter(s) in each column are not significantly different ($p \leq 0.05$)
LH3=Lower highlands III agro-ecological zones

Table 4.48: Effect of Nitrogen (N) and Phosphorous (P) fertilization on growth and yield components of soybean Gazelle and TGx 1740 2F grown at UM4 agro-ecology (Nkoroi).

Fertilizer Treatment (Kg ha^{-1})	Plant height R7 stage (cm)	Branches /plant	Pods / Plant	Seeds /pod	1000 seed wt. (g)	Seed yield (kg ha^{-1})
	Gazelle (UM4- Nkoroi)					
N_0P_0 (Control)	53.26a	2.80ab	25.2ab	2.21a	154.72a	2972.1b
N 25	44.63b	2.53b	19.90c	2.15a	155.87a	2542.7b
P 60	52.60a	2.86ab	23.60b	2.24a	159.05a	3074.2b
N 25 + P 60	53.26a	3.70a	28.86a	2.21a	167.33a	3716.6a
LSD $_{0.05}$	3.51	1.02	3.47	0.09	14.53	538.86
	TGx 1740- 2F (UM4 Nkoroi)					
N_0P_0 (Control)	78.60a	3.30a	42.36a	1.66a	122.11a	2910.2a
N 25	78.80a	3.16a	49.33a	1.63a	119.72a	2722.9a
P 60	83.10a	3.53a	43.20a	1.64a	116.66a	2544.0a
N 25 + P60	80.23a	3.23a	52.26a	1.58a	120.15a	2218.1a
LSD $_{0.05}$	12.75	1.86	19.36	0.38	10.92	1452.3

Values with same letter(s) in each column are not significantly different ($p \leq 0.05$)
UM4=Upper Midlands IV agro-ecological zone.

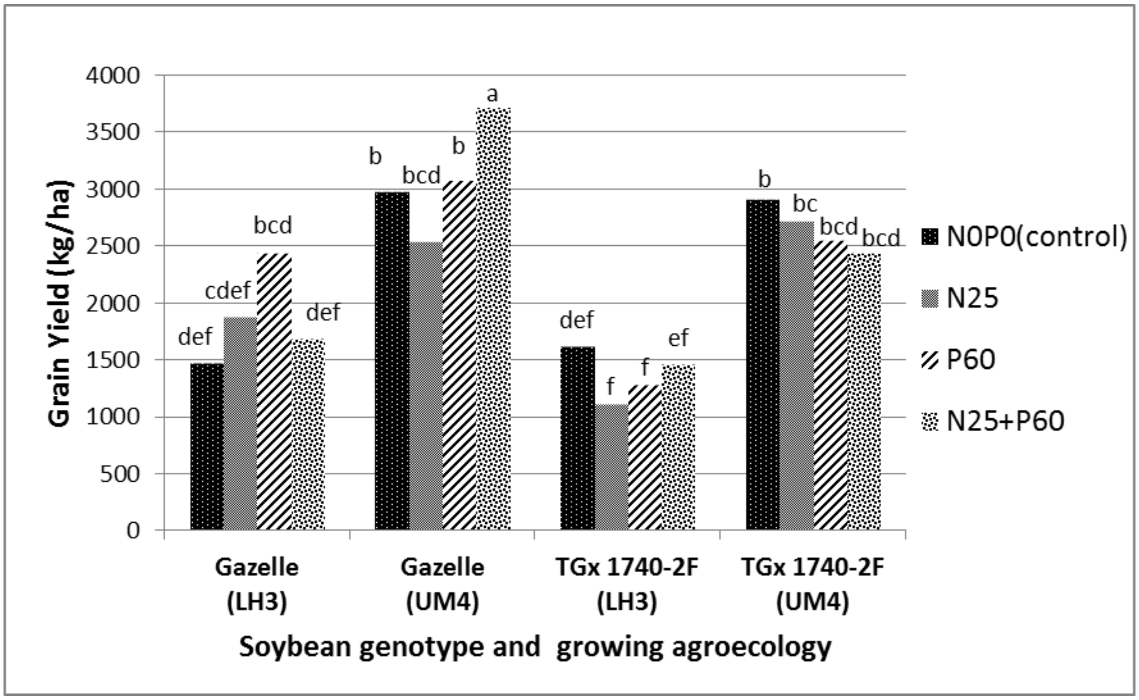

Figure 4.11: Effect of N (25kg-1ha) and P (60kg-1ha) fertilization on seed yield of soybean genotypes Gazelle and TGx 1740-2F grown at Lower highlands III(Muguga) and Upper midlands IV(Nkoroi) during short rains of October –November 2013.

At the higher altitude (LH3), application P at 60 kg ha^{-1} on genotype Gazelle increased the number of branches and number of pods per plant but had no effect on seed yield (Table 4.47 and Fig. 4.11). All other treatments across sites had no significant effect on plant height, number of branches, number of pods per plant, number of seeds per pod, seed weight and seed yield for Gazelle and TGx 1740 2F (SB19). Consequently, the effects of N and P fertilization were not consistent, as it had a positive effect in one site but not in the other, and in some growth components but not in the others. Hence response to application of N and P fertilizers varied with site and genotype.

These results agree with the findings of several soybean researchers who have observed favorable as well unfavorable effects of the application of mineral nitrogen, and phosphorus depending upon the cultivar, quantity and source of nutrients, sowing date and plant population/area, as well as environmental conditions. Krueger *et al.*, (2013) reported that P and K fertilization effects in soybean were unclear since fertilization rates had a positive effect on yield and composition in some growing locations and years but not in others. Nedic *et al*. (2005) found a small but positive effect on soybean seed yield with application of P_{35} and N_{100} with inoculation. Mugendi *et al*.(2010) reported that soil amendments with Phosphate, Potassium and Sulphur fertilizers was desirable to achieve maximum benefits from soybean in Meru South Sub-county, while Abuli *et al.* (2012) while working in the same study area, reported increased soybean yields only in soils with limited phosphorous levels. Similarly, Bishnoi *et al*., (2007); Borges and Mallarino, (2000) and Thalooth *et al.* (1989) reported increase in soybean grain yield in soils with low soil test phosphorus levels.

In the current study, the soil test results (Table 4.46) revealed high levels of P (59ppm at LH3 and 71ppm at UM4)) and N (0.34% at LH3 and 0.30% at UM4) in the experimental sites. Consequently, this could be one likely reason for the lack of response to N and P fertilizer application in most treatments. In addition soybean has been shown to fix an average of 175 kg Nha-1 /year in irrigated Production and 100kg N ha^{-1} per year in dry land production (Unkovich and Pate, 2000). Consequently, TGX 1740 2F being a promiscuous soybean variety that nodulates freely, may have improved N soil fertility through biological nitrogen fixation, hence the lack of response to N fertilizer application compared to Gazelle which is not promiscuous. These results are of particular importance for resource poor farmers who cannot afford expensive farm inputs. In particular, where soil levels of N and P are adequate, there may be no need to add supplementary fertilizers in soybean production.

4.4.2.2. Effect of growing agro ecology on growth and yield

The agro-ecological site in which soybean was grown had significant effects on its growth and yield components (P≤0.05) (Figure 4.12).

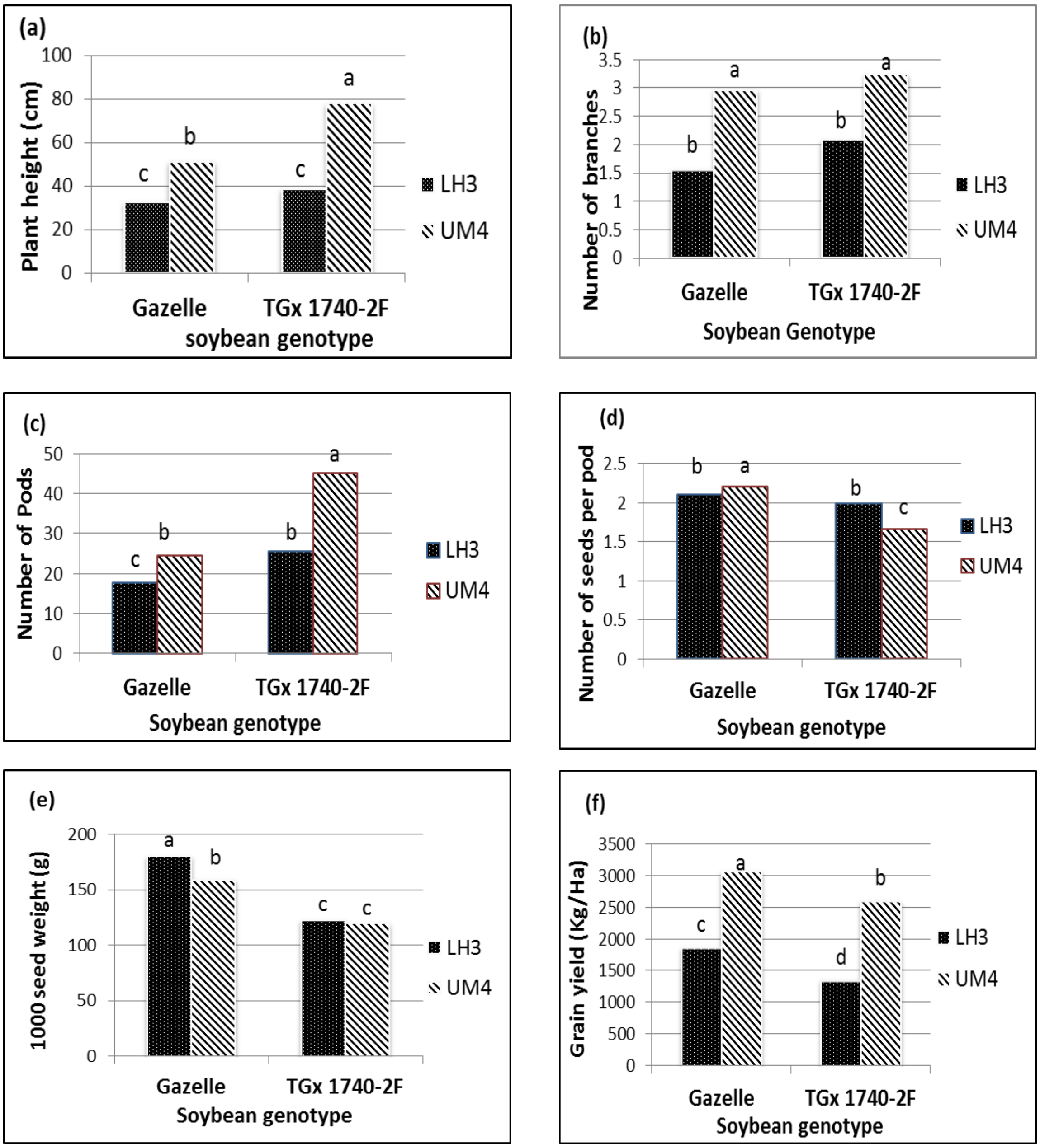

Figure 4.12: Effect of genotype and agro-ecology on soybean (a) Plant height (b) Number of branches (c)Number of pods/plant (d) Number of seeds per pod (e) 1000 seed weight (f) Seed yield.

Growing agro ecology had no significant effect on 1000 seed weight of genotype TGx 1740-2F, averaging 121g (Fig.4.12e). However, seed weight of Gazelle was greater in the higher altitude LH3 (180.5g) than lower altitude UM4 (159g). In addition, the number of pods and maturity plant height were significantly higher in the lower elevation agro-ecology (UM4), than in the higher elevation site (LH3) for both soybean genotypes. However, the number of branches per plant was not affected by growing agro ecology but the numbers of seeds per pod were greater in the highlands for genotype SB19. These results suggest that the heavier seeds of the crop in the highlands may be due to delayed maturity which may have resulted in greater accumulation of assimilates in the seed. In general however, soybean performed better in the mid-altitude UM4 (Nkoroi site), where they produced double the seed yields than at the high altitudes Lower Highlands III (Muguga site).

These results agree with what has been found elsewhere. Ogema *et al*. (1988) reported that in Kenya, altitude influences temperature, which in turn affects the initiation of flowering and maturity in soybeans; and that at very high altitudes, flowering may not occur and the crop remains vegetative, hence the soybean crop requires warm climates and is suitable for low to medium altitudes. Phenological development and yield of soybean genotypes has been found to decrease with increasing elevations (lower temperatures) due to a reduction in the rate of dry matter accumulation and that growth rate was strongly influenced by temperature but the rate of development and the duration of phenological phases was determined by both temperature and photoperiod (George, 1988). Soybean yield has also been reported to vary with temperature, quantities and distribution of precipitation (Popovic *et al.*, 2013).

4.4.2.3. Effect of Genotype and ecological interactions on soybean growth characteristics and yield

Data on the effect of genotype on soybean growth characteristics and seed yield are presented on Table 4.49. The results showed that soybean genotype significantly affected all growth characteristics except for the branching habit and seed yield at LH3 and UM4 growing sites ($p \leq 0.05$)

Table 4.49: The effect of interactions between genotype and agro-ecology (LH3 and UM4) on soybean growth and yield components

Agro-ecology	**Genotype**	**Plant height R7 Stage (cm)**	**Branches /plant**	**Pods / Plant**	**Seeds /pod**	**1000 seed wt. (g)**	**Seed yield ($kgha^{-1}$)**
LH3-	Gazelle	32.35b	1.55a	17.59b	2.11a	180.47a	1864.4a
Muguga	TGx 1740-2F	38.83a	2.13a	25.31a	2.00b	122.93b	1363.4a
	LSD $_{0.05}$	**3.34**	**0.60**	**5.91**	**0.10**	**5.78**	**541.71**
UM4-	Gazelle	50.94b	2.97a	24.39b	2.21a	159.25a	3076.4a
Nkoroi	TGx 1740-2F	80.13a	3.31a	46.79a	1.63b	119.66b	2654.3a
	LSD $_{0.05}$	**3.90**	**0.81**	**6.25**	**0.12**	**7.52**	**469.89**

Values with same letter(s) in each column are not significantly different ($p \leq 0.05$)
LH3=Lower highlands III; UM4=Upper Midlands IV agro-ecological zones

The study revealed significant genotypic interaction with agro-ecologies on some studied parameters, e.g. differences in the plant height at maturity, number of pods per plant and number of seeds per pod, with TGx 1740-2F(SB19), having significantly higher pod numbers and maturity plant height, but fewer number of seeds per pod than cv. Gazelle. Seed weight varied with genotype with cv. Gazelle having a significantly higher 1000 seed weight of 180.5 (LH3) & 159.2 (UM4) than genotype TGx 1740 2F with 122.9 at LH3 and 119.6 at UM4. There was however, no significant influence of the interaction between genotypes and agro-ecologies on the number of branches per plant and seed yield. These results are contrary to the findings of Mahasi *et al.* (2011) who reported in a multi locational trial higher seed yields of TGx-1740 2F than Gazelle and other local checks under western Kenya Conditions. This could be explained by differences in soil chemical properties particularly the pH and Aluminum saturation is common in western Kenya, and variety resistant to this no doubt performed better.

In soybean, grain yield as in other crops is a complex character which is dependent on genetic potential, agronomic factors, biotic and environmental factors. The results obtained in the current study showed genetic differences in growth characteristics but not in yield. It is likely therefore that during the growing season, genotype Gazelle which matured earlier (3.5-4 months) than TGx 1740-2F (4.5-5 months) was able to escape drought. The mid-season dry spells which were experienced during crop growth (short rains 2013/2014) subjected soybean genotype 1740-2F to moisture stress which may have limited its potential productivity. These results agree with the findings obtained by mahasi *et al*. (2011) that the late maturing promiscuous soybean varieties produce huge biomass, but their grain yield is low as compared to early maturing varieties and that farmers preferred early maturing varieties that escaped drought.

4.4.3. Soybean seed quality as influenced by mother plant nutrition, genotype and agro-ecology

The effect of Nitrogen and phosphorus fertilization, including its interactions with agro-ecological site and genotype on soybean seed longevity and vigor was found significant ($p \leq 0.05$) (Figures 4.13; 4.14 and Tables 4.50, 4.51, 4.52 and 4.53).

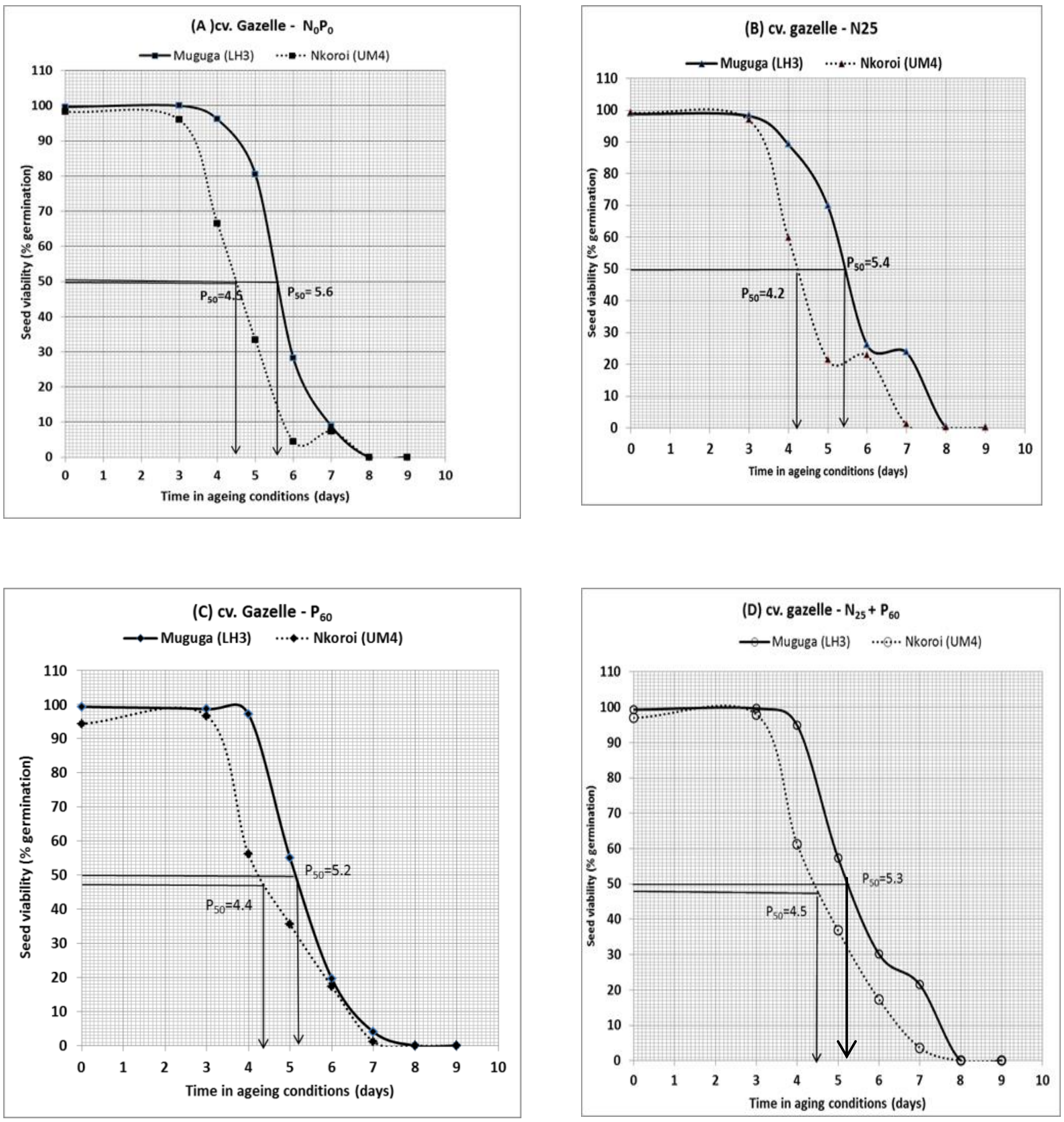

Figure 4.13: Seed survival curves for seed lots of genotype Gazelle grown in two agro-ecologies Muguga (LH3)and Nkoroi(UM4) under fertilizer treatment (A)N 0 kg ha^{-1}+ P 0 kg ha^{-1}; (B)N 25 kg ha^{-1}; (C)P 60 kg ha^{-1} and (D) N 25 kg ha^{-1}+ P 60 kg ha^{-1}.

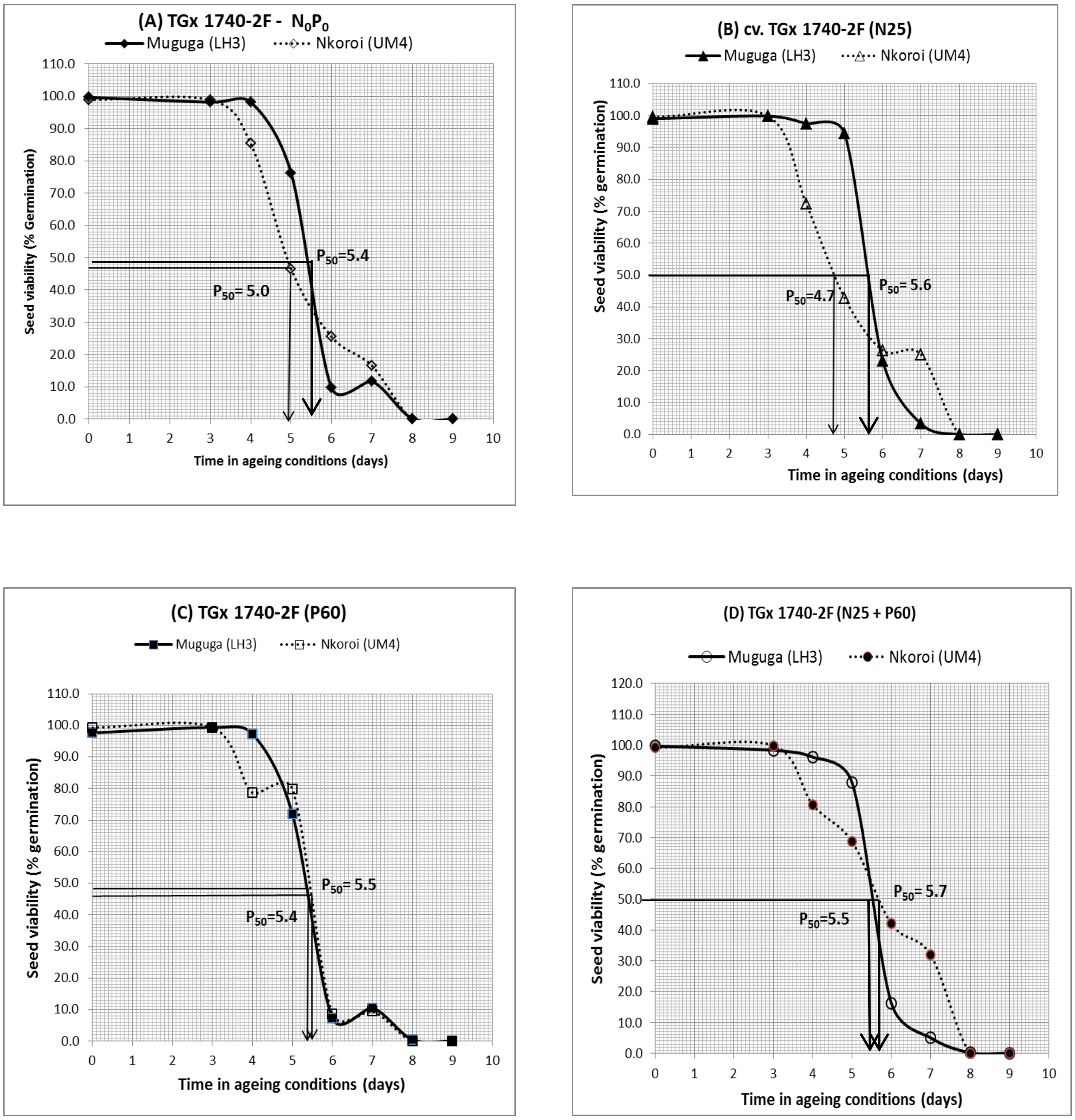

Figure 4.14: Seed survival curves for seed lots of genotype TGx 1740-2F grown in two agro-ecologies Muguga (LH3) and Nkoroi (UM4) under fertilizer treatment (A) N 0 kg ha^{-1}+ P kg ha^{-1}; (B) N 25 kg ha^{-1}; (C) P 60 kg $ha^{-1}$and (D) N 25kg ha^{-1} + P 60 kg ha^{-1}

The seed survival curves after accelerated ageing are presented on Figures 4.13 and 4.14. The time for viability to decline by 50% (p50) as influenced by N and P fertilization, genotype and seed growing agro-ecology was read off seed survival curves and summarized on Table 4.50. Discussions on the effect of studied factors on potential seed longevity (p50) of soybean are discussed under sections 4.3.3.1 to 4.4.3.4 below.

Table 4.50: Effect of genotype, agro ecology and N and P fertilizers on time for viability to decline to 50% (p50).

		Time for viability to decline by 50% (P50)			
GENOTYPE	**site**	**Control**	**N25**	**P60**	**N25+P60**
Gazelle	LH3-Muguga	5.6	5.4	5.2	5.3
	UM4 -Nkoroi	4.5	4.2	4.4	4.5
TGX 17402F	LH3 –Muguga	5.4	5.6	5.4	5.5
	UM4 -Nkoroi	5	4.7	5.5	5.7

P_{50} values were read off the seed survival curves on figures 4.13 and 4.14.

4.4.3.1. Effect of N and P mother-plant nutrition on longevity and vigor of soybean

Nitrogen and Phosphorous fertilizer application to mother plants of soybean showed significant but variable effects on soybean potential seed longevity and vigor ($p \leq 0.05$) (Tables 4.50, 4.51 and figures 4.13, and 4.14).

Table 4.51: Effect of Phosphorus and Nitrogen fertilization on seed leachate conductance of soybean genotype Gazelle and SB 19 grown LH3 and UM4 agro-ecologies at harvest.

Soybean Genotype	**Fertilizer Treatment**	**Electrical conductivity(µs/cm/g) at LH3-Muguga site**	**Electrical conductivity(µs/cm/g) at UM4- Nkoroi site**
Gazelle	N_0P_0 (Control)	24.44 ab	35.35 ab
	N 25	23.79 b	32.02 bc
	P 60	25.18 a	37.09 a
	N 25 + P 60	24.95 a	30.46 c
	$LSD_{0.05}$	*0.79*	*4.10*
TGx 1740-2F (SB19)	N_0P_0 (Control)	29.95 a	29.21 b
	N 25	29.71 a	30.16 b
	P 60	30.24 a	30.08 b
	N 25 + P 60	28.77 b	35.05 a
	$LSD_{0.05}$	*0.90*	*2.89*

Values with the same letter(s) in each column are not significantly different ($p \leq 0.05$)
LH3=Lower highlands III; UM4=Upper Midlands IV agro-ecological zones

Seed leachate conductance: Application of N and P fertilizers to mother plants had both negative and positive effects on seed vigor as shown by the seed membrane leachates and varied with site and genotype (Table 4.51). Phosphorous application at 60kg^{-1}ha (P_{60}) and Nitrogen at 25kg^{-1}ha (N_{25}) had no significant effect on seed leachates of Gazelle and TGx 1740 2F at both LH3 Muguga and UM4 Nkoroi sites. However, application of both N_{25}+P_{60} enhanced vigor of soybean genotype Gazelle as shown by reduced seed leachates at warmer UM4 but had no effect at LH3. On the contrary, N_{25}+P_{60} reduced seed leachates for TGx 1740-2F meaning enhanced vigor at cooler LH3 Muguga, but increased membrane leakiness at UM4 site, indicative of a reduction in seed membrane integrity, hence seed vigor.

Time for viability to decline by 50% (P_{50}): The effect of N and P fertilizer application to mother plants on potential seed longevity as determined by the time for viability to decline by 50% (P_{50}) under accelerated ageing conditions (41^{0}C, 100%RH) varied with site and genotype (Table 4.50, Figures 4.13 and 4.14). Application of N at 25kg ha^{-1} increased potential seed longevity of genotype TGx 1740 2F at highlands (LH3) (P_{50} of 5.6 days) but reduced it at the lower UM4 site. On the other hand, N reduced potential seed longevity at both sites for genotype Gazelle; but application of P at 60 kg ha^{-1} (P_{60}) had no effect on Gazelle at both sites. However, application of P to mother plants of TGx 1740 2F increased potential seed longevity (5.5 days) than control (5.0 days) at lower altitude warmer UM4 but had no effect at the cooler higher altitude LH3. A combined application of P_{60} + N_{25} enhanced potential longevity for genotype TGx 1740 2F at LH3 and UM4; but reduced seed longevity for genotype Gazelle at LH3 and had no effect at UM4.

The results of the study revealed that a combined application of P (60 $kgha^{-1}$) followed by top dressing with N (25$kgha^{-1}$) was better than fertilization with N and P separately, as it improved the integrity of seed membranes as shown by the reduced seed leachates in both soybean genotypes Gazelle and TGX 1740-2F. However, this positive effect was not consistent as it reduced seed membrane leakiness in one site but not in another. Moreover, potential seed longevity (P_{50}) was enhanced by application of all fertilizer treatments (N_{25}, P_{60} and N_{25}+P_{60}) only for genotype TGx 1740 2F, but this effect was not consistent in all sites. However, N_{25}+P_{60} mother plant nutrition of genotype Gazelle at UM4 had no effect on potential seed longevity but reduced it in all other treatments and sites. Overall treatments and sites, N and P fertilization enhanced longevity of soybean genotype TGx 1740 2F but reduced it for Gazelle.

These results revealed that the effect of N and P fertilization on soybean mother plants seed longevity and vigor was not clear as it showed no effect, detrimental and beneficial outcomes, depending on site and genotype. These results agree with the findings of Krueger *et al.,* 2013 who reported that the effects of P and K fertilization in soybean seed quality were unclear since fertilization rates had a positive effect on yield and composition in some growing locations and years but not in others. Moreover, Lott *et al.,* (1995) suggested that increased levels of phosphorus in the seed may result in increases in seed leakage due to more phosphorus leakage during germination and higher pathogen loads, but their relationship was unclear. Results by Krueger *et al.,* (2012) also reported that high levels of phosphorus fertility negatively impact soybean seed vigor in many production environments.

In addition, Nitrogen fertilization has been reported both to have no effect and to increase seed vigor. N application to the mother plants has been found to enhance the integrity of seed membranes (Bewley and Black1985) and to increase seed germination and uniformity in tobacco (Thomas and Raper, 1979) while Soffer and Smith, (1974) reported a linear relationship between seedling vigor, nitrogen supply and general soil fertility in lettuce. However, response of soybean to N fertilizer has been found to be contradictory and to depend on cultivar, quantity and source of nitrogen, sowing date and plant population/area, as well as environmental conditions (Gibson, 1976, Marcos-Filho *et al.,* 1994). Soybean grown with *bradyrhizobium japonicum* inoculant was reported to have better yield and seed quality than with the use of mineral nitrogen (Marcos-Filho *et al.,* 1994). Soybeans that are well nodulated with rhizobia bacteria have been found not to respond to N fertilizer, however, irrigated soybeans with high yield potential have been found to respond to Nitrogen application at the R3 growth stage (Mengel, 2011).

From the current study, one likely reason for the poor response of seed longevity and vigor to increased fertilization was the above optimum initial soil fertility levels of the experimental sites (Table 4.46). However the smaller seeded promiscuous soybean with large biomass (plant height 37- 83cm) genotype TGX1740-2F responded better to fertilization in terms enhanced seed longevity and vigor than the larger seeded non-promiscuous soybean Gazelle with smaller biomass (plant height 30-53cm). Possibly, the likely reason is that TGx 1740 2F used the above optimum N and P nutrition in production of biomass and less was translocated to seed. However, because Gazelle had less biomass the excess N and P may have negatively impacted on potential seed longevity and vigor by increasing leakiness of seed membranes. However, these results were unclear as the addition of supplementary N and P fertilizer had no effect, had a positive effect or negatively impacted on potential seed longevity and vigor of soybean genotypes Gazelle and TGx-1740 2F.

4.4.3.2. Effect of genotype on soybean seed longevity and vigor

The effect of soybean genotype on seed longevity under ageing conditions and vigor was found significant $p \leq 0.05$).

Seed leachate conductance at harvest: The seed leachate conductance at harvest for tested genotypes of soybean that were produced in two contrasting agro-ecologies is presented on Table 4.52.

Table 4.52: Comparison of means of seed leachate conductance (EC) of soybean genotypes grown at LH3 and UM4 agro-ecologies.

Growing agro-ecology	Genotype	EC µs/cm/g
LH3-Muguga	Gazelle	24.59 b
	TGX 1740-2F (SB 19)	29.66 a
	LSD $_{0.05}$	0.43
UM4- Nkoroi	Gazelle	33.73a
	TGX 1740-2F (SB 19)	31.12 b
	LSD $_{0.05}$	1.74

Values with the same letter in the column are not significantly different ($p \leq 0.05$)
LH3=Lower highlands III; UM4=Upper Midlands IV agro ecological zones

From the analysis of presented data, it is clear that seed leachate conductance (EC) at harvest showed varied with site and genotype. At higher altitude LH3 Muguga site, genotype Gazelle (24.59 µs/cm/g) had significantly less leachates than TGx 1740 2F (29.66 µs/cm/g), while at the lower altitude UM4 agro-ecology, the opposite occurred with Gazelle (37.73 µs/cm/g) having more leachates than TGx 1740 2F (31.12 µs/cm/g). The likely reason for this was that Gazelle was susceptible to field weathering causing a reduction in seed membrane integrity at the warmer site than SB19, probably due inherent qualities of the species such as larger seed size and weaker seed coat properties.

Time for viability to decline by 50% (P_{50}): Data on seed longevity as determined by the time for viability to decline by 50% (P_{50}) after accelerated ageing for 9 days are presented in Table 4.50 and figures 4.13 (Gazelle) and fig. 4.14 (TGx 1740-2F)

Prior to accelerated ageing, the seed germination means were 99% and 97% for genotype Gazelle at higher elevation (LH3) Muguga and at lower elevation (UM4) Nkoroi experimental sites respectively; but was 99 % for genotype TGx 1740-2F in both sites. After accelerated ageing for 9 days (41^0C, 100%RH), the results revealed that across agro-ecologies and nutrient profiles genotype TGx 1740 2F had a greater potential seed longevity (P_{50}) than Gazelle. (Table 4.50 and Figures 4.13 and 4.14).

These observations revealed that there was greater decline of seed longevity and vigor in the large seeded (1000 seed weight = 170g) with yellow seed coat soybean genotype Gazelle than in the smaller seeded (1000 seed weight = 120g) with yellow seed coat TGx 1740- 2F. Genetic differences have been known to determine the rate of seed deterioration (Hinson and Hartwig, 1977). Deterioration of soybean seed quality has been associated with large seed size and permeable seed coats (Horlings *et al.*, 1991). Singh *et al*., 1978, reported a strong negative association of germination with seed weight among soybean genotypes. Nangju, (1977) and Dassou & Kueneman, (1984) reported that black and small-seeded soybean genotypes were more resistant to field weathering than the yellow and large-seeded ones. Higher seed quality of soybean has been associated with higher percentage of seed coat and slower rate of imbibition.

The seed with thicker seed coats had delayed moisture absorption resulting in good quality seeds (Srijankul, 2001).

The results of this study agree with these findings, since the larger seeded genotype Gazelle lost viability and vigor faster than the smaller seeded TGx 1740- 2F (SB19), under ageing conditions. The seed coat properties may also contribute to the observed genotypic differences between the two studied genotypes. Moreover, seed survival curves have been reported to show variety and seed lot differences in potential seed longevity among soybean varieties (Zanakis *et al*., 1993). This study therefore showed that genotype TGx 1740 2F had greater potential seed longevity and vigor than Gazelle.

4.4.3.3. Effect of growing agro-ecology on soybean seed longevity and vigor

In view of the fact that seed longevity is dependent on environmental factors, in particular relative humidity and temperature, the corresponding environmental factors during soybean growth were assessed from existing data published in the Farm Management Handbook of Kenya (Jaetzold *et al*., 2011). The effect of growing agro-ecology: wetter and cooler Lower Highlands III as well as the drier and warmer Upper Midlands IV on seed longevity and vigor was found significant ($P \leq 0.05$) (Tables 4.50, 4.53 and Figures 4.13 and 4.14).

Seed leachate conductance, which is an indicator of the integrity of seed membranes showed that soybean seeds grown in the warmer lower elevation (1805masl) UM4 had significantly higher leachates, indicating greater loss of seed membrane integrity than seed grown in the cooler higher elevations (2100masl) LH3 (Table 4.53).

Table 4.53: Effect of growing agro-ecology (LH3 and UM4) on seed leachate conductance of soybean Gazelle and SB19.

Growing Agro-ecology	Electrical conductivity (µs/cm/g)	Electrical conductivity (µs/cm/g)
	Gazelle	**TGx 1740-2F (SB19)**
LH3- Muguga	24.59 b	29.66 b
UM4 - Nkoroi	33.73 a	31.12 a
$LSD_{0.05}$	1.48	1.07

Values with the same letter in each column are not significantly different ($p \leq 0.05$)
LH3=Lower highlands III; UM4=Upper Midlands IV agro ecological zones

Time for viability to decline by 50% (P_{50}): Similarly, data on the effect of growing agro ecology on potential seed longevity revealed that seeds grown in the lower, warmer altitude UM4 had reduced potential seed longevity than seed grown in the highlands (LH3). This was shown by the shorter P_{50} ranging from 4.2 to 4.4 days (Gazelle) and 4.7-5.7days (TGx-1740 2F) at UM4, than seed grown in the higher cooler elevations of LH3 which showed greater potential longevity with P_{50} *of* 5.2-5.6 days and 5.4-5.6 days for genotype Gazelle and TGx 1740-2F respectively.

These results revealed that soybean seeds lost vigor prior to harvest with the loss being exacerbated with increased temperatures during growth experienced in the lower altitudes. Soybean seeds may lose vigor prior to harvest, especially when grown in humid, tropical environments. According to Harrington's rule (1960) rule of the thumb, seed longevity is approximately doubled for every 5^0C drop in temperature and for every 1% drop in moisture. Therefore viability of seeds is not only influenced by relative humidity and consequently seed moisture content, but also with seed temperature. Tropical conditions of high temperature and relative humidity during the seed maturation period are not conducive to the production of high quality seed (Paschal and Ellis, 1978). Deterioration of soybean seed in pods on the plants after maturity and before harvest (field weathering), has been found to be caused by several environmental factors such as high air temperature and relative humidity as well as percent precipitation per day (Yaklich and Cregan 1987, TeKrony *et al*., 1980)

These differences in growing agro-ecologies were confirmed by observed changes in seed longevity and vigor. The soybean seed grown in the cooler highland Muguga site had higher potential longevity (P_{50}), lower seed membrane leachates and higher 1000 seed weights than seed grown in the warmer lower altitude UM4 Nkoroi site. Therefore this study recommends that soybean farmers and seed producers in general should grow seed in higher cooler altitudes since such seeds are of greater longevity than seed produced in the lower hotter altitudes. However, due to the ability of the smaller seeded genotype TGx 1740 2 F to resist field weathering, it can be grown in the lower altitudes of UM4 without much loss in seed longevity and vigor.

4.4.3.4. Relationship between seed viability and vigor of soybean under accelerated ageing

The correlation between germination percent and seed leachate conductance was highly significant and negative ($r = 0.91$; $p \leq .0001$) (Fig. 4.15). This means that as germination percent decreased, seed leachate conductance increased with increasing deterioration time under aging conditions (41^0C and 100%RH); showing the adverse effect of deterioration on soybean seed viability and vigor.

.

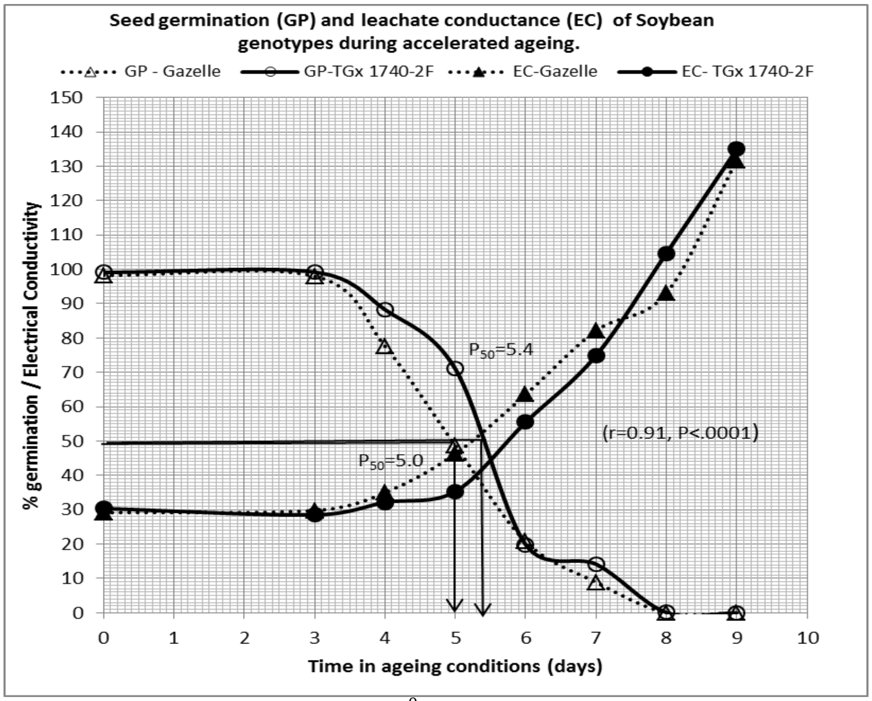

Figure 4.15: Effect of accelerated aging (41^0 C, 100% relative humidity) on germination and seed leachate conductance of soybean seed variety Gazelle and TGx 1740-2F (SB19).

Genotypic differences in seed vigor (electrical conductivity) and potential seed longevity (P_{50}) was evident as shown on the seed survival curves. Genotype Gazelle had more seed membrane leakiness and a shorter P_{50} of 5.0 days than TGx-1740 2F (5.4 days). The observations made in this study revealed a negative cumulative normal distribution pattern in the decline of seed viability under aging conditions and a positive exponential increase in seed leachates with ageingThese results agree with the findings of Ellis and Robert (1980) who observed that seed deterioration in storage follows a negative cumulative normal distribution pattern and the time taken for viability to decline by 50% (P_{50}) is a measure of absolute seed longevity. This study also revealed greater seed vigor and potential seed longevity in genotype TGx-1740 2F (SB19) than Gazelle. These results agree with the findings of Zanakis *et al*. (1993) who found variety and seed lot differences in potential seed longevity among soybean genotypes.

4.4.4. Summary of findings

The findings of the study on the effect of mother plant nutrition, genotype and agro ecology on soybean productivity and quality revealed that: (a) Soybean productivity was mainly influenced by genotype and growing agro-ecology but not by addition of supplementary N and P fertilizers. Genotype Gazelle produced higher yields than genotype. TGx 1740-2F (SB19), with the low altitude crop producing higher yields than the high altitude crop. Best plant performance regarding early maturity, greater plant height at R7 growth stage, more pods and higher yield was found in the mid altitude site. Gazelle produced 1864and 3076 $kgha^{-1}$ while TGx 1740- 2F produced 1351 and 2599 kg ha^{-1} at higher altitude (LH3) and mid altitude (UM4) sites respectively. (b) Application of N and P fertilizers mostly had no significant effect in improving soybean growth and productivity possibly most likely because of the high levels of initial soil fertility. However, addition of Phosphorous at 60kg ha^{-1} followed by top dressing with N at 25kg-1ha to genotype. Gazelle at Mid altitude Nkoroi site showed positive yield response. Soybean seed longevity and vigor was influenced by genotype and agro-ecology. The small seeded genotype TGx1740-2F resisted field weathering and was of higher longevity and vigor than the large seeded genotype. Gazelle. Soybean seeds grown in the cooler highlands (LH3) had larger seed weight (Gazelle), greater number of seeds per pod, greater seed longevity and vigor than seed produced in the warmer mid altitude (UM4). Among the nutrition treatments studied, best results in terms of enhancement of seed longevity and vigor was obtained when N and P were applied at (N25 and N 25+P 60) but the this response was evident on soybean genotype TGx 1740 2F but not Gazelle. The effect of N and P fertilization on soybean mother plants on seed longevity and vigor was not clear as it showed no effect, detrimental and beneficial outcomes, depending on site and genotype.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Introduction

This chapter covers the conclusions drawn from the findings and the recommendations. All the subsections follow chronologically in the order of objectives. Based on the findings and recommendations, areas of further research are outlined.

5.1. Conclusions

- Soybean in Meru south sub-county is a small scale, newly introduced crop that is faced various challenges: lack of a proper seed system, low yields, poor agronomic practices, poor utilization, inadequate processing and lack of established markets. Farmers relied on farm saved seed and seed exchange with other farmers because there was no established source of certified seed in Meru South Sub-county. Soybean was mainly grown as a pure crop, without mechanization in the short rains (Oct/Nov), with Gazelle being the most preferred genotype because of high yields, large grain size and early maturity. The farm saved seed quality was affected by poor seed handling practices and seed storage agro ecology. Soybean seed was exposed to field weathering, mechanical damage during threshing, heat damage with sun drying and exposure to moisture and pests during storage in synthetic gunny bags; predisposing seed to ageing. The farm saved seed obtained from the higher and cooler agro-ecologies of Chuka and Magumoni wards had greater viability and vigor than seed found in the lower warmer elevations of Igamba’ngombe.

- There was a significant reduction in soybean seed viability and vigor during 8 months of ambient storage in contrasting agro ecologies in Meru South Sub-county. However the degree of seed deterioration was influenced by genotype, seed storage agro-ecology, type of storage containers used and seed dressing applied at storage. The small seeded genotype TGx1740-2F (SB19) was a better storer than larger seeded Gazelle. Sealed plastic cans, seed dressing with ash and storage in the cooler agro-ecology (UM2) was found effective for enhancing seed viability, longevity and vigor of soybean genotypes Gazelle and TGx 1740-2F (SB 19) in Meru South Sub-county.

- Priming enhanced vigor but reduced germination. However vigor enhancement was evident on genotype TGx 1740-2F (SB19) but not Gazelle. Osmo-priming with polyethylene glycol 6000 at -1.0 Mpa and for 6 and 24 hours was the most beneficial treatment. Primed soybean seed was found storable as the enhanced vigor was retained after 8 months of post-priming seed storage in all treatments than non-primed seed.

- Growing Agro-ecology influenced yield and quality of soybean. The cooler higher altitude LH3 produced lower yields but higher quality seeds than the warmer mid altitude UM4 which produced higher yields but poorer seeds. There was no yield response to N and P fertilization to soybean except for Gazelle at UM4. However N 25 $kgha^{-1}$ and a combination of N 25 $kgha^{-1}$+P 60 $kgha^{-1}$ improved seed vigor but P_{60} alone reduced vigor , but effects were not conclusive as they varied with genotype and agro-ecology. Genotypic differences in seed quality were evident, with larger seeded genotype. Gazelle having poorer seed as shown by the shorter potential seed longevity

(p_{50}) and susceptibility to damage due to priming and field weathering than the smaller seeded TGx 1740 2F (SB19).

5.2. Recommendations

From the findings, the following recommendations were derived:

- There is need to streamline the entire soybean value chain in in Meru South sub-county in order to increase production to meet the high market demand. This should be done by Streamlining of the seed system; Ensuring access to affordable farm inputs; Providing assured markets; Improving crop management for better yields; Providing early maturing varieties for drought escape; Promoting soybean in traditional diets for nutritional benefits; Expanding utilization; Easing processing through appropriate technology and; Promoting youth engagement in agriculture as a business to take over from aged farmers. In addition, farmers should source their soybean seeds from the cooler higher altitudes of Meru south as they showed greater seed viability and vigor than seed from Lower warmer areas.

- Sealed plastic Jeri cans, seed dressing with ash and storage in cooler agro-ecologies is recommended for enhanced soybean seed longevity and vigor under ambient conditions. Seed can be safely stored this way for up to 8 months with germination percent being retained above 96% hence is the recommended storage method for soybean in such environments. If need be, such seed can be transferred to the warmer agro-ecologies for planting during the planting season. This will eliminate the need for cold storage of seed using cold rooms which are expensive to maintain resulting in increased prices of seed. Genotype TGx 1740 2F showed better storability than Gazelle even in the warmer lower altitudes, hence TGx 1740 2F is a superior variety in terms of storability under adverse ambient conditions and is recommended for adoption in such environments.

- Priming using Polyethylene glycol 6000 at -1.0 Mpa for 6 and 24 hours duration is recommended for invigoration of low vigor soybean seeds of SB19. This practice can offer potential benefits in solving soybean seed viability problems in high humidity, high temperature agro-ecologies where the rate of soybean deterioration is high. Storage of primed seed is recommended especially for low vigor seeds, since the benefits of priming of enhanced seed vigor were retained during the 8 months post-priming storage in ambient conditions of20 ± 2^0C and RH 50% in the study regions.

- It is recommended to produce soybean seed in the cooler highlands for greater longevity and vigor, but produce in the midlands for higher grain yields. Yield response to N and P fertilizers was poor; hence use of supplementary fertilizers on soybean should take into consideration the initial soil fertility levels. Preferably soybean should be grown as a second crop after crops like maize and wheat, so that they can utilize residual fertilizers, while at the same time improving soil fertility by biological nitrogen fixation. Moreover, a combined application of Phosphorous at 60 kg ha^{-1} followed by topdressing with Nitrogen at $25kg^{-1}$ha is recommended for quality seed especially on soils with low fertility. Since application of P 60 kg ha^{-1} reduced seed vigor, application of high levels of phosphorous is not recommended for production of quality seed. However, further investigation is required since the response was not clear as it varied with genotype and growing agro-ecology. In order to obtain maximum yields for the late maturing genotype TGx 1740-2F (SB19), it is recommended to be grown where there is sufficient rainfall. Because of the ability of SB19 to withstand field weathering, it can be grown in the lower warmer altitudes without much loss in seed viability and vigor.

5.3. Areas for further research

Based on the findings of the research, the following areas for further research were identified:

- There is need to further look into the development of holistic approaches in the development of the soybean value chain. Such approaches should incorporate scientific research findings, farm household based strategies, seed systems, utilization, processing and marketing in order to reduce risks and enhance adoption strategies and decision making by all investors.

- Further research should be done to characterize the biochemical, seed coat properties and composition of fatty acids of the two soybean genotypes –TGx-1740-2F and Gazelle with a view of understanding the reason for the superior nature of TG-1740-2F in with standing deterioration under tropical conditions than Gazelle. The superior qualities of TGx 1740-2F could be incorporated in breeding programs to improve storability (longevity) and vigor of genotype. Gazelle under tropical conditions of high temperature of moisture.

- There is need to explore further the effect of priming and post priming storage on soybean seed with initial low viability and vigor; and whether this practice can offer potential benefits in solving soybean seed viability problems in high humidity, high temperature agro-ecologies where the rate of soybean deterioration is high.

- The yield, seed longevity and vigor response of soybean nitrogen and phosphate fertilizer mother plant nutrition needs to be examined in subsequent studies since the response was not clear as it varied with genotype and site. On the other hand, the late maturing genotype. TGx 1740-2F (SB19), should be put under breeding programs in order to incorporate early maturity so that it can be grown in low rainfall areas successfully. Farmers then can reap its potential benefits of high yields, resistance to field weathering, good seed storability and soil fertility improvement through biological nitrogen fixation.

REFERENCES

Abbasi S.A, Sharif-Zade F., Tavakkol A.R, Majnoun H.N and Gazor H.R (2009). Optimization of soybean (*Glycine max* Merr.) seed drying conditions with response surface methodology in a constant-bed dryer using two cultivars. *Seed Sci Technol.* 37:650-666.

Abdul-Baki, A. and Anderson J. D. (1970).Viability and leaching of sugar from germinating barley. *Crop Science*, 10 (1): 31-34.

Abdul-Baki, A. and Anderson J.D. (1973). Vigor determination in Soybean seed by multiple criteria. *Crop Science*, 13: 630-633.

Abdulrahmani B, Ghassemi-Golezani K, Valizadeh M, Feizi-Asl V. (2007). Seed priming and seedling establishment of barley (*Hordeum vulgare* L.). *J Food Agric. Environ.* 5:179-184.

Abnavi M. S.I and Ghobadi M.R (2012). The effects of source of priming and post-priming storage duration on seed germination and seedling growth characteristics in wheat (*Triticum aestivum* L.). *Journal of Agricultural Science*; 4(9) 237-282.

Abuli J. S., Mugwe J. N. and Mugendi D. N. (2012). Effects of phosphorus sources on soybean yield in Central Highlands of Kenya. Department of Agricultural Resource Management, Kenyatta University. 591-601

Acklin T. (1998). Soybean handling and storage. In *World-Grain.com*.

Adebayo R.A. and Ibikunle O. (2015). Potentials of rice husk ash, cow dung ash and powdered clay as grain protectants against *Callosobruchus maculatus* (F) and *Sitophilus zeamais* (Mots). Department of Crop, Soil and Pest Management, Federal University of Technology, Akure, Nigeria: 48-53.

Adebisi, M A. Daniel O. and Ajala M.O. (2004). Storage life of soyabean (*Glycine max*.L.) seeds after seed dressing. *Journal of Tropical Agric*. 42 (1&2): 3-7.

Afzal I., Ahmad N., Basra S.M.A, Ahmad R. and Iqbal A. (2002). Effect of different seed vigour enhancement techniques on hybrid maize (*Zea mays* L.). *Pakistan J Agric Sci.* 39:109-112.

Ajouri A., Haben A., and Becker M. (2004). Seed priming enhances germination and seedling growth of barley under conditions of P and Zn deficiency. *J Plant Nutrition Soil Sci.* 167: 630-636.

Akter N., Haque M. M., Islam M. R. and Alam K. M. (2014). Seed Quality of Stored Soybean (*Glycine max* L.) as Influenced by Storage Containers and Storage Periods. *The Agriculturists.* 12(1): 85-95

Amico R.U, Zizzo G.V, Agnello S, Sciortino A and Iapichino G. (1994). Effect of seed storage and seed size on germination, emergence and bulbelt production of *Amaryllis belladonnal* L. *Acta. Hortic*. ISHS 362: 281-288.

Ansari O. and Sharif-Zadeh F. (2012). Osmo and hydro priming improvement germination characteristics and enzyme activity of Mountain Rye (*Secale montanum*) seeds under drought stress. *Journal of Stress Physiology & Biochemistry*.8(4):253-261.

AOSA (2009). Baalbaki, R., S. Elias, J. Marcos-Filho and M.B.McDonald (eds.). Seed vigor testing handbook. Contribution 32.AOSA, Ithaca, NY.

AOSA (1983). Seed vigor testing handbook. Springfield. 1p

Argerich C.A, and Bradford K.J, (1989). The effects of priming and ageing on seed vigour in tomato. *J. Exp. Bot.*, 40:599-607.

Argerich CA, Bradford KJ, Tarquis AM. (1989). The effects of priming and ageing on resistance to deterioration of tomato seeds. *Journal of Experimental Botany* 40: 593–598.

Arif M., Jan M.T., Marwat K.B and Khan M.A (2008). Seed priming improves emergence and yield of soybean. *Pak. J. Bot*., 40(3): 1169-1177

Arif M., Jan M.T., Mian I.A., Khan S.A., Hollington P. and Harris D. (2014). Evaluating the impact of osmopriming varying with polyethylene glycol concentrations and durations on soybean. *Int. J. Agric. Biol*. 16: 359–364.

Babiker, A. Z., Dulloo, M. E., Mustafa, M. A., Balla, E. and Ibrahim, E. T. (2010). Effects of low cost drying methods on seed quality of Sorghum bicolor (L.) Monech. *African Journal of Plant Science*, 4(9):339-345.

Bailly C. (2004) Active oxygen species and antioxidants in seed biology. *Seed Science Research.* 14: 93-107.

Bailly C., Bogatek-Leszczynska, R., Côme, D. and Corbineau F. (2002).Changes in activities of antioxidant enzymes and lipoxygenase during growth of sunflower seedlings from seeds of different vigour. *Seed Science Research.* 12: 47–55.

Balešević-Tubić M., Tatić V., Đorđević Z., Nikolić, J. Subić and Đukić V. (2011) Changes in soybean seeds as affected by accelerated and natural aging. *Romanian Biotechnological Letters*. 6(6)

Balešević-Tubić, S., Tatić, M., Đorđević, V., Nikolić, Z. and Đukić, V. (2010). Seed viability of oil crops depending on storage conditions. Institute of Field and Vegetable Crops, M. Gorkog 30, 21000 Novi Sad, Republic of Serbia.

Basra S. M. A., M. N. Zia, T. Mehmood, I. Afzal and A. Khaliq (2003). Comparison of different invigoration techniques in wheat (*Triticum aestivum* L.) seeds. *Pak. J. Arid Agric*. 5: 6-11.

Basra S.M, Ullah E, Warriach E.A., Cheema M.A. and Afzal I. (2003a). Effect of storage on growth and yield of primed canola (*Brassica napus*) seeds. *Int. J. Agric. Biol*. 5:117-1120.

Bellaloui Nacer, Roddy K.N., Bruns A.H., Gillen A.m, Mengistu A., Zobiole L.H.S, Fischer D.K, Abbas H.K, Zablotowicz R.M. and Kremer J.R. (2011). Soybean seed composition and quality: Interactions of Environment, genotype and Management Practices. In soybeans: Cultivation, Uses and Nutrition. ISBN: 978-1-61761-762-1.

Bewley J.D, (1997). Seed germination and dormancy. *Plant Cell* 9:1055- 1066.

Bewley, J.D; Black, M. (1985). Seeds - physiology of development and germination. New York, Plenum Press.367.

Bishnoi U.R., Kaur G. and Khan M.H. (2007). Calcium, phosphorus, and harvest stages effects soybean seed production and quality. *Journal of Plant Nutrition* 30:2119-2127

Biswas J.C., Ladha J.K. and Dazzo F.B (2000). Rhizobia inoculation improves nutrient uptake and growth of lowland rice. In *Soil Science Society of America*. (Impact Factor 2) 09/2000; 64(5): 1644-1650.

Bittencourt M.L.C, Dias D.C.F.S, Dias L.A.S. and Araújo E.F (2005). Germination and vigour of primed asparagus seeds. *Sci. agric.* (Piracicaba, Braz.) 62(4).

Borges R., A.P Mallarino. (2000). Grain yield, early growth, and nutrient uptake of no-till soybean as affected by phosphorus and potassium placement. *Agronomy Journal*. 92:380-388.

Bradford K.J. (1986). Manipulation of seed water relations via osmotic priming to improve germination under stress conditions. *Hort. Sci.* 21:1105-1112.

Brady, N.C. (2002). Phosphorus and potassium. In: The nature and properties of soils. Prentice-Hall of India, Delhi. 352.

Bray C.M. (1995). Biochemical processes during the osmopriming of seeds. Seed development and germination. Marcel Dekker Ed., New York.

Bruggink G.T., Ooms J.J.J. and Van der Toorn P. (1999). Induction of longevity in primed seeds. *Seed Sci Res.* 9:49-53.

Buchvarov P.and Gantcheff T. (1984). Influence of accelerated and natural aging on free-radical levels in soybean seeds. *Physiologia Plantarum.* 60:53-56.

Bulisani E. and Warner R.L. (1980). Seed protein and nitrogen effects upon seedling vigor in wheat. *Agronomy Journal*, Madison, 72:657-662.

Burgass R.W. and Powell A.A. (1984). Evidence for repair processes in the invigoration of seeds by hydration. *Annals of Botany*. 53: 753–757.

Burris J.S. (1980). Maintenance of soybean seed quality in storage as influenced by moisture temperature and genotype. *Iowa State J. of Research* 54: 337-389.

Butler L. H., Hay F. R., Ellis R. H., Smith R. D. and Murray, T. B. (2009). Priming and re-drying improve the survival of mature seeds of Digitalis purpurea. *Annals of Botany*. 103: 1261–1270.

Carlos A.P. and Cantliffe D.J., (1992). Priming leek seed for improved germination and emergence at high temperature. *HortScience*, 27: 1077–1079

Caseiro, R., Bennett, M. A., & Marcos-Filho, J. (2004). Comparison of three priming techniques for onion seed lots differing in initial seed quality. *Seed Sci. Technol*. 32: 365-375.

Chanhan K. P. S., Negi M. C. S. and Verma M. M. (1984). The effects of Thiram on the incidence of ageing induced changes in seeds. *Seed Research.* 12: 110-119.

Chianu J. (2006). Soybean (*Glycine max*) promotion for improved nutrition and soil fertility in smallholder farms, East Africa. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture (CIAT).

Chianu J. N, Vanlauwe B, Mahasi J.M., Katungi E, Akech C, Mairura F.S, Chianu Justina N, and Sanginga N (2008). Soybean Situation and Outlook Analysis: The Case of Kenya.1-50

Ching T.M. and Schoolcraft I. (1968). Physiological and chemical differences in aged seeds. *Crop Science*. 8:407.

Ching T.M.and Rynd L. (1978). Developmental differences in embryos of high and low protein wheat seeds during germination. *Plant Physiology*, Rockville. 62: 866-870.

Chiu K.Y, Chen C.L and Sung J.M. (2002). Effect of priming temperature on storability of primed Sh-Z sweet corn seed. *Crop Science*. 42:1996-2003

Clark L.J., Whalley W.R., Ellis-Jones J., Dent K., Rowse H.R., Finch-Savage W.E, Gatsai T., Jasi L., Kaseke N.E, Murungu F.S., Riches C. R. and Chiduza C. (2001). On-Farm Seed Priming in Maize: A Physiological Evaluation. Seventh Eastern and Southern Africa Regional Maize Conference. 268-273.

Copeland L. O. (1976). Principles of Seed Science and Technology. Burgess Pub.

Copeland L.O. and M.B McDonald. (1995). Principles of seed science and technology. 3rd edition. Chapman and Hall. New York, USA. 409

Copeland, L.O. and McDonald, M.B. (1999): Principles of seed science and technology. Kluwer Academic Publishers Group, Dordrecht.

Cromarty, A.S., Ellis, R.H. and Roberts, E.H. (1985). Design of seed storage facilities for genetic conservation. International Board for Plant Genetic Resources, Rome, Italy.

Danso S.K.A., Kapuya J. and Hardarson G. (1990). Nitrogen fixation and growth of soybean as influenced by varying the methods of inoculation with Bradyrhizobium japonicum. *Plant and Soil*, 25:81-86.

Dassou S. and Kueneman E.A. (1984). Screening methodology for resistance to field weathering of soybean seed. *Crop Science*. 24: 774-779.

Daws M.I., Lydall E., Chmielarz P., Leprince O., Mathews S., Thanos C.A., Pritchard H.W. (2004). Developmental heat sum influences recalcitrant heat traits in Aesculus hippocastanum across Europe. *New Phytologist*, 162:157-166.

Delouche J.C. and Baskin, C.C. (1973). Accelerated aging techniques for predicting the relative storability of seed lots. *Seed Science and Technology*, Zurich. 1(2): 427-452.

Demir I. (2003). Effect of controlled hydration treatment on quality of aubergine seeds following storage. *Phyton Annales Rei Botanicae*, 43:307–317.

Demir Kaya M., Okçu Gamze., Atak M., Çikili Y. and Kolsarici Ö. (2006). Seed treatment to overcome salt and drought stress during germination in sunflower (*Helianthus annuus* L.). *Eur. J. Agronomy*, 24: 291-295.

Desai, B. B, Kotecha, P. M. and Salunkhe, D. K. (1997). Seeds Handbook: Biology, Production, Processing and Storage, Marcel Dekker Inc., New York.

Dezfuli P.M., Sharif-zadeh F. and Janmohammadi M. (2008). Influence of priming techniques on seed germination behavior of maize inbred lines (Z*ea mays* L.) *ARPN Journal of Agricultural and Biological Science*, 3(3) ISSN 1990-6145.

Dickson, (1980). Genetics aspects of seed Quality. *Hortscience*, 15(6): 771-774

Dornbos D.L., Mullen R.E. and Shibles R.M. (1989) Drought stress effects during seed fill on soybean seed germination and vigor. *Crop Science*. 29:476–480

Douglas J.E., (1975) Seed storage and packaging. In WP Feistritzer, ed, Cereal Seed Technology. Food and Agriculture Organization of the United Nations, Rome, :87-107.

Edge O. T. and Burries J. S. (1970). Seedling vigor in soybeans. Proceedings Association of Official Seed Analysts. Ed. AOSA. Ithaca, NY. p149-157.;

Egli, D.B. and Tekrony, D.M. (1995). Soybean seed germination, vigor and field emergence. *Seed Science and Technology* 23:595-607.

Egli, D.B. and Tekrony, D.M. (1996). Seedbed conditions and prediction of field emergence of soybean seed. *Journal Production Agriculture*. 9:365-370.

Ellis R.A. and Roberts E.H. (1981).The quantification of ageing and survival in orthodox seeds. *Seed Sci Technol.* 9:373-409.

Ellis R.H., K. Oseibonsu, E.H. Roberts (1982). The influence of genotype, temperature and moisture on seed longevity in chickpea, cowpea and soya bean. *Annals of Botany,* 50:69-82.

Ellis, R.H. (1998) Longevity of seeds stored hermitically at low moisture contents. *Seed Science Research*, 8(1): 9-10.

Ellis, R.H., and E.H. Roberts (1980). Improved equations for the prediction of seed longevity. *Annals of Botany* 45:13-30.

Emmerich W. E. and Hardgree S. P. (1990). Polyethylene glycol solution contact affection seed germination. *Agron. J.*, 82: 1103-1107.

FAO (1995). Women, agriculture and rural development, a synthesis report of the near East. Economic and Social development Department. FAO corporate Document Depository.

FAO (1999). Manual for training in seed production. Eds. R. K. Trivedi. I. A.Usman and J. C. Umah, FAO, United Nations. 116p.

FAO. (2011). FAOSTAT Accessed on http://faostat.fao.org/default.aspx.

Farooq M., Basra S. M. A., Hafeez K. and Ahmad N. (2005). Thermal hardening: a new seed vigor enhancement tool in rice. *Acta Botanica Sinica,* 47: 187-193.

Farooq M., Basra S. M. A., Hafeez-u-Rehman and Saleem B. A. (2008). Seed priming enhances the performance of late sown wheat (*Triticum aestivum L.*) by improving chilling tolerance. *J. of Agronomy and Crop Science,* 194(1): 55-60.

Farooq M., Basra S. M.A. and Hafeez-u-Rehman. (2006). Seed priming enhances emergence, yield and quality of direct-seeded rice. *Crop management and physiology*, 42-44.

Farooq M., S.M.A. Basra, H. Rehman, N. Ahmad and B.A. and Saleem Pak. J. (2007). Osmopriming improves the germination and early seedling growth of melons (*Cucumis Melo* L.). *Agri. Sci*. 44(3):529

Fehr W.R. and Caviness, C.E., (1977). Stages of soybean development. Ames, Iowa State University of Science and Technology. Cooperative Extension Service. 80: 11

Filmer, D., and L.H. Pritchett. (2001). Estimating wealth effects without expenditure data – or tears: An application to educational enrolments of India. *Demography*, 38 (1): 115–32.

Fischer A. A., Liang J. E., Stoeckel J.E. and Townsend J.W. (1998). Handbook for Family Planning Operations Research Design. 2nd Edition. Population Council, New York, USA 2: 77.

Fu J. R., Lu X. H., Chen R. Z., Zhang B. Z., Liu Z. S, Li Z. S. and Cai D. Y. (1988). Osmo conditioning of peanut (*Arachis hypogaea* L.) seeds with PEG to improve vigour and some biochemical activities. *Seed Sci. Technol.* 16: 197-212.

Furseth B. and Conley S.P. (2011). Updating Wisconsin Inoculant Recommendations. Proc. of the 2011 Wisconsin Crop Management Conference: 50.

Garrity D., Dixon J. and Boffa J.M. (2012). Understanding African farming systems. Food Security in Africa: bridging research and Practise:1-50.

Gaydou E.M. and Arrivets J. (1983). Effects of phosphorus, potassium, dolomite, and nitrogen fertilization on the quality of soybean - yields, proteins, and lipids. *Journal of Agricultural and Food Chemistry* 31:765-769.

George T. (1988). Growth and yield responses of *Glycine max* and *Phaseolus vulgaris* to mode of nitrogen nutrition and temperature changes with elevation. PhD Dissertation: 29.

Georghiou K, Thanos C.A and Passam H.C., (1987). Osmo conditioning as a means of counteracting the aging of pepper seeds during high temperature storage. *Ann. Bot.*, 60:279-285.

Gharib F.A., and Hegazi, A.Z. (2010). Salicylic Acid Ameliorates Germination, Seedling Growth, Phytohormone and Enzymes Activity in Bean (*Phaseolus vulgaris* L.) under Cold Stress. *Journal of American Science*, 6(10): 675-683.

Ghasem P., Ebadi A., Jahanbakhsh S. and Davari M. (2013). The Effect of Seed Priming and Accelerated Aging on Germination and Physiochemical Changes in Milk Thistle (*Silybum marianum*). *Not Sci Biol*., 5(2):204-211

Ghassemi-Golezani K. and Esmaeilpour B. (2008). The effect of salt priming on the performance of differentially matured cucumber (*Cucumis sativus*) seeds. *Not. Bot. Horti. Agrobo.* 36:67-70.

Ghassemi-Golezani K., Jabbarpour S., Zehtab-Salmasi S. and Mohammadi A. (2010). Response of winter rapeseed (*Brassica napus* L.) cultivars to salt priming of seeds. *Afr. J. Agric*. 5:1089-1094.

Ghassemi-Golezani Kazem, Somayeh Farshbaf- Jafari, Jalil Shafagh-Kolvanagh (2011). Seed Priming and Field Performance of Soybean (*Glycine max* L.) in Response to Water Limitation. Not Bot Horti Agrobo, 2011, 39(2):186-189.

Ghassemi-Golezani, K., Aliloo A.A., Valizadeh M. and Moghaddam M. (2008). Effects of hydro and osmo–priming on seed germination and field emergence of lentil (*Lens culinaris* Medik.). *Not. Bot. Hort. Agrobot*. *Cluj*., 36: 29–33

Ghiyasi M., M. Pouryousef Myandoab, M. Tajbakhsh, H. Salehzadeh and M. V. Meshkat (2008). Influence of different osmopriming treatment on emergency and yield of Maize (*Zea mays* L.). *Res. J. Biol. Sci*., 3(12): 1452-1455.

Gibson, A.H., (1976). Limitation to dinitrogen fixation by legumes. In: International Symposium of Nitrogen Fixation, 1., Pullman. Proceedings. Washington SNF.

Giri G. S. and Schilinger W. F.. (2003). Seed priming winter wheat for germination, emergence, and yield. *Crop Sci*., 43: 2135-2141.

Girolamo D. G and L. Barbanti (2012). Treatment conditions and biochemical processes influencing seed priming effectiveness. Department of Agro-environmental Science and Technology (DiSTA), University of Bologna, Italy. *Italian Journal of Agronomy*, 7:e25.

Gold K. (2013). Royal Botanic Gardens, Kew. In Training Workshop Proceedings. Sustainable production, harvesting and conservation of botanical pesticides January 28 - 31, 2013 World Agroforestry Centre (ICRAF) Nairobi, Kenya

Gray, D., Brocklehurst P.A.,. Steckel J.A and Dearman J. (1984). Priming and pre-germination of parsnip (*Pastinaca sativa* L.) seed. *Hort. Sci*. , 59: 101-108.

Greenberg, P. and Hartung, H.N. (1998). The whole soy cookbook: 175 delicious, nutritious, easy-to-prepare recipes featuring tofu, tempeh, and various forms of nature's healthiest bean. Three Rivers Press, New York.

Gregg B. R., (1982). Soybean seed quality and practical storage P. 52-56.In J.B. Sinclair and J.A. Jacobs (eds.). Soybean Seed Quality and Stand Establishment. (proc. conf. for scientists of Asia. Jan. 25-31, 1981). International Agriculture Publications. INTSOY 22.

Gupta P.C., (1993). Seed Vigour Testing. In: Agarwal, P.K. (Ed.), Handbook of Seed Testing: 242-249.

Gurusinghe S. and Bradford K.J (2001). Galactosyl-sucrose oligosaccharides and potential longevity of primed seeds. *Seed Sci. Res*., 11:121-133.

Gurusinghe S., Powell A.L.T. and Bradford K.J. (2002). Enhanced expression of BiP is associated with treatments that extend storage longevity of primed tomato seeds. *J. Am. Soc. Hortic. Sci*., 127:528-534.

Guy, P.A. and Black, M. (1998). Germination-related proteins in wheat revealed by differences in seed vigour. *Seed Science Research*, 8:99–111.

Hadavizadeh, A. and George, R.A.T. (1988). The effect of mother plant nutrition on seed vigor as determined by the seed leachate conductivity in pea, cultivar Sprite. *Seed Science and Technology*, Zurich, 6:589-599.

Hall, R.D. and. Wiesner L.E. (1990). Relationship between seed vigor tests and field performance of Regar meadow brome grass. *Crop Sci*., 30: 967-970

Hampton, J. G., (1995). Conductivity test. In: Seed Vigor Testing Seminar, Handbook. Copenhagen [Proceedings]. International Seed Testing Association, 10-28.

Hardegree, S.P. (1998). Optimization of seed priming treatments to increase low–temperature germination rate. *J. Range Manage*. , 49: 87–92

Harrington, J. F. (1972). Seed storage and longevity. In: Seed Biology. Ed. T. T. Koslowski. Academic Press, N. Y. 3:145-245.

Harrington, J.F. (1960). Thumb rules of drying seed. *Crops and soils*, 13: 16-17.

Harrington, J.F. (1973): Biochemical basis of seed longevity. *Seed Science and Technology*, 1: 453-461.

Harris D., Breese W.A. and Rao J.V.D.K. (2005). The improvement of crop yield in marginal environments using 'on–farm' seed priming. *Aus. J. Agric. Res*., 56: 1211–1218

Harris D, Joshi A, Khan P.A, Gothkar P. and Sodhi P.S. (1999). On-farm seed priming in semi-arid agriculture development and evaluation in maize, rice and chickpea in India using participatory methods. *Exper. Agric*., 35:15-29.

Harris, D., A.K. Pathan, P. Gothkar, A. Joshi, W. Chivasa and P. Nyamudeza, (2001). On–farm seed priming: using participatory methods to revive and refine a key technology. *Agric. Syst*., 69:151–164

Hartwig, E.E. and Potts H.C. (1987). Development and evaluation of impermeable seed coats for preserving soybean seed quality. *Crop Science*, 27: 506-608

Hayma, J., 1990. The storage of tropical agricultural products. 2nd Edn., pp: 14, 15 and 57.

Heatherly, L.G., Elmore, R.W. (2004). Managing Inputs for Peak Production. In: Soybeans: Improvement, Production and Uses. Eds. Boerma H.R., Specht, J.E. 3rd Edition, Agronomy N-16, ASA, CSSA, SSSA, Madison, Wisconsin, USA, 451-536.

Heydecker W, Gibbins BM. (1978). The 'priming' of seeds. *Acta Horticulturae,* 83: 213–113.

Heydecker W. (1972). Vigour , in: E. H. Roberts (Ed.), Viability of seeds, Chapman and Hall, London. p. 209-252.

Heydecker W., Higgins J. and Gulliver R.L. (1973). Accelerated germination by osmotic seed treatment. *Nature,* 246: 42–44.

Heydecker, W. (1977). Stress and seed germination: an agronomic view. In: Khan, A. A., ed. The physiology and biochemistry of seed dormancy and germination. Amsterdam: Elsevier/North-Holland Biomedical Press:

Heydecker, W. (1979).The vigor of seeds- a review. Proceedings of the International Seed Testing association, 34: 201- 209.

Hinson K and Hartwig, E.E. (1977) Soybean Production in the tropics. F.A.O Rome Italy.

Horlings G.P., Gamble E.E. and Shanmugasundaram S. (1991). The influence of seed size and seed coat characteristics on seed quality of soybean in the tropics: Field weathering. *Seed science and Technology,* 19: 665-685

Hur S.N. (1991). Effect of osmo conditioning on the productivity of Italian ryegrass and sorghum under suboptimal conditions. *Korean J Animal Sci.* 33:101-105.

Hurburgh, C.R. Jr. (2008). Soybean Drying and Storage. In IOWA State Extension:1-2.

Hussain M, Farooq M, Basra S.M.A and Ahmad N. (2006). Influence of seed priming techniques on the seedling establishment, yield and quality of hybrid sunflower. *Int. Agric. Biol.,* 8:14-18.

IEBC (2012). Independent Electoral and Boundaries commission. Kajiado North constituency.

IITA (2009). Soybean. International Institute of Tropical Agriculture publication.p1

Israel D.W., Kwanyuen P., Burton J.W. and Walker D.R. (2007). Response of low seed phytic acid soybeans to increases in external phosphorus supply. *Crop Science,* 47:2036-2046.

ISTA (1976). International Rules for Seed Testing. International Seed Testing Association. Annexes. Seed Science and Technology, Zurich, 4:51-177.

ISTA (1996). Rules for Seed Testing. International Seed Testing Association. *Seed Sci Technol.,* Zurich, Switzerland.

ISTA (1999). International Rules for Seed Testing. *Seed Sci Technol.,* 27:333.

ISTA (2007). ISTA Handbook on Moisture Determination. Eds. Nijënstein, H., Nydam, J., Don, R., McGill, C. International Seed Testing Association, Bassersdorf.

ISTA (2011).International Rules for Seed Testing. International Seed Testing Association, Bassersdorf : 27-40

ISTA, (1995) ISTA (1995). Handbook of vigour test methods (eds. J.G Hampton and D.M.TeKrony), 3rd edition, International Seed Testing Association, Zurich.

ISTA. (1993). International Rules for Seed Testing. Seed Sci. and *Technol.* 21, 1-288.

Jaetzold R, Schmidt H, Hornetz B, Shisanya C. (2011). Farm Management Handbook of Kenya Vol. II - Natural Conditions and farm Management Information. 2nd Edition PART B. Central Kenya. Sub-Part B1a. Southern Rift Valley Province. 501-551.

Jaetzold R, Schmidt H, Hornetz B, and Shisanya C (2006b). Farm Management Handbook of Kenya Vol. II - Natural Conditions and farm Management Information. 2nd Edition PART C; East Kenya. Sub-Part 1C. Eastern Province. 167-260.

Jaetzold R. and H. Schmidt (1983). Farm Management Handbook of Kenya. Vol. IIC: East Kenya. MoA/GTZ. Nairobi.

Jaetzold R., Schmidt H., Hornetz B. and Shisanya C (2006a). Farm Management Handbook of Kenya Vol. II - Natural Conditions and farm Management Information. 2nd Edition PART B; Central Kenya. Sub-Part B2. Central Province : 149-245.

Jet L.W., Welbaum G.E., Morse R.D. (1996). Effect of matric and osmotic priming treatments on broccoli seed germination. *J. Am. Soc. Hortic. Sci.,* 121:423-429.

Johnson, R. R. and Wax, L. M. (1978). Relationship of soybean germination and vigor tests to field performance. *Agronomy Journal*, 70(2): 273-278.

Kaara J.W., Werner J. and Wasike V.W. (1998). Soybean impact study: A case study on the status of small-scale soybean production, cottage processing, and consumption in selected areas of Kenya. Soybean project, Nairobi, Kenya.

Kandel Hans (2010). Soybean Production Field Guide for North Dakota and North Western Minnesota. NDSU Extension Service. 68-122

Karuga, S. and Gachanja, J. (2004). Soybeans development study: Final report prepared by Market Economies. 1-53.

Kasasa P., Mpepereki S. and Giller K.E. (2000). Quantification of nitrogen fixed by promiscuous soybean varieties under Zimbabwean field conditions. In: forum 4 working Document 1. Programme extended abstracts. Fourth regional meeting of the Forum for Agricultural Husbandry, Lilongwe, Malawi.

Kaur S, Gupta A.K and Kaur N. (2005). Seed priming increases crop yield possibly by modulating enzymes of sucrose metabolism in chickpea. *J. Agron. Crop Sci*., 191:81-87.

Kaya M., Kaya G., Kaya M.D., Atak M., Saglam S., Khawar K.M., Ciftci C.Y. (2008) Interactions between seed size and NaCl on germination and early seedling growth of some Turkish cultivars of chickpea (*Cicer arietinum* L.). *J Zhejiang Univ Sci B* (*JZUS-B*) 9:371-377.

Kaya M.D., Gamze O., Atal M., Yakup C. and Ozer K. (2006). Seed treatments to overcome salt and drought stress during germination in sunflower (*Helianthus annuus* L.). *Eur. J. Agron.,* 24:291-295.

Keeling, B. L (1974). Soybean seed rot and the relation of seed exudates to host susceptibility. *Phytopathology,* 64(11):1445-1447.

Keigley, P.J. and Mullen R.E. (1986). Changes in soybean seed quality from high temperature during seed fill and maturation. *Crop Science,* 26: 1212-1216.

Kendal A. A., Sharif A. E. and Sheteiwy M. S. (2013) Effect of Seed Storage Periods, Conditions and Materials on Germination of Some Soybean Seed Cultivars. *American Journal of Experimental Agriculture*, 3(4): 1020-1043, 2013.

Khajeh-Hosseini M., Lomholt A. and Matthews S. (2009). Mean germination time in the laboratory estimates the relative vigour and field performance of commercial seed lots of maize (*Zea mays* L.). *Seed Sci.Technol*., 37:446-456.

Khalil S.K, Mexal J.G, Rehman A, Khan A.Z, Wahab S, Zubair M, Khalil I.H and Mohammad F. (2010). Soybean mother plant exposure to temperature stress and its effect on germination under osmotic stress. *Pak. J. Bot.,* 42:213-225.

Khan A, Khalil SK, Khan S, Afzal A (2005). Priming affects crop stand of mung bean. *Sarhad J Agric.*, 21:535-538.

Kleczewski N. (2013). Soybean disease management. Cooperative Extension, Department of Plant and Soil Sciences, University of Delaware. extension.udel.edu.

KNBS (2009). Kenya Population and Housing Census 2009. Kenya National Bureau of Statistics (KNBS).

Krauss, A. (1978). Tuberization and abscissic acid content in *Solanum tuberosum* as affected by nitrogen nutrition. *Potato Research*, 21:183-193.

Krueger K. A., Goggi S.,. Mallarinob A. P. and Mullen R.E (2013). Phosphorus and Potassium Fertilization Effects on Soybean Seed Quality and Composition. *Crop Sci.*, 53: 602–610

Krueger, K., (2011) "Effects of phosphorus and potassium fertilization rate and placement method on soybean (*Glycine max* L.) seed quality and long-term storability". Graduate Theses and Dissertations. Paper 12217. http://lib.dr.iastate.edu/etd/12217

Kuchlan M. K., Dadlani M. and Samuel D. V. K. (2010).Seed Coat Properties and Longevity of Soybean Seeds. *Journal of New Seeds*, 11:239–249.

Kulik, M.M. (1995). Seed quality and microorganisms. In: Seed quality: basic mechanisms and agricultural implications (ed. A.S. Basra). Food Products Press, New York. 153-171.

Langyintuo, A.S., and C. Mungoma, C. (2008). The effect of household wealth on the adoption of improved maize varieties in Zambia. Food Policy, 33: 550–59.

Lanteri S., Kraak H.L, Ric De Vos C.H. and Bino R.J. (1993). Effects of osmotic reconditioning on nuclear replication activity in seeds of pepper (Capsicum annuum). *Physiologia Plantarum*, 89: 433–440.

Lekić, S. (2003). Vigor of seed, Belgrade: Association of breeders and seed researchers of Serbia.

Lele U., Christiansen R.E., Kadiresian K. (1989). Fertilizer policy in Africa. Lessons from development programs and adjustment lending 1970-1987. In Managing Agricultural Development in Africa: 41.

Loeffler, T.M., TeKrony, D.M. and Egli, D.B. (1988).The bulk conductivity test as an indicator of soybean seed quality. *Journal of Seed Technology*, 12:37-53.

Lott J.N.A., Greenwood J.S. and Batten G.D. (1995). Mechanisms and regulation of mineral nutrient storage during seed development, in: J. Kigel and G. Galili (Eds.), Seed Development and Germination, Marcel Dekker, New York, New York: 215-235.

Mahasi J.M., J. Mukalama. R.C. Mursoy, P. Mbehero and B. Vanlauwe (2011).A sustainable approach to increased soybean production in western Kenya. African Crop Science Conference Proceedings 10:115 – 120.

Marcos-Filho J.; C.C. Custodio; G.M.S. Camara; E.A. Marcos; R.E. Miranda (1994) Relationship between nitrogen sources, Germination and vigor of soybean seeds. Departamento de agricultura, esalq/usp, *Sci. Agric. Piracicaba*, 51 (2):305-314.

Mathu R.W., Nandokha, T., Riungu, T. C., Matere, S. and Bendera, N. K (2010). The potential of soybean to increase agricultural productivity in dry areas of Central Kenya. Kenya Agricultural research Institute publ. 156-161

Matthews S. and Powell A. (2011). Towards automated single counts of radicle emergence to predict seed and seedling vigour . In Seed Testing International. :142

Matthews S., Beltrami, E., El-Khadem R., Khajeh Hosseini M., Nasehzadeh, M. and Urso, G. (2011).Evidence that time for repair during early germination leads to vigour differences in maize. *Seed Science and Technology*, 39: 501–509.

Matthews, S. and Khajeh H., S. (2007). Length of the lag period of germination and metabolic repair explain vigour differences in seed lots of maize (*Zea mays*). *Seed Science and Technology*, 35:200–212.

McDonald M.B. (1994). Standardization of Seed Vigor Tests. In Seeds: Trade, Production and Technology.

McDonald, Jr. M.B (1980). Assessment of Seed Quality. *HortScience*, 15:784-788.

McDonald, M. B. and C. J. Nelson (1986). Physiology of seed deterioration. Proc. Sym. Crop Sci. Soc. America, November Madison, Wisconsim, USA:123.

McDonald, M.B. (1988). Challenges in seed technology. In Proceedings 10th Seed Technology Conference. Ed. J.S. Burris. Ames, I.A:11-31.

Mengel D., (2011). Kansas State University Agricultural Experiment Station and Cooperative Extension Service News.

Michel B.E and Kaufmann M.R. (1973). The osmotic potential of polyethylene glycol 6000. *Plant Physiol.*, 51:914-916.

Ministry of Agriculture (2009). Resource Management Guidelines for Meru South District. District Agricultural Office, Meru South: 1-95.

Ministry of Agriculture (2012).Strategy for Soybean Production and Marketing in Kenya. Unpublished, 1-20.

Ministry of Agriculture Report (2013). Brief on soyabean production in Meru South Sub-county. Unpublished, 1-6

Misiko M., Tittonell P., Ramisch, J.J, Richards, P. and Giller, K.E, (2008). Integrating new soybean varieties for soil fertility management in smallholder systems through participatory research: Lessons from western Kenya. *Agricultural Systems*, 97(1-2):1-12.

Misra N.M. and D.P. (1980).Effect of pre-sowing seed treatment on growth and dry-matter accumulation of high-yielding wheat under rainfall conditions. *Indian J. Agron.*, 25:230-234.

Monira U.S., Amin M. H. A., Aktar M. M. and Mamun M.A.A. (2012).Effect of Containers on Seed Quality of Storage Soybean Seed. *Bangladesh Res. Pub. J.*, 7(4): 421-427.

Monyo E.S (2013). Bulletin of the Tropical Legumes http://www.icrisat.org/TropicallegumesII/Bulletin-of-Tropical-Legumes.htm. 18:4-5

Morello J. R., Motilva M. J., Tovar M. J. and Romero M.P. (2004). Changes in commercial virgin olive oil (CV Arbequina) during storage with special emphasis on the phenolic fraction. *Journal of Food Chemistry,* 85: 357-364.

Mosavian S.N and Eshraghi-Nejad M. (2013).The effects of seed size and salinity on seed germination characteristic in wheat (var. Chamran).In *International Journal of Farming and Allied Sciences*, 2(2): 1379-1383

Mpepereki A., Javaheri F., Davis P. and Giller K.E. (2000). Soyabeans and sustainable agriculture. Promiscuous soyabeans in southern Africa. *Field Crops Research*, 65:137-149.

Mubshar H., M. Farooq S. M. A. Basra and N. Ahmad. (2006). Influence of seed priming techniques on the seedling establishment, yield and quality of hybrid Sunflower. *Int. J. Agri. Biol.,* 8(1): 14-18.

Mugendi, D., Mucheru-Muna, M., Mugwe, J., & Bationo A. (2003) Enhancement of food productivity using leguminous shrubs in the Eastern highlands of Kenya. *African Crop Science Conference Proceedings*, 6:581-586.

Mugendi, E., Gitonga, N., Cheruiyot, R and Maingi, J. (2010). Biological Nitrogen Fixation by Promiscuous Soybean (*Glycine max* L. Merril) in Central Highlands of Kenya: Response to Inorganic Fertilizer Soil Amendment. *World Journal of Agricultural Sciences,* 6(4): 381-387.

Muhammad L. D. Mwabu, R.Mulwa, W.Mwangi, A. Langyintuo, and R. L. Rovere (2010). Characterization of Maize Producing Households in Machakos and Makueni Districts in Kenya DTMA Country Report – Kenya, 2-15

Mutegi E., Misra A.K. and Kiambi D.K. (2001).Predicting the longevity of finger millet and vegetable amaranth seed during storage under controlled temperature and moisture content conditions. *Seed technology, 23:58*-67.

Myaka F.A, Kirenga G. and Malema B. (Eds). (2005). Proceedings of the First National Soybean Stakeholders Workshop, 10–11 November 2005, Morogoro, Tanzania.

Naito A. (1999) Low Cost Technology for Controlling Soybean Insect Pests in Indonesia. www.fftc.agnet.org.

Nangju, D. (1977). Effect of date of harvest on seed quality and viability of soya beans. *J. Agr. Sci*., 89: 107-112.

Nedic M., Zivanovic L.J., Vukovic Z. and Jovanovic B. (2005). Effect of Nitrogen and Phosphorous on soybean yield and nutritive value. *Biotechnology in Animal Husbandry*, 21(5-6):181-186.

NEMA (2007). Kenya District Environmental Action Plan 2006-2011. Meru South District: 31-38.

Newton R., F. Hay and R. Probert (2009). Protocol for comparative seed longevity testing. Technical Information Sheet_01. Millennium Seed Bank Project, Wakehurst Place, Ardingly, West Sussex RH17 6TN, UK.

Ng, N. Q. (1988) .Long-term seed conservation. In: Proceedings of International Conference on Crop Genetic Resources of Africa, Kenya. Eds. F. Attere, N. Ng and P. Perino: 135 - 148.

Nkang, A. and E.O Umho (1996). Six month storability of five soybean cultivars as influenced by stage of harvest, storage temperature and relative humidity. *Seed Science and Technol*. 25:93:99

Nyarko G., Bayor H., Craigon J. and Suleimana I.A., (2006). The Effect of Container Types, Seed Dressings and Desiccants on the Viability and Vigour of Roselle (Hibiscus sabdariffa L. var. sabdariffa) Seeds. *Pakistan Journal of Biological Sciences,* 9: 593-597.

Ogema M.W, Ayiecho P.O, Okwirry J.J, Kibuthu I., Riungu T.C, Karanja D.D, Ng'ang'a C.N ,Ocholla P. and Ireri E.K (1988). Oil crop Production in Kenya. Vegetable Oil/Protein System programme working paper series. Egerton University, Njoro, Kenya.

Ogunlela, Y. I., & Mukhtar, A. A. (2009). Gender issues in agriculture and rural development in Nigeria: The role of women. *Humanities and Social Sciences Journal*, 4:19-30.

Oguntade Temitope O. and Adedotun A. Adekunle (2010) Preservation of seeds against fungi using wood-ash of some tropical forest trees in Nigeria. *African Journal of Microbiology Research*, 4 (4): 279-288.

Oh M.K., Rhee S.H., Cheigh H.S. (1992). Changes of lipid composition of Korean black soybean before and after soaking. *J. Korean Soc. Food Nut., 21:29*-35.

Okalebo , J.R. (1987). A study of the Effects of Phosphate Fertilizers on maize and sorghum production in some East African Soils. PhD dissertation, University of Nairobi, Kenya.

Okalebo J.R., Kenneth W. Gathua and Paul L. Woomer P.L. (2002). Laboratory methods of soil and plant analysis: A working Manual 2:1-121

Okalebo J.R.., Simpson Keating B.A.,and Gathua K.W.(1989). The distribution of available phosphorous and the effect of phosphate fertilizer on crop production in soils of semi-arid Machakos District in Kenya. Presented at the 9th Annual General Meeting of the Soil Science Soc. of East Africa Kisumu, Kenya.

Pallais N., Villagarcia, S. Tapia, J. and Garcia R. (1987). Effect of supplemental nitrogen on true potato seed weight. *American Potato Journal*, 64:483-491.

Parera C.A., and Cantliffe D.J. (1994). Pre-sowing seed priming. *Hort. Rev.*, 16:109-139.

Parrish D. J. and Leopold A. C. (1978).On the Mechanism of Aging in Soybean Seeds. *Plant Physiology*,. 61:365-368

Pascha, E.H. and Ellis M.A. (1978). Variation in seed quality characteristics of tropically grown soybeans. *Crop Sci*., 18: 837-840.

Pessu P.O., Adindu M.N., Umeozor O.C. (2005). Effects of long-term storage on the quality of soybean, *Glycine max* (L.) Merrill, in different containers in southern Nigerian. *Global Journal of Pure and Applied Sciences,* 11(2): 165-168

Pill W.G, Frett J.J. and Morneau D.C (1991). Germination and seedling emergence of rimed tomato and asparagus seeds under adverse conditions. *Hort. Sci.*, 26:1160-1162.

Popovic V, Malesevic M, Miladinovic J., Maric V. and Zivanovic L. (2013). Effect of agro ecological factors on variations in yield, protein and oil contents in soybean grain. *Nardi Fundulea*, Romania Romanian Agricultural Research: 30.

Potts, H.C., J. Duangpatra, W.G. Hairston and J.C. Delouche. (1978). Some influences of hard seediness on soybean seed quality. *Crop Sci.*, 18: 221-224.

Powell A.A., Yule L.J., Jing H., Groot S.P.C., Bino R.J. and Pritchard H.W. (2000). The influence of aerated hydration seed treatment on seed longevity as assessed by the viability equations. *Journal of Experimental Botany*, 51: 2031–2043.

Powell, A. A. (1988). Seed vigour and field establishment. *Advances in Research and Technology of Seeds,* 11(4):9-61,

Priestley D.A. (1986). Seed Aging. Implications for Seed storage and Persistence in the Soil. *J. Exp. Bot.,* 38 (4): 724-725.

Rahman, M. M., Hossain, M. M., Anwar, M. P. and Juraimi, A. S. (2011). Plant density influence on yield and nutritional quality of soybean seed. *Asian Journal of Plant Sciences*, 10(2): 125-132.

Rao N.K, Hanson J, Dulloo M.E, Ghosh K, Nowell D and Larinde M. (2006). Manual of seed handling in gene banks. Handbooks for Gene banks No. 8.Bioversity International, Rome, Italy.

Rastegar Z., Sedghi M. and Saeid K.I.S. (2011). Effects of Accelerated Aging on Soybean Seed Germination Indexes at Laboratory Conditions. *Notulae Scientia Biologicae,* 3(3):126-129.

Reynaldo M. T., Vieira R.D. and Panobianco M. (2004). Accelerated aging and seedling field emergence in soybean. *Sci. Agric*. (Piracicaba, Braz.), 61(5): 476-480.

Ries S.K., Moreno O., Meggitt W.L., Scheweizer J. and Aslikar S.A. (1970). Wheat seed chemical protein influence on and relationship to subsequent growth and yield in Michigan and Mexico. *Agronomy Journal,* 62:746-748.

Roberts, E. H. (1973). Predicting the storage life of seeds. *Seed Science and Technology*, 1:499-514.

Robinson R.G. (1974). Sunflower performance relative to size and weight of achenes planted. *Crop Sci.*, 14:616-618.

Roche P, Griere L., Babre D., Calba H. and Fallavier P. (1980). Phosphorous in Tropical Soils: Assesing deficiency levels and phosphorous requirements. IMPHOS. World Phosphate Institute, 75008 Paris; France, Scientific Publication 2.

Ross, E.E. (1980). Physiological, biochemical and genetic changes in seed quality during storage. *Journal of the American Society for Horticultural Science*, 15:781-784.

Rouhi H.R., Surki A.A., Sharif-Zadeh, Farzad A., Reza T., Aboutalebian M.A. and Ahmadvand G.(2011). Study of different priming treatments on germination traits of soybean seed lots. *Notulae Scientia Biologicae*, 3(1):101.

Ruan S., Q. Xue and Tylkowska K. (2002). The influence of priming on germination of rice *Oryza sativa* L. seeds and seedling emergence and performance in flooded *soil. Seed Sci. Technol*., 30: 61-67.

Sadeghi H. F., Khazaei Y. L.and Sheidaei S. (2011). Effect of seed osmopriming on seed germination behavior and vigor of soybean (*Glycine max* l.) *Arpn Journal of Agricultural and Biological Science,* 6 (1) Issn 1990-6145.

Sadeghi R.H., Surki A.A, Sharif-Zadeh F., Afshari R.T., Aboutalebian M.A. and Ahmadvand G. (2011). Study of different priming treatments on germination traits of soybean seed lots in *Not Sci Biol.*, 3(1):101-108.

Salinas A.R., Craviotto M.R., Beltrán C., Bisaro V. and Yoldjian A.M. (2010). Electrical conductivity of soybean seed cultivars and adjusted models of leakage curves along the time. *Revista Caatinga,* 23(1)1: 1-7.

Sanginga N., Dashiell K., Diels J., Vanlauwe B., Lyasse O., Carsk, R.J., Tarawali S., Asafo-Adjei B., Menkir A., Schulz S. Singh B.B., Chikoye D., Keatinge D and Rodomiro O. (2003). Sustainable resource management coupled to resilient germplasm to provide new intensive cereal–grain legume–livestock systems in the dry savanna. *Agriculture, Ecosystems and Environment*, 100: 305–314

Sanginga, N. (2003). Role of biological nitrogen fixation in legume based cropping systems; a case study of West Africa farming systems. *Plant and Soil*, 252: 25-39.

Sanginga, N., Okogun, J.A., Vanlauwe, B., Diels, J., Carsky, R.J. and Dashiell, K. (2001). Nitrogen contribution of promiscuous soybeans in maize-based cropping systems. In Soil fertility Maintenance in West Africa, Ed. G. Tian *et al.*, ASA, Madison I:157-177.

Saranga Y, Levi A, Horcicka P, Wolf D.S. (1998). Large sunflower seeds are characterized by low embryo vigor. *Journal of American Society of Horticultural Science*, 123: 470-474.

Schwember A.R and Bradford K.J. (2005). Drying rates following priming affect temperature sensitivity of germination and longevity of lettuce seeds. *HortScience*, 40: 778–781.

Sharif A., Anwar F., Bakht J., Anwar S. and Akhter S. (2006). Effect of different seed priming methods on the germination of various cereals. *Sarhad J Agric.*, 22:2-5

Shatters, Jr. R.G., Abdelghanny A., Olfat E. and West S.H. (1994). Soybean seed deterioration and response to osmotic priming: Changes in specific enzyme activities in extracts from dry and germinated seeds. *Seed science research*, 4: 33-41.

Simon W. and Raja-Harun R.M (1972). Leakage during seed imbibition. *Exp. Bot.*, 23: 1076-1085.

Sims J.T., Edwards A.C., Schoumans O.F. and Simard R.R. (2000). Integrating soil phosphorus testing into environmentally based agricultural management practices. *Journal of Environmental Quality*, 29:60-71.

Singh C. B., Dalal M. A. and Singh S. P. (1978) Genetic analysis of field germination in soybean (*Glycine max.* (L) merill.) In *Theoretical and Applied Genetics*, (4):165-169

Sivritepe H.O. and Dourado A.M. (1995). The effect of priming treatments on the viability and accumulation of chromosomal damage in aged pea seeds. *Annals of Botany,* 75: 165–171.

Sliwin´ska E and Jendrzejczak E. (2002). Sugar-beet seed quality and DNA synthesis in the embryo in relation to hydration–dehydration cycles. *Seed Science and Technology,* 30: 597–608.

Smith M.T and Berjak P. (1995). Deteriorative changes associated with the loss of viability of stored desiccant-tolerant and desiccation-sensitive seeds. In Seed Development and germination (J. Kigel and G. Galili eds.) Markel Dekker. Inc. N.Y.

Smith, R.S.; Ellis, M.A. (1980). Soybean nodulation as influenced by seedling vigor. *Agronomy Journal,* Madison. 72:605-608, 1980.

Soeda Y., Konings C.J.M. and, Vorst O. (2005). Gene expression programs during Brassica oleracea seed maturation, osmopriming, and germination are indicators of progression of the germination process and the stress tolerance level. *Plant Physiology,* 137: 354–368.

Soffer, H. and Smith, G.E. (1974). Studies on lettuce seed quality, nutritional effects. *Journal of the American Society for Horticultural Science,* 6:2-3.

Srijankul W. (2001). Variation in quality and physical characteristics of seed of 10 soybean (*Glycine max* (L.) Merr.) genotypes. *Agricultural Science Journal*, 32(1-4):25-38.

Stanley C.J., Tustin D.S, Lupton G.B., McCartney S, Cashmore W.M., De Silva H.N. (2000). Towards understanding the role of temperature in apple fruit growth responses in three geographical regions within New Zealand. *Journal of Horticultural Science and Biotechnology,* 75: 413-422.

Subedi K.D. and Ma B.L. (2005). Seed priming does not improve corn yield in a humid temperate environment. *Agron J.,* 97:211-218.

Subramanya K. N., Prakash H. S., Shetty H. S. and Karanth N. G. K. (1988). Effect of Thiram and Baristin on sorghum seeds stored under different conditions. *Pesticides,* 22: 25-27.

Sumner P.E. and Williams E.J. (2006). Grain and soybean drying on Georgia farms. Bulletin of University of Georgia, College of Agricultural and Environmental Sciences and Family and Consumer Science, 873:12.

Sung F.J.M. (1992). Field emergence of edible soybean seeds differing in seed size and emergence strength. *Seed Science and Technology,* 20:527-532.

Sung J.M., and Chiu C.C. (1995). Lipid-peroxidation and peroxide-scavenging enzymes of naturally aged soybean seed. *Plant Science,* 110:45-52.

Sung, J.M. and Chang Y.H. (1993). Biochemical activities associated with priming of sweet corn seeds to improve vigor. *Seed Science and Technology,* 21: 97-105.

Tarquis A.M. and Bradford K.J. (1992). Prehydration and priming treatments that advance germination also increase the rate of deterioration of lettuce seeds. *J. Expt. Bot.,* 43:307–317.

Taylor A.G., Allen P.S., Bennett M. A., Bradford K. J., Burrisand J. S. and Misra M. K. (1998). Seed enhancements. *Seed Sci. Res*., 8: 245-256.

Tekalign, T., Haque, I., and Aduayi E. A. (1991). Soil, plant, water, fertilizer, animal manure and compost analysis manual. Plant Science Division Working Document 13, ILCA, Addis Ababa, Ethiopia.

TeKrony D.M., Egli D.B. and Phillips A.D. (1980). Effect of field weathering on the viability and vigor of soybean seed. *Agron. J*., 72: 749-755.

TeKrony D.M. and. Egli D.B. (1991). Relationship of seed vigor to crop yield; a review. *Crop Science,* 31:816-822.

TeKrony D.M., Egli D.B. and Rucker M. (2000). Survival characteristics of inbred corn seed during storage. *Seed Technology*, 23: 197–205.

TeKrony, D.M. (1995). Accelerated ageing. In: Van DeVenter, H.A. (ed.). Proc. Seed Testing Seminar. International Seed Testing Association, Zurich, Switzerland. 53–73.

TeKrony, D.M. and Egli, D.B. (1977). Relationship between laboratory indices of soybean seed vigor and field emergence. *Crop Science,* 17: 573-577.

TeKrony, D.M., Egli, D.B. and Tang, S. (1999). Predicting changes in corn seed germination during storage. *Seed Technology*, 21: 77–86.

Tewari M.N. and Gupta P.C. (1981). Effect of genotype, seed grade and environment on viability and vigor of sunflower seed in storage. *Seed Res*., 9, 126-131.

Thalooth A.T., T.A. Nour, M.A. El-Seessy. (1989). Growth and yield responses of three soybean varieties to foliar application of some nutrient compounds. Annals of Agricultural Science (Cairo) 34:939-951.

Theis J.E., Singleton P.W. and Bohlool B.B. (1991). Modeling symbiotic performance of introduced rhizobia in the field by use of indices of indigenous population size and nitrogen status of the soil. *Appl*. *Environ*. *Microbiol*., 57:29-37.

Thomas F. and Raper C.D. (1979). Germinabilities of tobacco seed as affected by culture of the mother plant. *Agronomy Journal*, 71:694-696.

Thomas W. (1980). Seed viability in relation to storage conditions in varieties of soybean *Glycine max* L. Merr. *J. Agri. Sci*., 14:721.

Tinsley R. L (2009). Assessing the Soybean Value Chain Analysis in Kenya. CNFA: 1-44.

Tisdale S.L and Rucker D.L. (1964). Crop response to various phosphates. Tech Bull No. 9. The Sulphur Institute, Washington USA.

Tompsett P.B. and Pritchard H.W. (1993). Water status changing during development in relation to the germination and desiccation tolerance of *Aesculus hippocastanum* L. seeds. *Annals of Botany*, 71, 107-116)

Unkovich, M.J. and Pate, J.S. (2000). An appraisal of recent field measurements of symbiotic N_2 fixation by annual legumes. *Field Crops Research,* 65: 211–228.

Usha T.N. and Dadlani M. (2015). Evaluation of seed vigour in soybean (Glycine max). *Agricultural Research Communication Center Journal*, 38(3): 308-312.

Vanlauwe B., Mukalama J., Abaidoo R. & Sanginga N (2003). Soybean varieties, developed in West Africa, retain their promiscuity and dual purpose nature under Western Kenyan conditions. African Crop Science Conference Proceedings 6:58-68.

Verde B.S., Danga .B.O and Mugwe J.N. (2013). The effects of manure, lime and P fertilizer on N uptake and yields of soybean (*Glycine max* (L.) Merrill) in the

Central Highlands of Kenya. *Journal of Environmental Science and Engineering,* B 2:111-116

Villiers T.A. (1973). Aging and the longevity of seeds in field conditions. In W. Heydecker, ed, Seed Ecology. Butterworths, London:265-288

Viro P. J. (1955). Use of ethylenediaminetetraacetic acid in soil analysis. I. *Experimental Soil Sci*., 79: 459- 465.

Wagner, J. and Mitterhofer, E. (1998). Phenology, seed development and reproductive success of an alpine population of *Gentianella germanica* in climatically varying years. *Botanica Acta,* 111, 159-166.

Wambugu P.W., Mathenge P.W., Auma E. O. and van Rheenen H.A. (2009). Efficacy of traditional maize (zea mays l.) seed storage methods in western Kenya. In *African Journal for Food and Nutrition Development*, 9(4) 2009.

Wechsberg G.E. (1994). Seed longevity and response to priming in *Ranunculus sceleratus* L. PhD Thesis, University of Manchester, UK.

West, S.H. (1986). Physiological and pathological interactions affecting seed deterioration. Special publication. Crop Science Society of America.

Wien H.C. and Kueneman E.A. (1981).Soybean seed deterioration in the tropics. II. Varietal differences and techniques for screening. In *Field Crops Research,* 4: 123-132.

Willenborg C.J., Wildeman J.C., Miller A.K., Rossnaged B.G. and Shirtliffe S.J. (2005). Oat germination characteristics differ among genotypes, seed sizes and osmotic potentials. *Crop Science,* 45: 2023-2029.

Yaklich R. W. and P. B. Cregan (1987). A field study of moisture content of soybean pods and seeds after harvest maturity. *Journal of Seed Technology* 11(1):62-68.

Yaklich R. W., Kulik M. M. and Anderson J. D. (1979). Evaluation of vigour tests in soybean seed: relationship of ATP, conductivity and radioactive tracer multiple criteria laboratory tests to field performance. *Crop Science,* 19(6): 806-810.

Yari L., Aghaalikani M. and Khazaei F. (2010). Effect of seed priming duration and temperature on seed germination behavior of bread wheat (*Triticum aestivum* L.). ARPN *Journal of Agricultural and Biological Science,* 5(1):1990-6145.

Zanakis, G.N., Ellis, R.H. and Summerfield R.J. (1993). Response of seed longevity to moisture content in three genotypes of soybean (*Glycine max*). *Exptl. Agric*., **29**: 449-459

Zilli J.E, Ribeiro K.G, Campo R.J and Hungria M. (2009). Influence of fungicide seed treatment on Soybean nodulation and grain yield. In *R. Bras. Ci. Solo***,** 33:917-923.

Appendix 1: SOYBEAN SURVEY DATA COLLECTION QUESTIONNAIRE

Serial No…………….

Objectives

a. To assess the seed production, processing and storage activities of soybean crops as practiced by the farmers.
b. To document soybean seed management scenario for designing future strategies of seed production.
c. To determine the quality of farmers' homegrown soybean seeds.

Name of enumerator/interviewer ………………………………. Date ………..………………..

I. General information

a. Location details: County ……………. … District (Sub-county)…………………….
b. Location (ward)……………………… sub-location (Village) …………….……
c. Nearest market or town ………………………………
d. GPS data: Latitude………………. Longitude ………………Altitude ……………

II. Personal details of farmer

a. Name of Household Head (HH) …………………………Sex: M or F Age …………
b. Name of respondent ………………………………… Age ……. Gender……….
c. Education level ……………… Occupation ………………………………
d. Contact Address …………………………………….. Telephone ……………………………..

III. Economic level of farmer (indicator: use type of housing to be scored by observation only)

a. Permanent - stone housing/mabati/tiled roof
b. Wooden walled/ corrugated iron sheet roof
c. Mud walled/ corrugated iron sheet roof
d. Mud walled/Grass thatched/
e. Other (specify)

IV. Farming

1. How big is your farm ……………… (acres).
2. Which crops do you grow on your farm ………………………………………..…………………………………………………………..
3. Do you grow soybeans?
   a. Yes
   b. No
4. Since when did you start growing soybeans (year) …………………………
5. Who introduced soybean the crop to you? ……………………………………………………………………….

6. During which season do you grow soybean?
   c. Long Rains **(LR) … (**March/April)
   d. Short Rains **(SR)…** (October/November)

e. Both **LR + SR**

7. For the **last Long Rains Season crop** (if any) Indicate:
   f. Planting dates ………………............
   g. Harvesting dates …………………………….
   h. Acreage ……………………………
   i. Total yields …………………………Yield/acre (kg) ………………………
8. For the **last Short Rains Season crop** Indicate (if any):
   j. Planting dates ………………..........
   k. Harvesting dates …………………………
   l. Acreage …………………………
   m. Total yields………………………Yield/acre (kg) ………………………
9. **How long does soybean crop take to mature in this area** (months)? ……………………………
10. Land preparation methods used in soybean plots
    n. Hand hoeing
    o. Oxen ploughing
    p. Tractor ploughing
11. Which Varieties of soybean have you ever grown ……………….…………………………………………………………..………
12. Which Varieties of soybean did you grow in the last crop ……………………………………………………………..………
13. What soybean variety do you prefer …………………………? and why ……………………………………………………………..
    ………………………………………………………………………………?
14. **How do you grow soybeans** (tick)
    a. pure cropping
    b. intercropping
    c. others (specify) ………………………………………………………………………………
15. **What fertilizers do you use for planting soybeans if any and quantities used** (tick and specify)
    a. Manure
    (Yes)………… (Quantity) …………………………
    (No) ………
    b. Inorganic fertilizers ……… (Yes) ………... (No)………….
    (Fertilizer types)……………..………..…………………..……..
    (Quantity kg/plot) ………………………………………….…..….
    c. Foliar Feeds
    d. None.
16. Have you experienced soybean Pest and/or Disease Problem
    a. Yes …….
    b. No………
    (Specify pests and/or diseases if any) ……………………………………………………………………………..
17. Do You use crop protection chemicals on soybean?

a. Yes ….
b. **No……….**

If yes specify

a. Insecticides …………………………………………………………………….,
b. Fungicides ………………………..………………………………………
c. Herbicides ……………………………………………………………………
d. others ……………………..…………………………………………….

18. **What is your source of soybean Seed for planting?**
    a. Own seed.
    b. exchange with other farmers
    c. Purchase from market
    d. Purchase from seed stockists (agro-vets)
    e. Other (specify) ………………………………………….
19. **At what Price/kg is soybean seed for planting sold**……………
20. **Do you separate seed crop from grain crop?**
    a. Yes
    b. No

If yes, how do you manage the seed crop?

……..……………………………………………………………………………

21. **What is the level of field germination of soybean crop in the in the last season planting?**
    a. 0-50% (Poor)
    b. 51-70% (Average)
    c. 71-100% (Good)
22. **When do you harvest the soybean seed crop?**
    a. Immediately they mature (yellowing)
    b. When totally dry.
23. **How do you thresh the soybean after harvest ?**
    a. manually by hand
    b. beating with sticks
    c. machine thresher
24. **Do you dry soybean after threshing?**
    a. Yes
    b. No

If yes, how do you dry soybean

a. Sun drying
b. Machine drying
c. Other (specify) …………………….

25. **Do you sort soybean grain**?
    a. Yes
    b. No.

If yes what percentage is lost (damaged/rotten) …………………………………………

26. What **type(s) of treatment do you apply to the threshed/processed soybean grain?**
    a. Chemical dressing (name the type) ………………………………...
    b. Others (specify) ……………………………………………………..
    c. None ………………………………………………………………...

27. **Where do you store your soybeans after harvesting?**
    - **a.** granary
    - **b.** In the house (specify where) ……………………………………..
28. Do you separate soybean grain from seed (meant for planting next season)
    - **a.** Yes
    - **b.** No
29. **What type of container do you use to store your soybean seed meant for planting.**
    - **a.** Sisal gunny bags
    - **b.** Synthetic gunny bags
    - **c.** Pots
    - **d.** Bins and Plastic cans. Specify whether:
      - (i) Sealed ………………..
      - ii) Unsealed …………………
    - **e.** Others (Specify) …………………………………………………….
30. **Do you treat soybean seed with seed dressing before storage or planting**?
    - **a.** Yes,
    - **b.** No,

If yes specify type of seed dressing treatments used

- **a.** Commercial………………………………………………………………
- **b.** Traditional ……………………………………………………………..
- **c.** Others ………………………………………………………………..

31. **For how long do you store the soybean seed before planting (in months)?**

A. <u>For Long rains planting (Months)</u>	**B. <u>For Short Rains Planting (In Months)</u>**
a. 1 month	**a**. 1 month
b. 2 months	**b.** 2 months
c. 3 months	**c**. 3 months
d. 4 months	**d.** 4 months
e. 5 Months	**e.** 5 Months
f. 6 Months	**f.** 6 Months
g. 7 Months	**g.** 7 Months
h. 8 Months	**h.** 8 Months
i. 9 Months	**i.** 9 Months

32. **For what purpose do you plant soybean crop?**
    - **a.** Home use (specify utilization) ……………………………………………………………………………..………
    - **b.** Sale (specify use by market) …………………………………………………………………………………
    - **c.** Home use and sale
33. **If sold, where do you sell your soybean?** ……………………………………………………..……………………………
34. **At what price did you sell last season soybean crop of** (if sold)
    Price per kg …………………………………………………………………………………….
35. **What constraints do you face in soybean production?** (tick and explain/specify)
    - **a.** Lack of Seeds …………………………………………………

b. Poor quality seed ………………………………………………………
c. Lack of inputs (fertilizers, pesticides). If so why
……………………………………
d. Pests and diseases (specify)
……………………………………………………..…………………………
e. Markets (explain)
……………………………………….……………………………………..…
f. Agronomic knowledge
………………………………………………………………..………..………
g. Unreliable weather
……………………………………………………………………………..
h. Processing ……………………………………………………………………
i. Utilization challenges
…………………………………………………………………………….….
j. Others (specify)
…………………………………………………………..……………..

Appendix 2: Discussion guide for qualitative data

Qualitative data from focused group discussions and key informant interviews from researchers, extension staff, processors, marketers, seed dealers/companies.

1. Soybean production history and data in the region.
2. Soybean growing season and farming systems used.
3. Prevalence of soybean farming in the region –location of target farmers growing the crop.
4. Soybean Research and outputs in terms of new locally adapted varieties, uptake by farmers.
5. Soybean extension programs- successes and failures and reasons thereof.
6. Commonly grown soybean varieties in your area.
7. Soybean promotion programs/projects, present and past and their impacts.
8. If introduced/promoted, by who, when and why?
9. Did the introduction/promotion improve production, consumption and sale of soybeans?
10. Purpose for which soybean is grown by farmers;-
    - **a.** Home consumption only and specify uses
    - **b.** Home consumption and sale
    - **c.** Sale only and for what purpose
11. Soybean processing:
    - **a.** source of soybean grain;
    - **b.** preferred varieties,
    - **c.** processed products;
    - **d.** whether they contract farmers to grow;
    - **e.** Constraints if any.
12. Markets for soybeans?
13. Sources of soybean seed?
    - **a.** Seed companies
    - **b.** Agro-vets,
    - **c.** Research stations and if so which ones, which varieties; prices
    - **d.** Farm saved seed
    - **e.** Exchange with neighbors
    - **f.** Others (e.g. imports
14. Seed quality Challenges if any.
15. Seed companies –
    - **a.** whether they produce soybean seed;
    - **b.** if not why?
    - **c.** If yes which varieties
    - **d.** Seed certification if any?

Appendix 3: Farmers from whom farm-saved Soybean seed was sampled from various agro ecologies in Meru South Sub-county; from 19th - to 26th February 2013

	Name of farmer	AEZ	Location	variety	Planting date	Harvesting date
1.	Mary kangai	UM_3	Gitareni	Gazelle	Oct 2012	Feb 2013
2.	Ignatius Mutegi	UM_3	Gitareni	Gazelle	20-10-12	12-2-13
3.	Douglas Kinyua	LM_3	Kiamuguongo	gazelle	12-10-12	11-2-13
4.	Lucy Mofat	UM_2	kirege	gazelle	Oct 2012	Feb 2013
5.	Bernard Mate	UM_3	Gitareni	gazelle	Oct 2012	Jan 2013
6.	Maria Mwithi Muriithi	LM_4	Mbogooni	gazelle	Oct 2012	Jan 2013
7.	Joseph Muriuki	LM_4	Itungururu	gazelle	Oct 2012	Jan 2013
8.	Real Ciamwari	UM_3	Mukuuni	gazelle	Oct 2012	Jan 2013
9.	Patric Muriithi	UM_3	Gitareni	gazelle	Oct 2012	Jan 2013
10.	Catherine Kaari	LM_4	Itungururu	gazelle	Oct 2012	Jan 2013
11.	Odrine Ciambaka	UM_3	Mukuuni	gazelle	Oct 2012	Jan 2013
12.	Josephat Zephania	UM_2	Mugwe	gazelle	Oct 12	Feb 13
13.	Ephraim Kinyua	UM_3	Mukuuni	Gazelle	17-10-12	17-1-13
14.	Dominic Njeru	UM_3	Mukuuni	SB 13	Oct 12	Feb 13
15.	Purity Mbindu	LM_4	Itungururu	Gazelle	Oct 2012	Jan 2013
16.	Lydia Kagendo Nguo	LM_4	Itungururu	Gazelle	Oct 2012	Jan 2013
17.	Jedline Ciamwari	LM_4	Itungururu	Gazelle	Oct 2012	Jan 2013
18.	Dorcas Clemante	UM_2	Mugwe	SB19	Oct 2012	Feb 2013
19.	Naftali Njagi	LM_4	Itungururu	Gazelle	Oct 2012	Feb 2013
20.	Mbae Rachi	UM_2	Mugwe	Gazelle	Oct 2012	19/2/2013
21.	Loyston Mutegi	LM_4	Itungururu	Gazelle	Oct 2012	Feb 2013
22.	Enid Muthoni	LM_4	Itungururu	Gazelle	Oct 2012	Jan 2013
23.	Benson Mureithi	LM_3	Gatereni	Gazelle	18-10-12	15-1-13
24.	Agliphina Ciathuni	LM_3	Gatereni	Gazelle	11-10-12	7-2-13
25.	Kirege Secondary school	UM_2	Mugwe	Gazelle	12-10-12	11-2-13
26.	Mary kengai	UM_3	Gitareni	Gazelle	Oct 2012	Feb 2013
27.	John Gitari Kagoru	LM_4	Itungururu	Gazelle	31-10-12	21-2-13
28.	Mutembei Mutheke	LM_4	Itungururu	Gazelle	9-10-12	22-1-13
29.	Florance wanja	UM_3	Gitareni	Gazelle	15-10-12	30-1-13
30.	John Gitari kagorwe	LM_4	Itungururu	Gazelle	31-10-12	19-2-13

Appendix 4: Effect of N and P fertilization on growth and yield components of soybean

Effect of N (25kg-1ha) and P (60kg-1ha) fertilization on soybean genotypes gazelle and TGx 1740-2F grown in two agro-ecologies (Lower highlands III-Muguga site and Upper midlands IV-Nkoroi site) during short rains of October –November 2013

Agro-ecology - SITE	GENOTYPE	FERTILIZER	Plant height - R7 stage (cm)	Number of Branches/plant	Number of Pods/Plant	Number of Seeds/Pod	1000 seed weight (g)	Yield (Kg/ha)
Muguga (LH3)	Gazelle	N_0P_0 (Control)	31.67^{ef}	1.20^{e}	14.90^{e}	2.14^{abc}	183.64^{ab}	1463.18^{ef}
		N_{25}	30.27^{f}	1.67^{de}	15.70^{de}	2.08^{abc}	188.58^{a}	1869.54^{cdef}
		P_{60}	36.00^{def}	1.93^{cde}	22.57^{cde}	2.15^{abc}	175.63^{abc}	2441.49^{bcd}
		N_{25} P_{60}	31.47^{ef}	1.43^{e}	17.20^{cde}	2.09^{abc}	174.01^{bc}	1683.53^{def}
	TGx 1740-2F (SB19)	N_0P_0 (Control)	42.30^{cde}	2.40^{abcde}	29.17^{bc}	2.00^{bc}	124.52^{e}	1612.15^{def}
		N_{25}	36.92^{def}	2.20^{bcde}	22.87^{cde}	2.05^{abc}	124.76^{e}	1106.23^{f}
		P_{60}	37.18^{def}	1.93^{cde}	23.13^{cde}	1.95^{c}	117.55^{e}	1281.96^{f}
		N_{25} P_{60}	36.84^{def}	1.83^{cde}	26.59^{cde}	1.99^{bc}	123.13^{e}	1404.09^{ef}
Nkoroi (UM4)	Gazelle	N_0P_0 (Control)	53.27^{c}	2.80^{abcd}	25.20^{cde}	2.21^{ab}	154.73^{d}	2972.08^{ab}
		N_{25}	44.63^{cd}	2.53^{abcde}	19.90^{cde}	2.15^{abc}	155.87^{d}	2542.70^{bcd}
		P_{60}	52.60^{c}	2.87^{abcd}	23.60^{cde}	2.25^{a}	159.05^{d}	3074.16^{ab}
		N_{25} P_{60}	53.27^{c}	3.70^{a}	28.87^{cd}	2.21^{ab}	167.34^{cd}	3716.64^{a}
	TGx 1740-2F (SB19)	N_0P_0 (Control)	78.60^{ab}	3.30^{ab}	42.37^{ab}	1.66^{d}	122.11^{e}	2910.19^{ab}
		N_{25}	78.80^{ab}	3.17^{abc}	49.33^{a}	1.63^{d}	119.72^{e}	2722.90^{bc}
		P_{60}	83.10^{a}	3.53^{ab}	43.20^{a}	1.64^{d}	116.66^{e}	2543.99^{bcd}
		N_{25} P_{60}	70.94^{b}	3.01^{abc}	45.56^{a}	1.70^{d}	122.24^{e}	2218.09^{bcde}
	Mean		**50.54**	**2.49**	**28.53**	**1.99**	**145.58**	**2239.64**
	Pr>F		<.0001	0.0109	<.0001	<.0001	<.0001	<.0001
	CV%		14.18	32.21	28.22	7.36	5.49	26.06

Appendix 5: Accelerated ageing germination % and p50 of soybean genotype Gazelle and TGX 1740-2F (SB19).

Accelerated ageing germination, and time for viability to decline by 50% (P50) of soybean Gazelle and TGx 1740 2F during accelerated ageing (41^0C, 100% RH) as influenced by N and P fertilization and seed production agro-ecology [Muguga LH3 and Nkoroi UM4] .

Accelerated ageing duration (days)	Seed Viability (% germination)					Seed Viability (% germination)			
		Fertilizer level					Fertilizer level		
	Control	N_{25}	P_{60}	$N_{25}+P_{60}$		Control	N_{25}	P_{60}	$N_{25}+P_{60}$
	Gazelle at LH3 Muguga site					TGx 1740-2F(SB19) at LH3 Muguga site			
0	99.67	98.83	99.33	99.33		99.67	99.00	97.67	99.67
3	100.00	98.17	98.67	99.67		98.17	99.83	99.33	98.33
4	96.17	89.17	97.17	94.83		98.17	97.50	97.33	96.17
5	80.50	69.83	55.00	57.33		76.17	94.33	72.00	87.83
6	28.17	26.00	19.67	30.17		9.67	23.00	7.33	16.17
7	8.83	23.67	4.00	21.50		11.67	3.33	10.50	5.00
8	0.00	0.17	0.00	0.00		0.17	0.00	0.50	0.17
9	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
P50 (days)	**5.6**	**5.4**	**5.2**	**5.3**		**5.4**	**5.6**	**5.4**	**5.5**
	Gazelle at UM4 Nkoroi site					TGx 1740-2F(SB19)at UM4 Nkoroi site			
0	98.33	99.17	94.33	97.00		98.91	99.50	99.33	99.17
3	96.00	96.83	96.67	98.00		98.83	99.83	99.33	99.83
4	66.50	59.67	56.17	61.17		85.33	72.33	78.67	80.67
5	33.33	21.33	35.50	36.83		46.50	42.83	79.83	68.67
6	4.50	22.67	17.33	17.33		25.50	26.33	8.67	42.00
7	7.33	1.00	1.17	3.67		16.50	25.00	9.50	31.83
8	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
P50 (days)	**4.5**	**4.2**	**4.4**	**4.5**		**5.0**	**4.7**	**5.5**	**5.7**

Appendix 6: Seed leachate conductance of soybean genotype Gazelle and TGx 1740-2F(SB19) after accelerated ageing

Seed leachate conductance of soybean genotype Gazelle and TGx 1740-2F(SB19) during accelerated ageing (41^{0}C, 100% RH) as influenced by N and P fertilization and seed production agro-ecology (MugugaLH3 and Nkoroi UM4

Accelerated ageing duration (days)	Seed leachate conductance (**µs/cm/g**)					Seed leachate conductance (**µs/cm/g**)			
	Fertilizer level					**Fertilizer level**			
	Control	**N_{25}**	**P_{60}**	**N_{25}+P_{60}**		**Control**	**N_{25}**	**P_{60}**	**N_{25}+P_{60}**
	Gazelle at LH3 Muguga site					**TGx 1740-2F(SB19) at LH3 Muguga site**			
0	24.45	23.80	25.18	24.95		29.95	29.71	30.24	28.77
3	21.65	23.78	23.67	24.22		27.88	27.15	26.48	25.82
4	28.88	31.93	28.43	31.01		32.70	33.81	32.12	33.28
5	34.67	34.36	34.43	40.31		36.00	35.49	33.02	34.21
6	43.37	46.20	47.06	45.28		61.41	59.67	61.68	56.35
7	56.43	59.18	52.01	64.71		74.00	79.03	77.09	80.31
8	78.48	72.75	74.01	83.60		115.08	107.48	109.85	107.49
9	120.01	115.28	124.79	126.21		134.04	134.05	146.14	126.36
	Gazelle at UM4 Nkoroi site					**TGx 1740-2F(SB19)at UM4 Nkoroi site**			
0	35.36	32.02	37.10	30.47		29.28	30.05	30.02	34.80
3	36.94	40.34	38.00	29.67		30.15	29.14	30.43	30.94
4	45.31	38.28	40.63	35.40		30.00	30.15	32.99	32.39
5	61.76	58.09	56.21	50.63		35.85	35.86	34.31	37.88
6	84.54	88.99	81.51	71.75		53.35	53.30	50.61	47.70
7	103.78	112.55	117.14	91.41		70.54	61.45	89.40	67.34
8	111.92	115.95	114.81	93.16		108.84	90.27	110.70	87.85
9	142.34	151.21	142.39	131.51		136.59	130.85	143.31	128.20

Appendix 7: ANOVA tables

Table 1: ANOVA on the effect of seed sampling agro-ecology (site) on farm-saved soybean seed quality in Meru South Sub-county.

a. **% Seed moisture content (fwb) of farm saved seed**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replicates	3	0.0000000	0.0000000	0.00	1.0000[ns]
site	3	203.6319095	67.8773032	21.32	<.0001*

b. **Seed leachate conductance (μs/cm/g) of farm saved seed**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replicates	3	557.0771464	185.6923821	143.17	<.0001*
site	3	55.2371611	18.4123870	14.20	<.0001*

c. **Percent germination of farm saved seed**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Replicates	3	67.53571	22.51190	0.02	0.9961[ns]
site	3	33926.07540	11308.69180	10.15	<.0001*

* Significant at the P ≤ 0.05 probability level. ns = Not significant at p≤0.05 probability level

Table 2: ANOVA on the effects of storage containers(C) and seed dressing (D) on seed quality of soybean genotype Gazelle after 4 and 8 months of storage at Lower Midlands IV (LM4) - Igambatuntu

Gazelle after 4 months storage - LM4									
Source	%MC	EC	GP	MGT	GI	T50	EG	SE	SVI
Replicates	NS	NS	NS	NS	NS	NS	NS	NS	NS
Container (C)	<.0001*	<.0001*	NS	<.0001*	0.0008*	<.0001	NS	NS	<.0001*
Dressing(D)	<.0001*	NS	NS	0.0241*	0.0198*	0.0265	NS	NS	<.0001*
C*D	<.0001*	NS	NS	NS	NS	NS	NS	NS	0.0166*
Gazelle after 8 months storage - LM4									
Source	%MC	EC	GP	MGT	GI	T50	EG	SE	SVI
Replicates	NS	NS	NS	NS	0.0484*	NS	NS	NS	NS
Container(C)	<.0001*	NS	0.0021*	NS	NS	NS	0.0021*	NS	NS
Dressing(D)	<.0001*	0.0299*	NS	NS	NS	NS	NS	NS	NS
C*D	<.0001*	0.0128*	NS	0.0101*	NS	0.0206*	NS	NS	NS

* Significant at the P ≤ 0.05 probability level. † NS = no significant differences at P ≤ 0.05.
%MC-Moisture content; EC-Electrical conductivity; GP-Germination %; MGT-Mean germination time; T50-Time to 50% germination; GI-Germination Index; EG-Energy of Emergence; SE-Speed of Emergence; SVI-Seedling vigor Index.

Table 3: ANOVA on the effects of storage containers (C) and seed dressing (D) on seed quality of soybean genotype Gazelle after 4 and 8 months of storage at cooler Upper Midlands II (UM2) - Kirege

	Gazelle after 4 months storage - UM2								
Source	%MC	EC	GP	MGT	GI	T50	EG	SE	SVI
Replicates	NS	NS	NS	NS	NS	NS	NS	NS	NS
Container(C)	<.0001*	<.0001*	NS	NS	NS	NS	0.0207*	NS	NS
Dressing(D)	<.0001*	NS	NS	0.0005*	0.0060*	0.0049*	NS	NS	NS
C*D	<.0001*	NS	NS	NS	NS	NS	NS	NS	NS
	Gazelle after 8 months storage - UM2								
Source	%MC	EC	GP	MGT	GI	T50	EG	SE	SVI
Replicates	NS	NS	NS	NS	NS	NS	NS	NS	NS
Container(C)	<.0001*	<.0001*	NS	<.0001*	<.0001*	<.0001*	NS	NS	<.0001*
Dressing(D)	<.0001*	0.0030*	NS	NS	0.0297*	NS	NS	NS	NS
C*D	<.0001*	NS	NS	0.0056*	0.0025*	0.0335*	NS	NS	<.0001*

* Significant at the $P \leq 0.05$ probability level. † NS = no significant differences at $P \leq 0.05$.
%MC-Moisture content; EC-Electrical conductivity; GP-Germination %; MGT-Mean germination time; T50-Time to 50% germination; GI-Germination Index; EG-Energy of Emergence; SE-Speed of Emergence; SVI-Seedling vigor Index.

Table 4: ANOVA on the effects of storage containers(C) and seed dressing (D) on seed quality of soybean genotype TGX 1740-2F after 4 and 8 months of storage at Lower Midlands IV (LM4) - Igambatuntu

	TGX 17402F after 4 months storage-LM4								
Source	%MC	EC	GP	MGT	GI	T50	EG	SE	SVI
Replicates	NS	NS	NS	NS	NS	NS	NS	NS	NS
Container(C)	<.0001*	<.0001*	NS	NS	NS	NS	NS	NS	0.0445*
Dressing(D)	<.0001*	NS	NS	NS	NS	NS	NS	NS	NS
C*D	<.0001*	0.0009*	NS	0.0007*	0.0005*	0.0013*	NS	NS	NS
	TGX 17402F after 8 months storage-LM4								
Source	%MC	EC	GP	MGT	GI	T50	EG	SE	SVI
Replicates	NS	NS	NS	NS	NS	NS	NS	NS	NS
Container(C)	<.0001*	0.0122*	NS	NS	NS	0.0373*	NS	NS	NS
Dressing(D)	<.0001*	NS	NS	NS	0.0138*	0.0136*	NS	NS	NS
C*D	<.0001*	NS	NS	NS	0.0087*	0.0081*	NS	NS	0.0374*

* Significant at the $P \leq 0.05$ probability level. † NS = no significant differences at $P \leq 0.05$.
%MC-Moisture content; EC-Electrical conductivity; GP-Germination %; MGT-Mean germination time; T50-Time to 50% germination; GI-Germination Index; EG-Energy of Emergence; SE-Speed of Emergence; SVI-Seedling vigor Index.

Table 5: ANOVA on the effects of storage containers(C) and seed dressing (D) on seed quality of soybean genotype TGX 1740-2F after 4 and 8 months of storage at Upper Midlands II (UM2) - Kirege

	TGX 1740-2F after 4 months storage - UM2								
Source	%MC	EC	GP	MGT	GI	T50	EG	SE	SVI
Replicates	NS	NS	NS	NS	NS	NS	NS	NS	NS
Container (C)	<.0001*	<.0001*	NS	NS	NS	NS	NS	NS	NS
Dressing(D)	<.0001*	NS	NS	NS	0.0422*	NS	NS	NS	0.0001*
C*D	<.0001*	NS	NS	0.0070*	NS	NS	NS	NS	NS
	TGX 1740-2F after 8 months storage - UM2								
Source	%MC	EC	GP	MGT	GI	T50	EG	SE	SVI
Replicates	NS	NS	NS	NS	NS	NS	NS	NS	NS
Container (C)	<.0001*	<.0001*	NS	NS	0.0327*	NS	NS	NS	NS
Dressing(D)	<.0001*	NS	NS	NS	NS	NS	NS	NS	NS
C*D	<.0001*	0.0038*	NS	0.0138*	0.0362*	0.0187*	NS	NS	NS

* Significant at the P ≤ 0.05 probability level. † NS = no significant differences at P ≤ 0.05.
%MC-Moisture content; EC-Electrical conductivity; GP-Germination %; MGT-Mean germination time; T50-Time to 50% germination; GI-Germination Index; EG-Energy of Emergence; SE-Speed of Emergence; SVI-Seedling vigor Index.

Table 6. ANOVA indicating the effect of phosphorus and Nitrogen fertilization (F) on growth and productivity of soybean Gazelle at Lower Highlands III (LH3) Muguga site.

	a. **Plant height (cm) at R7 stage for Gazelle at LH3**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	34.72625000	17.36312500	3.08	0.1199 ns
Fertilizer(F)	3	56.73000000	18.91000000	3.36	0.0964 ns
	b. **Number of branches per plant for Gazelle at LH3**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	1.60666667	0.80333333	6.95	0.0274*
Fertilizer(F)	3	0.88916667	0.29638889	2.56	0.1505 ns
	c. **Number of Pods per plant for Gazelle at LH3**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	61.2066667	30.6033333	2.67	0.1481 ns
Fertilizer(F)	3	107.1825000	35.7275000	3.12	0.1097 ns
	d. **Number of seeds per pod for Gazelle at LH3**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	0.07511667	0.03755833	2.62	0.1523 ns
Fertilizer	3	0.01189167	0.00396389	0.28	0.8408 ns
	e. **1000 seed weight (g) for Gazelle at LH3**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	22.1226000	11.0613000	0.14	0.8713 ns
Fertilizer	3	422.8708250	140.9569417	1.80	0.2478 ns
	f. **Seed yield (kg/ha) for Gazelle at LH3**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	1219696.212	609848.106	1.10	0.3913 ns
Fertilizer	3	1580247.675	526749.225	0.95	0.4733 ns

* Significant at the P ≤ 0.05 probability level. ns = Not significant at p≤0.05 probability level.

Table 7: ANOVA indicating the effect of phosphorus and Nitrogen fertilization (F) on growth and productivity of soybean Gazelle at Upper Midlands IV (UM4) Nkoroi site.

a. Plant height (cm) at R7 stage for Gazelle at UM4					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	22.8316667	11.4158333	3.69	0.0901^{ns}
Fertilizer(F)	3	160.0691667	53.3563889	17.26	0.0024*
b. Number of branches per plant for Gazelle at UM4					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	0.98000000	0.49000000	1.87	0.2340^{ns}
Fertilizer(F)	3	2.28916667	0.76305556	2.91	0.1230^{ns}
c. Number of Pods per plant for Gazelle at UM4					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	9.9116667	4.9558333	1.64	0.2707^{ns}
Fertilizer(F)	3	124.4425000	41.4808333	13.71	0.0043*
d. Number of seeds per pod for Gazelle at UM4					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	0.02746667	0.01373333	6.06	0.0363^{ns}
Fertilizer	3	0.01360000	0.00453333	2.00	0.2156^{ns}
e. 1000 seed weight (g) for Gazelle at UM4					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	1597.960350	798.980175	15.12	0.0045*
Fertilizer	3	291.885758	97.295253	1.84	0.2404^{ns}
f. Seed yield (kg/ha) for Gazelle at UM4					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	1733331.369	866665.684	11.91	0.0081*
Fertilizer	3	2116879.122	705626.374	9.70	0.0102*

* Significant at the $P \leq 0.05$ probability level. ns = Not significant at $p \leq 0.05$ probability level.

Table 8. ANOVA indicating the effect of phosphorus and Nitrogen fertilization (F) on growth and productivity of soybean TGx 1740-2F (SB19) at Lower Highlands III (LH3) Muguga site.

a. **Plant height (cm) at R7 stage for SB19 at LH3**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	86.60166667	43.30083333	2.01	0.2147^{ns}
Fertilizer(F)	3	55.26229167	18.42076389	0.86	0.5131^{ns}

b. **Number of branches per plant for SB19 at LH3**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	2.57166667	1.28583333	2.34	0.1772^{ns}
Fertilizer(F)	3	0.40000000	0.13333333	0.24	0.8636^{ns}

c. **Number of Pods per plant for SB19 at LH3**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	338.0016667	169.0008333	2.84	0.1356^{ns}
Fertilizer(F)	3	78.4625000	26.1541667	0.44	0.7332^{ns}

d. **Number of seeds per pod for SB19 at LH3**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	0.02301667	0.01150833	1.89	0.2303 ^{ns}
Fertilizer	3	0.01630000	0.00543333	0.89	0.4964 ^{ns}

e. **1000 seed weight (g) for SB19 at LH3**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	235.2109500	117.6054750	8.93	0.0159*
Fertilizer	3	116.2281667	38.7427222	2.94	0.1208ns

f. **Seed yield (kg/ha) for SB19 at LH3**

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	1234570.851	617285.425	3.16	0.1152^{ns}
Fertilizer	3	428244.893	142748.298	0.73	0.5697^{ns}

* Significant at the $P \leq 0.05$ probability level. ns = Not significant at $p \leq 0.05$ probability level.

Table 9: ANOVA indicating the effect of phosphorus and Nitrogen fertilization (F) on growth and productivity of soybean TGx 1740-2F (SB19) at Upper Midlands IV (UM4) Nkoroi site.

	a. **Plant height (cm) at R7 stage for SB19 at UM4**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	105.0466667	52.5233333	1.29	0.3421[ns]
Fertilizer(F)	3	38.7900000	12.9300000	0.32	0.8129[ns]
	b. **Number of branches per plant for SB19 at UM4**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	5.22666667	2.61333333	2.98	0.1260[ns]
Fertilizer(F)	3	0.22916667	0.07638889	0.09	0.9645[ns]
	c. **Number of Pods per plant for SB19 at UM4**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	194.6466667	97.3233333	1.04	0.4107[ns]
Fertilizer(F)	3	206.7491667	68.9163889	0.73	0.5689[ns]
	d. **Number of seeds per pod for SB19 at UM4**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	0.01401667	0.00700833	0.19	0.8350[ns]
Fertilizer	3	0.00936667	0.00312222	0.08	0.9669[ns]
	e. **1000 seed weight (g) for SB19 at UM4**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	53.28971667	26.64485833	0.89	0.4579[ns]
Fertilizer	3	45.73860000	15.24620000	0.51	0.6896[ns]
	f. **Seed yield (kg/ha) for SB19 at UM4**				
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	292409.0646	146204.5323	0.28	0.7675[ns]
Fertilizer	3	384697.4911	128232.4970	0.24	0.8637[ns]

* Significant at the P ≤ 0.05 probability level. ns = Not significant at p≤0.05 probability level.

Table 10: ANOVA on the effect of growing agro-ecological site (S), genotype (G) and phosphorus & Nitrogen fertilization (F) on soybean growth and yield components

source	**Plant height(cm)**	**Branches/plant**	**Pods/ Plant**	**Seeds per Pod**	**1000 Seed weight(g)**	**Yield Kgha-1**
Site (s)	<.0001*	<.0001*	<.0001*	0.0033*	<.0001*	<.0001*
Genotype(G)	<.0001*	NS	<.0001	<.0001*	<.0001*	0.0049*
Fertilization(F)	NS	NS	NS	NS	NS	NS
S x G	<.0001*	NS	0.0105*	<.0001	0.0003	NS
S x F	NS	NS	NS	NS	NS	NS
G x F	NS	NS	NS	NS	NS	NS
S x G x F	NS	NS	NS	NS	NS	NS

† NS = no significant differences at P ≤0.05. * Significant at the P ≤ 0.05 probability level.

Table 11: ANOVAon the effect of Genotype (G), phosphorus and Nitrogen fertilization (F) on seed germination and leachate conductance of soybean genotypes Gazelle and TGx 1740-2F (SB 19) grown at Lower highlands III (LH3) IV agro-ecology - Muguga

a. Seed leachate conductance at LH3

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	28.1239021	14.0619510	12.04	<.0001*
Genotype(G)	1	618.1350000	618.1350000	529.37	<.0001*
Fertilizer (F)	3	13.3695375	4.4565125	3.82	0.0128*
G x F	3	14.7570250	4.9190083	4.21	0.0079*

b. Germination % at LH3.

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Block	2	16.58333333	8.29166667	1.54	0.2203^{ns}
Genotype(G)	1	2.04166667	2.04166667	0.38	0.5397^{ns}
Fertilizer (F)	3	20.79166667	6.93055556	1.29	0.2840^{ns}
G x F	3	15.45833333	5.15277778	0.96	0.4169^{ns}

† NS = no significant differences at P ≤0.05. * Significant at the P ≤ 0.05 probability level.

Appendix 8: Soil Sampling

Soil sampling Nkoroi site

soil sampling at KALRO Muguga site

Appendix 9: Field experimental layout - RCBD

Appendix 10: Early maturing soybean Gazelle and late maturing TGx 1740 2F

Appendix 11: Seed germination in incubator set at alternating temperature 20/30^{0}C

Appendix 12: Priming in osmotic solutions kept in a walk in germination room at 25^0C

Appendix 13: Priming reduced germination percent but enhanced vigor

(a)Primed seed **(b)Non-primed control**