GENETIC CONTROL OF PHOTOPERIOD SENSITIVITY, SELECTION FOR SHORT-DAY ADAPTATION IN RUNNER BEAN AND VALIDATION OF MULTIPLE DISEASE RESISTANCE IN SNAP BEAN IN KENYA

MABLE MERCY MULANYA

BSc. Agriculture (Hons), University of Nairobi

THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN PLANT BREEDING AND BIOTECHNOLOGY

Department of Plant Science and Crop Protection,

College of Agriculture and Veterinary Sciences

UNIVERSITY OF NAIROBI

2016

DECLARATION

I declare that the work contained in this thesis is my original work and has not been presented for any award of a degree or its equivalent in this university or in any other institution of higher learning.

Mable Mercy Mulanya

Signature ……. Date ……..

This thesis is submitted with our approval as University Supervisors:

Signature …….. Date……

Prof. Paul M. Kimani,
Department of Plant Science and Crop Protection,
University of Nairobi

Signature…… Date…….

Prof. Rarma. D. Narla
Department of Plant Science and Crop Protection,
University of Nairobi

DEDICATION

To my Dear Mother, Phanice Mulanya and late dad, Job Mulanya:

In gratitude for your support, love and fervent prayers

ACKNOWLEDGEMENTS

I first thank the Almighty God for His grace, love and strength that has enabled me to complete this work. Indeed God; you always prove your victory in my life. Great is thy faithfulness.

I acknowledge and thank University of Nairobi through Prof. Kimani who gave me RUFORUM scholarship to pursue post graduate studies.

I am also thankful to my supervisors Prof. P.M. Kimani and Prof. R. D. Narla for your insightful advice and guidance throughout my study.

I thank the University of Nairobi Bean Research Program staff, the entire Department of Plant Science and Crop Protection, Longonot Horticulture Limited and Sunripe Company for the assistance you accorded to me.

My appreciation and special thanks to my Dear Mother, Phanice Mulanya and siblings: Polyn, Constance, Brigid, Evans, Truphena and Foulata for your prayers, support, encouragement and unending love. I will always be indebted to you.

Finally, my candid gratitude goes to all who encouraged and prayed for me, my friends and classmates and all those who contributed to this work directly or indirectly though I may not name you all you still remain dear to me.

ABSTRACT

Runner bean (*Phaseolus coccineus* L.) and snap bean (*Phaseolus vulgaris* L.) are the most cultivated species of Phaseolus. These crops offer a great potential for addressing food insecurity, income generation and poverty alleviation in Africa. However, production of runner bean and snap bean (French bean) in Africa is limited by photoperiod sensitivity and diseases. In Kenya, large scale companies produce long-day vegetable runner bean for export using expensive extended artificial light of 4h because preferred varieties do not flower under the natural short-day length (12h). The local grain type runner bean also known as butter bean is well adapted and flowers normally under short-day conditions. However, its productivity is low and not suitable for cultivation as a vegetable crop. There are no locally bred, short-day vegetable or improved grain type runner bean varieties in East Africa because no breeding programs for this crop in this region are carried out. Moreover, breeding short-day tropically adapted runner bean is constrained by lack of information on the mode of inheritance of photoperiod sensitivity and lack of a suitable breeding methodology. Production of snap bean is constrained by reliance on varieties which are susceptible to rust, angular leaf spot and anthracnose which result in yield losses and low product quality. Therefore, the objectives of this study were to: i) determine inheritance of photoperiod sensitivity, ii) select high yielding, disease resistant and market preferred short-day adapted vegetable runner bean, iii) select for high yielding and disease resistant grain type runner bean, iv) involve farmers in selecting improved grain runner bean lines, and v) validate multiple disease resistance and pod quality of new locally bred snap bean lines.

To determine the inheritance of photoperiod sensitivity, parental lines, F_1, F_2 and their backcross progeny developed from crosses between local landraces and long-day variety, White Emergo, were evaluated at Kabete (1820 masl) and Ol Joro-Orok (2300 masl) . Selection for short-day vegetable and grain type runner bean was conducted on $F_{6.7}$ lines grown at same locations. Snap bean lines selected from F_5 bulk populations were evaluated for disease and pod quality at Mwea and Embu respectively. Data was collected on days to 50% flowering, disease occurence, number of racemes per plant for runner bean and pod yield. Pods were graded using export standards of fresh produce commercial companies. Analysis of variance and generation means were used for data analysis.

After testing the 3-parameter model (m+a+d) and 6-parameter model (m+a+d+aa+ad+dd) based on the joint scaling test as proposed by Mather and Jinks (1982) genetic analysis showed, that additive-dominant model had the best fit. The gene estimates showed that the additive gene effects accounted for more than 90% of the genetic variability for days to 50 % flowering, number of

racemes and pods plant-^{1} in runner bean at both sites. The preponderance of additive gene action than dominance implies that several genes with small additive effects are involved in inheritance of short-day photoperiod in runner bean. This implies that runner bean can be improved through selection procedures like pedigree and single seed/pod descent method where selection of these phenotypic traits will be effective. A modification of these procedures may be necessary because of the insect mediated out-crossing recorded at the trial sites.

The $F_{6.8}$ vegetable bred lines flowered normally under local short-day conditions, and had significantly more racemes (on average 8 racemes plant^{-1}) and high pod yield compared with the long-day check, White Emergo at both sites and seasons. White Emergo had no marketable yield in the first year and had very low yields (25 kg ha^{-1}) in the second year compared to 1,000 kg ha^{-1} realized in commercial large scale cultivation when extended artificial lighting is used. Numbers of racemes of locally bred runner bean lines was higher during the second flush of flowers, which was cooler at both sites, suggesting better adaptation of runner bean to cooler higher altitudes. Six lines in the first year and four lines in the second year yielded more than 1,000 kg ha-^{1} per harvest which are the yields realized in commercial large scale companies.

The locally developed grain type runner bean showed higher degree of resistance to diseases (scores of 1 to 3) and yield advantage of up to 100% in the first year compared to the local landraces. Mean grain yield of runner bean varied from 2,300 kg ha^{-1} to 13,300 kg ha^{-1} in 2013 and from 2,500 kg ha^{-1} to 7,100 kg ha^{-1} in 2014. The best 22 lines with high yield at Kabete and Ol Joro-Orok were selected. Yield of the selected lines varied from 5,000 kg ha^{-1} to 13,300 kg ha^{-1}.

Results showed that positive criteria used by both male and female farmers in selecting grain runner bean were earliness, pods per plant, pods with well filled grains, uniform pod distribution, good plant standability and white grain colour. Negative selection criterion was based on late maturity, other grain seed colour apart from white and shorter pods with no grains. Therewere gender differences in selection with male farmers showing preference for plants that retained foliage even after maturity whereas female farmers selected for plants with less foliage.

Fifteen new snap bean lines which exhibited multiple disease resistance combined with better pod yield and pod quality compared with existing commercial varieties at both locations were identified. These lines had mean disease score of 1-3 for the three diseases and had fresh pod yield of up to 10,000 kg ha^{-1}, which was higher than average of 4,000 kg ha-^{1} realized in farmers' fields with commercial varieties. None of the commercial check varieties exhibited multiple disease resistance.

These results indicate the potential of developing snap bean varieties that combine multiple disease resistance as well as high yielding, short-day adapted runner bean with market preferred pod characteristics. New snap and runner bean varieties from these lines can increase smallholder production because they do not require expensive additional artificial light and reliance on costly fungicides. Utilization of the new lines can enhance competitiveness of green bean and grain legume products in domestic and export markets.

Key words: Runner bean, photoperiod, yield, disease resistance, French bean

TABLE OF CONTENTS

DECLARATION ii
DEDICATION iii
ACKNOWLEDGEMENTS iv
ABSTRACT v
TABLE OF CONTENTS viii
LIST OF FIGURES xiii
LIST OF TABLES xiv
CHAPTER ONE : INTRODUCTION 1
1.1 Background information 1
1.2 Problem statement 2
1.3 Justification 4
1.4 Study objectives 7
1.5 Null Hypothesis 7
1.6 Study Framework 7
CHAPTER TWO : LITERATURE REVIEW 10
2.1 Botany of runner bean 10
2.2 Origin and Distribution 11
2.3 Ecological requirements 11
2.4 Production and utilization 12
2.5 Inheritance of photoperiod sensitivity and flowering in runner bean 12
2.6 Methods used in determining inheritance of plant traits 13
2.7 Snap bean production in Kenya 14
2.8 Constraints to snap bean production in Kenya 15
2.9 Major diseases of snap bean 16
2.10 The importance of multiple disease resistance 17
2.11 Runner bean and snap bean breeding in East Africa 18
CHAPTER THREE: GENETIC ANALYSIS OF PHOTOPERIOD SENSITIVITY AND FLOWERING IN RUNNER BEAN 21
Abstract 21
3.1 Introduction 22
3.2 Materials and Methods 23
3.2.1 Plant materials 23
3.2.2 Trial sites 24
3.3 Methods 24
3.3.1 Characterization of parental lines used in crossing 24

3.3.1 Population development 25
3.3.2 Hybridization of parental lines 26
3.3.3 Experimental design 27
3.3.4 Crop husbandry 27
3.3.5 Data collection 27
3.3.6 Statistical Analysis 28
3.3.7 Genetic analyses 28
3.4 Results 30
3.4.1 Characterization of parental lines 30
3.4.2 Statistical analysis 34
3.4.3 Generation mean analysis 37
3.4 Discussions 48
3.4.1 Parental characterization 48
3.4.2 Mean analysis of generations 48
3.4.3 Genetic components 49
3.5 Conclusion 51
CHAPTER FOUR : SELECTION FOR SHORT-DAY ADAPTATION, POD QUALITY AND YIELD IN VEGETABLE RUNNER BEAN 53
Abstract 53
4.1 Introduction 54
4.2 Materials and Methods 55
4.2.1 Plant materials 55
4.2.2 Trial sites 56
4.2.3 Experimental design and crop husbandry 56
4.2.4 Data collection 56
4.2.5 Data Analysis 58
4.3 Results 59
4.3.1 Weather conditions at experimental sites 59
4.3.2 Plant vigor 60
4.3.3 Days to 50% flowering 62
4.3.4 Number of racemes in the first flush of flowering 63
4.3.5 Number of racemes in the second flush of flowering 65
4.3.6 Cumulative number of racemes for both first and second flushes of flowering 67
4.3.6 Reaction of genotypes to rust 68
4.3.7 Reaction of genotypes to common bacterial blight 69
4.3.8 Reaction of genotypes to bean common mosaic virus disease (BCMV) 71
4.3.9 Reaction of genotypes to powdery mildew 72

4.3.10 Marketable pod yield 73
4.3.11 Pod diameter 78
4.3.12 Pod length 79
4.4 Discussion 81
4.4.1 Growth vigor 81
4.4.2 Days to flowering 81
4.4.3 Raceme formation 82
4.4.4 Reaction of genotypes to the prevalent diseases under the field conditions 83
4.4.5 Marketable pod yield 84
4.4.6 Marketable pod diameter and pod length 85
4.5 Conclusion 85
CHAPTER FIVE : SELECTION FOR IMPROVED SHORT-DAY GRAIN TYPE RUNNER BEAN 87
Abstract 87
5.1 Introduction 88
5.2 Materials and Methods 89
5.2.1 Plant Materials 89
5.2.2 Trial sites 89
5.2.3 Experimental design and crop husbandry 90
5.2.4 Data collection 90
5.2.5 Data analysis 91
5.3 Results 91
5.3.1 Weather conditions at experimental sites 91
5.3.2 Plant Vigor 92
5.3.3 Days to 50% flowering 94
5.3.4 Raceme formation in 2013 96
5.3.5 Raceme formation in 2014 98
5.3.6 Reaction of genotypes to rust 100
5.3.7 Reaction of genotypes to common bacterial blight 102
5.3.8 Reaction of genotypes to powdery mildew 103
5.3.9 Reaction of genotypes to Bean Common Mosaic Virus 105
5.3.10 Grain yield 107
..... 109
5.4 Discussion 110
5.4.1 Plant vigour 110
5.4.2 Days to 50 % flowering 110
5.4.3 Raceme formation 110

5.4.4 Reaction of genotypes to diseases 110
5.4.5 Grain yield of genotypes 111
5.5 Conclusion 111
CHAPTER SIX : VALIDATION OF MULTIPLE DISEASE RESISTANCE, POD YIELD AND QUALITY OF ADVANCED SNAP BEAN LINES DEVELOPED IN KENYA 113
Abstract 113
6.1 Introduction 114
6.2 Materials and Methods 115
6.2.1 Plant Materials 115
6.2.2 Trial sites 115
6.2.3 Experimental design and Crop management 116
6.2.4 Data collection 117
6.2.5 Data analysis 118
6.3 Results 118
6.3.1 Preliminary Yield trials 118
6.3.2 Advanced Yield Trials 123
6.4 Discussion 138
6.4.1 Preliminary evaluation of snap bean lines at Mwea 138
6.4.2 Advanced yield evaluation at Mwea and Embu 138
CHAPTER SEVEN : PARTICIPATORY VARIETY SELECTION (PVS) OF SHORT-DAY ADAPTED GRAIN RUNNER BEAN LINES 144
Abstract 144
7.1 Introduction 145
7.2 Materials and Methods 146
7.2.1 Plant materials used 146
7.2.2 Farmer Selection 146
7.2.3 Trial sites 146
7.2.4 Experimental design and crop husbandry 147
7.2.5 Preparation for the participatory selection 147
7.2.5 Selection Procedure 148
7. 3 Results 149
7.4 Discussions 154
7.5 Conclusions 155
CHAPTER EIGHT : GENERAL DISCUSSION, CONCLUSION, AND RECOMMENDATION 156
8.1 General Discussions 156
8.2 General Conclusions 157

8.3 General Recommendations 157
References 159
Appendices 174

LIST OF FIGURES

Figure 1.1: Breeding scheme for runner bean improvement in the University of Nairobi. 8
Figure 1.2: Breeding scheme for snap beans improvement in the University of Nairobi. 9
Figure 2.1: Inflorescence and seed characteristics of runner beans 11
Figure 3.1: Seed colour of parental runner bean genotypes used in this study 23
Figure 4.1:Vegetable runner bean pod grading according to fresh produce Companies 58
Figure 4.2: Mean monthly temperature and total rainfall data for Kabete and Ol Joro-Orok in 2013 and 2014. 60
Figure 4.3 Pod characteristics of vegetable runner bean lines 80
Figure 4.4 Racemes and pods formed by vegetable runner bean lines 80
Figure 5.1: Mean monthly temperature for Kabete and Ol Joro-orok in 2013 and 2014.....92
Figure 5.2: Mean monthly rainfall for Kabete and Ol Joro-orok in 2013 and 2014 92
Figure 5.3: A) Rust infection (russetting) on pods and leaves B) Dwarf 1 variety infected by powdery mildew at Kabete Field Station. 107
Figure 5.4: High yielding runner bean lines at Kabete.....109
Figure 6.1: Pod shape of the new locally developed snap bean lines. 120
Figure 6.2: Number of pods of selected snap bean lines in the preliminary trial at Mwea.....121
Figure 6.3: Seed yield (kg ha^{-1}) of selected snap bean lines in the preliminary trial at Mwea 121
Figure 6.4: Pod yield of advanced snap bean lines at Mwea and Embu during the long rains.....131
Figure 6.5: Pod yield (kg ha^{-1}) of snap bean lines per harvest at two locations.....133
Figure 6.6: Pod colour of snap bean lines 138
Figure 7.1: Grain runner bean seeds used in PVS.....147
Figure 7.2:Farmers are familiarized with the field and selection ribbons before PVS exercise 148
Figure 7.3: Female and male farmers evaluating the new grain runner bean lines at dry pod maturity 148

LIST OF TABLES

Table 1.1: Production trends of vegetable runner bean in selected counties in Kenya 6
Table 1.2: Production trends of snap bean in selected counties in Kenya 6
Table 3.1: Descriptors used in characterizing runner bean lines in this study 25
Table 3.2: Coefficients of α_k and δ_k utilized for the construction of different models in generation mean analysis based on Mather and Jinks, 1971. 28
Table 3.3: Morphological characteristics of parental runner bean lines used in this study.....32
Table 3.4: Days to 50% flowering ofseven runner bean populations grown at two locations. 34
Table 3.5: Means for number of racemes formed during the first flowering in seven crosses at two locations.....35
Table 3.6: Number of racemes formed by populations in seven crosses during second flush of flowering at two locations 36
Table 3.7: Means of number of pods for the populations in seven crosses at two locations 37
Table 3.8: Scaling test for days to flowering, number of racemes and pods in seven runner bean crosses grown at two locations.....38
Table 3.9: Estimates of gene effects and standard errors when fitted to a 3parameter model for days to 50%flowering at two locations 42
Table 3.10: Estimates of gene effects when fitted to a 3 parameter model for number of racemes during the first flowering in seven crosses at two locations.....42
Table 3.11: Estimates of gene effects fitted to a 3-parameter model for number of racemes during the second flowering in seven crosses at two locations 43
Table 3.12: Estimates of gene effects fitted to a 3parameter model for number of pods formed by seven crosses at two locations.....43
Table 3.13: Different components of phenotypic variance, heterosis and heritability estimates of traits studied. 46
Table 4.1: Scale used to evaluate the reaction of vegetable runner bean germ plasm to fungal diseases.....57
Table 4.2: Description of commercial vegetable runner bean grades. 58
Table 4.3: Plant vigour of selected vegetable runner bean lines at two locations for two years.....61
Table 4.4: Number of days to 50% flowering of vegetable runner bean lines grown at two sites and in two years 62
Table 4.5:Number of racemes of vegetable runner bean lines during the first flowering at two sites for two years.....64
Table 4.6: Number of racemes of vegetable runner bean lines formed during the second flowering at two sites for two years.....66
Table 4.7: Cumulative number of racemes of vegetable runner bean lines grown at two locations for the two flushes of flowering 67
Table 4.8: Rust severity of vegetable runner bean lines at two sites for two years.....68
Table 4.9: Reaction of vegetable runner bean lines to common bacterial blight at two sites for two years.....70
Table 4.10: Reaction of vegetable runner bean lines to BCMV disease at Ol Joro-orok site in two years.....71
Table 4.11: Powdery mildew scores of vegetable runner bean lines at Kabete in two years.....72
Table 4.12: Marketable pod yield per harvest ofvegetable runner bean linesand proportions of yield per grade for two years.....75

Table 4.13: Cumulative marketable pod yield of vegetable runner bean lines in 2013 and 2014 at Kabete and Ol Joro-Orok 77
Table 4.14: Marketable pod diameter (cm) of vegetable runner bean lines in two seasons 78
Table 4.15: Pod lengths of vegetable runner bean lines grown at two locations for two years 79
Table 5.1: Scale used to evaluate the reaction of bean germplasm to fungal diseases.....91
Table 5.2: Plant vigor scores of grain runner bean lines at Kabete and ol Joro-orok for two years 93
Table 5.3: Days to 50% flowering of grain runner bean lines grown at two locations for two years 95
Table 5.4: Number of racemes plant-^{1} during the first and second flush of flowering of grain runner bean lines grown at two locations in the year 2013. 97
Table 5.5: Number of racemes plant-^{1} formed during the first and second flush of flowering of grain runner bean lines grown at two locations in 2014.....99
Table 5.6: Reaction of grain runner bean lines to rust at two locations over two years 100
Table 5.7 Reaction of grain runner bean lines to common bacterial blight infection at two sites for two years.....102
Table 5.8: Reaction of grain runner bean lines to powdery mildew infection at Kabete in two years. 104
Table 5.9. Reaction of grain runner bean lines to Bean Common Mosaic Virus at Ol Joro-Orok for two years.....105
Table 5.10: Grain yield of runner bean lines at Kabete and Ol Joro-Orok for two years 108
Table 6.1: Disease severity scale used to evaluate the reaction of bean germplasm to fungal diseases (van Schoonhoven and Pastor-Corrales, 1987). 117
Table 6.2: Performance of selected snap bean lines during preliminary evaluationat Mwea, Kirinyaga County in 2013 short rains. 122
Table 6.3: Plant vigor mean scores of advanced snap bean lines at Mwea and Embu during short rains in 2013. 123
Table 6.4: Days to 50% flowering of genotypes at Mwea and Embu. 125
Table 6.5: Mean rust severity scores of genotypes at Mwea and Embu during 2013 short rain season. 126
Table 6.6: Mean severity scores of angular leaf spot on genotypes grown at Mwea and Embu during 2013 short rain season.....127
Table 6.7: Anthracnose severity scores on snap bean lines at Mwea and Embu during 2013 short rain season 129
Table 6.8:Pod yield (kg ha^{-1}) of snap bean lines and distribution among market classes at Mwea and Embu in 2013 short rains.....132
Table 6.9: Pod lengths of advanced snap bean lines grown at two locations during 2013 short rains 134
Table 6.10: Pod curvature, shape and colour of advanced snap bean lines at Mwea and Embu ...135
Table 6.11:Selection of best advanced lines based on index selections for preliminary and advanced trials at Mwea an Embu.....137
Table 7.1 Runner bean cropping calendar during long rains at Ol Joro-Orok 147
Table 7.2: Votes of preferred and non-preferred lines as selected by farmers.....150
Table 7.3: Positive and negative criteria used by farmers in selection of grain runner bean lines at Ol Joro-Orok in 2013. 154

CHAPTER ONE
INTRODUCTION

1.1 Background information

Runner bean and snap bean offer a great potential for addressing food insecurity, income generation and poverty alleviation in Africa. Kenya's horticultural subsector has become a major foreign exchange earner, employer, and contributor to food needs. Vegetables are a major component of the sub-sector (Mutuku et al., 2004).The main vegetable crops grown in Kenya for export market include snap bean (*Phaseolus vulgaris* L.), runner bean (*Phaseolus coccineus* L.), garden pea (*Pisum sativum* L.), sugar snap pea (*Pisum sativum* L.), and baby corn (*Zea mays* L.). They account for 80% of vegetable exports. Although they are grown primarily for export, they are gaining popularity in domestic markets (HCDA, 2013). Production and area under runner bean has increased for the last few years except in 2013 when production area and quantity decreased. However, in Snap bean area under production has decreased (Table 1.1). Even though the sector seems to thrive well, farmers are faced with challenges in production of these crops.

Runner bean crop is grown as a vegetable for its immature green pods and also for its dry seeds as grain type. In Kenya, the local grain type landraces of runner bean is grown at elevations between 2000-2500 m.a.s.l in Nakuru and Nyandarua counties. Although there are several grain types, the white seeded variety commonly referred to as butter bean, is the dominant type in Kenya (Kahuro, 1990). Though, the grain type runner bean is grown at high altitudes of Eastern Africa where common bean (*Phaseolus vulgaris* L.) is poorly adapted, its productivity is low**.** The grain yield of runner bean is estimated at 900 to 1100 kg ha^{-1} (Brink, 2006). Grain type runner bean has largely been ignored; with breeders pre-dominantly focusing on improvement of common bean (Buruchara et al., 2011). The crop therefore has received virtually no research attention not only in Kenya, but also in Africa, and to a large extent globally. Furthermore, smallholder farmers who grow grain runner bean rely on low yielding traditional landraces, which are susceptible to diseases and have mixed grain types.

Vegetable runner bean is grown by fresh produce companies in Naivasha, Nyeri and Timau on the slopes of Mt Kenya. Major exporters rank runner bean among the highest quality green bean in the world (EPZA, 2005). Fresh produce companies rely on imported long-day varieties for production of vegetable runner beans**.** These varieties originate from temperate regions and therefore they fail to flower under short-day tropical conditions. In contrast, grain runner type that has been traditionally grown in the highlands of Kenya flowers normally. The main vegetable varieties grown by large scale companies are White Emergo, White Lady and Equator (Longonot

horticulture, personal communication, 2013). To enhance flowering of long-day vegetable varieties, day length is increased by additional artificial lighting, since Kenya being in tropics has short-day conditions. Large scale producers are forced to use artificial lighting which is expensive. Day length requirement in runner bean limits smallholder participation as well as area under production.

Most small scale farmers lack knowledge on vegetable production of runner bean since production of such beans has solely been done by large scale farmers. Few farmers grow grain runner beans mainly for subsistence use because of lack of pure seed. Therefore, participartory approaches of involving farmers in selection process of elite lines will offer opportunities to farmers to familairize with existing vegetable runner beans and improved grain runner bean.This will facilitate commercial production of runner bean for local, regional and international markets.

Snap bean also known as 'French bean' or fine beans, is a leading vegetable export crop from Kenya. Production of snap bean has faced several challenges. Insect pests and diseases are the major biotic constraints to snap bean production in Eastern and Central Africa causing significant losses (Ndegwa et al., 2009). The diseases of economic importance are rust, anthracnose, angular leaf spot and bacterial blight which not only affect yield, but also the quality of the produce, making the crop less marketable (Nderitu et al., 2009). Farmers have no choice but to use fungicides as a remedy to reduce disease pressure. Prevailing strict safety and quality standards enforced by the Global Gap which demand low residue levels of pesticides on fresh produce, further constrains farmers' access to markets. Use of pesticides further increases production costs and reduces profitability of snap bean crops (Kimani et al., 2002). Development of snap bean varieties with multiple disease resistance to major diseases will reduce yield losses; minimize use of chemicals and lower production costs. Therefore, the aim of this study was to contribute to the development of short-day adapted runner bean and snap bean with multiple disease resistance to improve productivity and quality of these crops in Kenya.

1.2 Problem statement

In Kenya, the dominant white seeded grain runner bean local landrace flowers and sets pods at altitudes of 1800m and above but it's primarily grown for dry grain (Kahuro, 1990). Furthermore, the grain type cannot be used for vegetable production because the pods are firm, curved with strings and hence do not meet preferred export market characteristics. Productivity of grain type runner bean is low because farmers grow local landraces which are low yielding and susceptible to pests and diseases. Area under production of grain runner bean is also small because farmers lack knowledge of the existing improved runner bean. This has limited commercial production and only small amounts of the grain yield are sold in the local markets. The available long-day vegetable

varieties commercially grown are poorly adapted to tropical conditions.Most small scale farmers lack knowledge of the production of vegetable runner bean and therefore have only focused on subsistence production of grain runner bean.

Fresh produce companies' use only imported long-day vegetable runner bean varieties which fail to flower and set pods under natural day length. This is because the imported cultivars were bred for production in temperate countries which have long-day conditions. Thus cultivation of imported vegetable varieties under short-day tropical conditions requires extended hours of artificial lighting to induce flowering. Provision of extended light hours is a major constraint to Kenyan smallholder producers due to the increased costs of production. Large scale producers install costly artificial lighting, which in turn reduces competitiveness of their products in export destinations. Requirement for extended lighting excludes participation of smallholder farmers in the lucrative runner bean trade. As a result, only a few large scale producers dominate the export market but cannot meet the demand due to inadequate production. Little has been done to develop short-day runner bean varieties suitable for production in tropical climates of Africa. Globally, breeders have focused on the common bean improvement. Consequently, little is known about the mode of inheritance of day length sensitivity and other traits in runner bean. Development of tropically adapted vegetable runner bean varieties is important in realizing increased production for export.

Angular leaf spot (*Phaeoisariopsis griseola*), rust (*Uromyces appendiculatus*), and anthracnose (*Collectotrichum lindemuthianum*) are the most economically important and widely distributed diseases of snap bean in eastern Africa (Monda et al., 2003). Smallholder snap bean farmers in their effort to manage these diseases mainly rely on pesticides to increase production. However, use of pesticides reduces the quality of the produce due to the residue level requirements set by the European markets (Wasonga et al., 2010). Continued use of pesticides furthermore leads to development of resistance in pathogen races to the pesticides, increased production costs and negative effect on the environment and human health (Wahome et al., 2011). Cultural practices such as crop rotation, intercropping, removal of plant debris, adjustment of planting dates, use of compost, and blending heterogeneous cultivars have been used and can reduce diseases severity though to a lesser extent (Deeksha et al., 2009). In as much as application of fungicides is an effective way of controlling diseases, there is need for an integrated disease management approach that includes genetic resistance (Wahome et al., 2011). This approach will enable farmers to grow resistant varieties with minimal use of fungicides hence reduce production costs reduce environmental risks and residue levels on the exported produce.

1.3 Justification

Development of short-day vegetable and grain runner bean variety is an effective strategy for enhancing participation of smallholder farmers and expanding area under production to increase exports. Runner bean has shown considerable promise as an export crop and for local production. It is an opportunity for Kenya to expand exports and take advantage of relatively low production costs and favorable climatic conditions. This research seeks to develop locally adapted short-day high yielding vegetable type and grain runner bean varieties for commercial production. Shortday vegetable varieties will save energy, reduce production costs associated with artificial lighting and expand area under production. Improved grain type runner bean varieties that combine high yield and disease resistance will enhance commercial production of the crop and increase its significance as a grain legume in Kenya and Africa in general. The crop is a potential alternative grain legume to common bean that has been adversely affected by pests, diseases, agronomical and nutritional factors. Runner bean is adapted to high altitudes which are too cold for common bean. Provision of short-day adapted and high yielding grain and vegetable varieties will enable smallholder farmers to access pure seed and allow them tap into opportunities for local and export production.

Increasing production of runner beans will be effective by involving farmers in variety improvement process. Participartory breeding approaches will grant farmers knowledge of existing vegetable and grain runner bean and also involve farmers in selection of improved varieties. This will enhance adoption of new developed runner bean varieties by farmers, increase area under production and productivity.Therefore, development of a local improvement program will enhance breeding capacity since little has been done to improve runner bean in Africa. This will also facilitate smallholder farmers to gainfully participate in the runner bean subsector, make local produce more competitive in international markets and available to local consumers.

In Kenya**,** snap bean production is done mainly by small to medium scale farmers. The enterprise creates on-farm employment opportunities for the rural community and benefits more than one million people (CIAT, 2006). Host plant resistance to diseases is the most economic and environmentally sustainable method of controlling bean diseases that affect crops (Kimani et al., 2006). Although some commercial varieties have been found to be resistant to one disease of snap bean, there are still threats of attack by different pathogens. Multiple disease resistance is the most cost effective and sustainable strategy for managing diseases of snap bean in low input production systems in Kenya and the region. Kenya relies wholly on imported seed of snap bean varieties which are protected by law, making seed expensive and inaccessible to smallholder producers. It would be expected that locally bred varieties will reduce production costs, increase access to seed which is locally bred, create new employment opportunities, incomes and enhance

competitiveness of Kenyan products in global markets. The current trend of bean improvement programs is to develop varieties that have multiple-constraint resistance (Miklas et al., 2002). Diseases resistance is one of the characteristics of interest for acceptable snap bean varieties in addition to good growth habit, high yield potential and market quality pods (Kimani et al., 2006; Muchui et al., 2006). Therefore, development of snap bean varieties with multiple resistance to rust, anthracnose and angular leaf spot diseases and good pod quality offers a long term solution to increased snap bean production.

Table 1.1: Production trends of runner bean in selected counties in Kenya

County	2011			2012			2013			
	Area (Ha)	Quantity(t)	Value (Kshs millions)	Area (Ha)	Quantity (t)	Value (Kshs millions)	Area (Ha)	Quantity (t)	Value (Kshs millions)	% share per county
Nyandarua	171	222	7.1	180	230	7.3	186	192	5.8	72
Meru	100	1000	0	150	1,500	1.5	120	1,200	1.2	15
Kakamega	6	7	0.5	31	31	1.9	7	10	1.0	12
Kisumu	20	20	0.2	20	20	0.2	10	10	0.1	1
TOTAL	**297**	**1,249**	**7.8**	**381**	**1,781**	**10.9**	**323**	**1,412**	**8.1**	**100**

Source: Production statistics of horticultural crops at www.hcda.co.ke

Table 1.2: Production trends of snap bean in selected counties in Kenya

County	2011			2012			2013			
	Area(ha)	Quantity(t)	Value(millions)	Area(ha)	Quantity(t)	Value(millions)	Area(ha)	Quantity(t)	Value(millions)	% share per county
Kirinyaga	1918	12114	398.5	1788	10583	450.9	1514	15222	869.4	47.7
Murang'a	803	3368	103.5	861	3848	118.5	885	4731	15.8	8.7
Taita taveta	50	1497	52.4	51	1227	43.5	134	3514	147.6	8.1
Meru	341	3206	124.7	326	6615	261.6	367	3328	130.3	7.1
Embu	74	562	29.5	56	765	39.9	176	2083	124.2	6.8
Machakos	245.8	625.2	28.7	329	1759	75.2	522	2415	106	5.8
Laikipia	195	1500	99	150	1080	76	185	1380	89	4.9
Narok	115	1254	61.8	148	1718	101	164	1046	60.4	3.3
Others	500	4726	93.5	518	5924	106	581	4679	137.8	7.6
Total	**4,242**	**28,852**	**991.5**	**4,227**	**33,520**	**1,272.7**	**4,528**	**38,398**	**1,823**	**100**

Source: Production statistics of horticultural crops at www.hcda.co.ke

1.4 Study objectives

Overall objective

To develop short-day adapted runner bean and disease resistant snap bean varieties with market preferred pod characteristics for smallholder farmers in Kenya.

Specific objectives

1. To determine the inheritance of photoperiod sensitivity and market preferred pod traits in vegetable runner bean in Kenya.
2. To select for well adapted short-day vegetable runner bean lines with market preferred pod quality, resistance to diseases and high pod yield from existing locally developed advanced lines.
3. To select high yielding grain type short-day runner bean lines from locally developed advanced lines.
4. To validate multiple disease resistance, pod yield and pod quality of new advanced snap bean lines developed in Kenya.
5. To involve farmers in selection of short-day adapted grain runner beans and familiarize them with vegetable runner beans.

1.5 Null Hypothesis

1. Photoperiod sensitivity, pod quality, phenology, and other morphological traits of runner bean are not genetically controlled.
2. There is no variation in pod quality, yield, disease resistance and short-day adaptation among existing runner bean lines and imported varieties.
3. There is no difference in grain yield and other agronomic traits between new advanced runner bean lines and existing local grain type landraces grown in Kenya.
4. Existing commercial varieties are not different in disease resistance, pod yield and pod quality with new snap bean lines developed in Kenya.
5. Plant breeders' criterion of selection of shortday adapted grain runner is not different from farmers' selection criterion.

1.6 Study Framework

Fig 1.1 and 1.2 shows the framework of this study. To determine photoperiod inheritance in runner beans, a crossing block was established to develop six populations; parents (P_1 and P2), F_1, F_2, BC_1P_1 (backcross one to parent one) and BC_1P_2 (backcross to parent 2).The populations were evaluated in the field to determine the gene effects that control the inheritance of photoperiod and preferred characteristics of vegetable runner bean so as to enhance the selection process in improving runner bean (Fig 1.1). Selection for vegetable and grain type lines from existing locally

bred lines was carried out under field experiments at two locations and years. The selection also involved farmers by use of participatory variety selection. The best lines were selected to be used in development of improved runner bean varieties. In snap beans, the advanced lines were evaluated in the field to determine if they exhibit combined resistance to diseases at two locations (Fig 1.2).

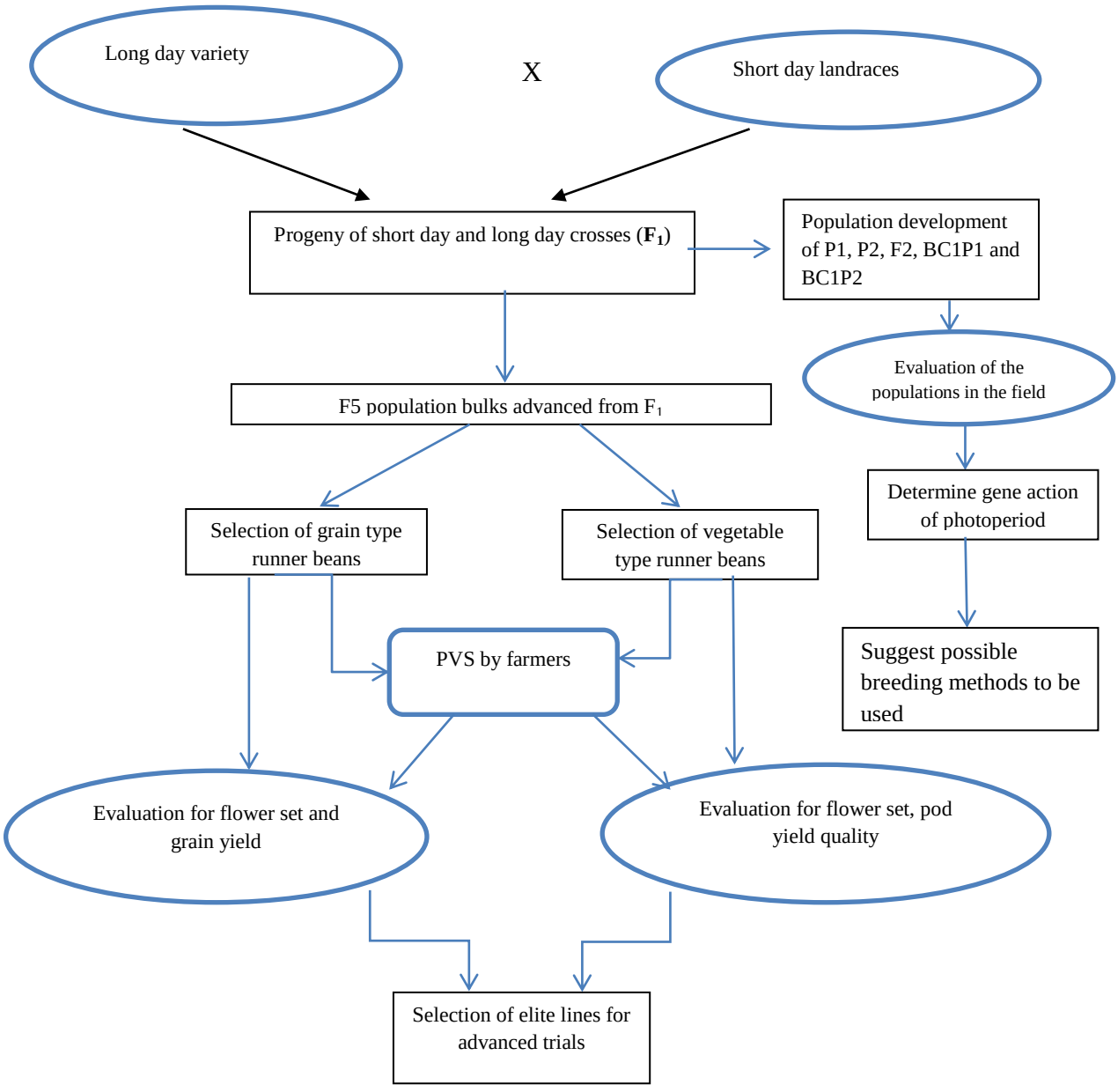


Figure 1.1: Breeding scheme for runner bean improvement in the University of Nairobi.

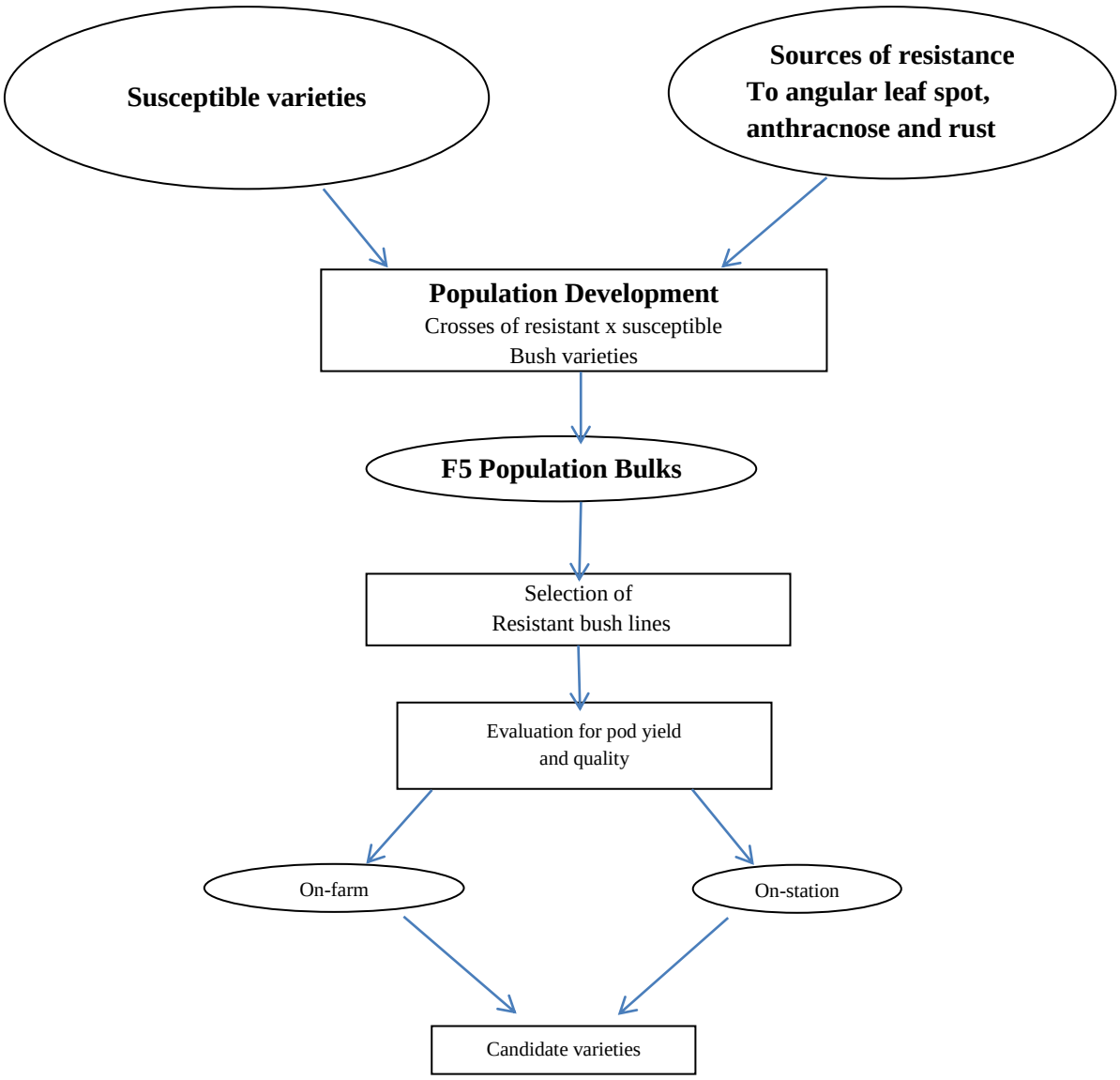


Figure 1.2: Breeding scheme for snap beans improvement in the University of Nairobi.

CHAPTER TWO
LITERATURE REVIEW

2.1 Botany of runner bean

Runner bean (*Phaseolus coccineus* L.), is one of the cultivated species of *Phaseolus* genus in the large family Papillionaceae (fabaceae). In Kenya, runner bean is commonly referred to as butter bean. It is a perennial, climbing and branching herb which is commonly grown for both dry seeds, immature beans and green pods as an annual. Its climbing characteristics allow it also to be grown as an ornamental (Brink, 2006). Like most of the species of *Phaseolus*, its chromosome number is 2n=22 (Raemarkers, 2001).

The crop has three sub-species, *P.albiflorus* (white flowers), *P.bicolor* (both white and red flowers) and *P.coccineus* (red flowers) based on flower colour which is correlated to the colour of stems and seeds, and to the seed colour pattern (Santalla et al., 2004; Zeven et al., 1993)**.** White flowered species produce white seeds, while red flowered types have variant colour types of either black, brown, or violet and the seed is either speckled or flecked. The bicolor subspecies is rare. The crop can grow to a height of 4m or more with green pods being harvested 80-90 days from sowing, and for mature seeds after 100-120 days (Purseglove, 1987). Flowering starts at 40 to 60 days after sowing. Harvesting of green pods starts at three months after sowing and can be easily sustained for two to three months. Bushy cultivars are smaller in size and produce earlier than climbing cultivars (Brink, 2006). Runner bean flowers in two stages; the first flowering and second flowering. However, due to non-uniform pod maturity, it's difficult to determine yield of each flowering stage. Runner bean has a tuberous tap root. Leaves are alternate, 3-foliolate; stipules triangular; petiole (6-16) cm long, stipels are 5 mm long. The inflorescence is an axillary or terminal raceme with many flowers (Fig 2.1A). Peduncles are 5 to 25.5cm long. The pods are usually 10-30 cm in length depending on the type. Vegetable types have longer pods than the grain types (Fig 2.1B).

In grain runner bean types, pods are often slightly pubescent, with stout bean and contain 1 to10 very large oblong seeds while vegetable ones have tender pods with no seeds and can snap easily. Flowers are bisexual usually bright scarlet and occasionally white (Purseglove, 1987; Kay, 1979). Pod of runner bean is a linear-lanceolate. Seeds are broad-oblong and can be black, white, cream or brown, often pink to purple speckled (Fig 2.1 C and D). Germination is hypogeal with the first pair of leaves being simple and opposite (Brink, 2006). In contrast to common bean, the runner

bean is a cross-pollinated species with medium to high variation within populations (Zeven et al., 1993).

A. Runner bean raceme, B. vegetable runner bean pods, C. speckled runner bean seeds and D. mono coloured seeds.

Figure 2.1: Inflorescence and seed characteristics of runner beans

2.2 Origin and Distribution

Runner bean (*P. coccineus*) is thought to have originated from Central America in the uplands of Chiapas and Guatemala (Purseglove, 1987; Westphal, 1974). According to archeological findings, *P. coccineus* L. was probably domesticated 2,200 years ago in the Tehuacan Valley in Mexico. Although it is cultivated as an annual, *P. coccineus* grows perennially in its natural habitats in the cool, humid highlands of Guatemala in altitudes above 1800 m.a.s.l. Hybrids of *P. vulgaris* x *P. coccineus* can be produced easily, while a reciprocal cross is only produced with difficulty (IBPGR, 1983). According to Delgado (1988), runner bean has one Centre of domestication in Mesoamerica. Today, scarlet runner bean is cultivated in temperate countries and occasionally in highland areas of Central and South America, Africa and Asia (Purseglove, 1987; Brink, 2006). In Africa, runner bean is cultivated in Ethiopia, Zimbabwe, Kenya, and South Africa mainly for export (Purseglove, 1987; Brink, 2006).

2.3 Ecological requirements

Scarlet runner bean is a crop for temperate climates. In the tropics, it is most successful at altitudes of 1500–2000 m.a.s.l. In Kenya, runner bean is grown at 1900–2600 m.a.s.l altitude. In Ethiopia ,runner bean is cultivated up to about 2000 m.a.s.l. Runner bean is more tolerant of cool conditions than other *Phaseolus* species, but damage occurs at temperatures below 5°C (Kay, 1979). Tindall (1983) reported that runner bean is mainly grown in the tropics at high altitudes above 1800m. At temperatures above 25°C fruit development and seed setting in runner bean are inhibited (Kay, 1979).

Scarlet runner bean is extremely susceptible to drought and requires a well-distributed rainfall throughout the growing period. Scarlet runner bean is adapted to a wide range of soils, but it prefers deep, well-drained, loamy, light- to medium-textured soils, with pH of 6–7.Water logging in runner bean is not tolerated (Brink, 2006). Runner bean set pods abundantly (Herklots, 1972).There are conflicting reports on light requirement of runner bean. Santon et al. (1966) stated that there are long-days as well as day-neutral and short-day types. Westphal (1974) on the other hand, stated that the scarlet runner bean is likely to be a quantitative short-day plant that thrives in the humid uplands of the tropics. Martin (1984) reported that it is often a short-day plant but most cultivars are day neutral. Purseglove (1987) concluded that it is a long-day plant, which is less sensitive than most of *Phaseolus spp* to cool summers and this has contributed to its success in Britain.

2.4 Production and utilization

In Kenya, the grain runner bean type is used for local consumption while the vegetable type is mainly for export. The white seeded variety which is also referred to as 'butter bean 'is grown in Nyandarua and Nakuru districts by smallholder farmers in Kenya (Kahuro, 1990; Brink, 2006). The yield of dry grain type in Kenya is estimated at 900 to 1100 kg ha-^{1} (Kahuro, 1990). Fresh produce companies that produce for export realize yield of up to 30,000 kg ha^{-1} of fresh runner bean pods (Sunripe Company, personal communication 2013). According to HCDA report 2013, vegetable runner was grown on 323 hectares giving a production of 1,412 tonnes and valued at Kshs 8.1million (HCDA, 2013). White-seeded grain cultivars are grown in South Africa for canning and direct household consumption. Runner bean is also very popular in the U.K, where it is grown as an annual and produced mainly for fresh vegetable market (Kay, 1979).

2.5 Inheritance of photoperiod sensitivity and flowering in runner bean

Flowering; the change from vegetative to reproductive stage, is an important developmental change for successful reproduction in plants. For flowering to occur, the plant has to integrate both environmental cues and endogenous factors. Photoperiodism, vernalization and hormonal regulation are among major factors which influence flowering (Sumin et al., 2013)**.** Flowering is a critical pre-requisite to good pod set and seed load and hence affects yield (Egli, 1998). Photoperiodism is described as the response to day length (Salisbury and Ross, 1992)**.** The inheritance of photoperiod sensitivity in runner bean is unknown and the crop is thought to be long-day or short-day depending on area of adaptation (Purseglove, 1987; Martin, 1984).

The first experiments on photoperiodism were done by Garner and Allard (1920, 1923) who discovered the effect of day length in influencing flowering using tobacco and soybean in controlled experiments. The crops were subjected to two treatments; natural conditions and

artificially shortened day length conditions by moving the plants into a dark room in afternoons and returning them back to the field in the morning. This accelerated the flowering of tobacco and soybean, causing Garner and Allard (1920, 1923) to deduce that the two crops could only flower when the day length is below a certain critical photoperiod. There are several studies that have attempted to explain the physiological mechanisms involved in regulating photoperiod response in *Phaseolus* species and other crops but few reports are available on genetic influence of photoperiodism. For instance, physiological studies on flowering time carried out on peas, cereals and Arabidopsis (novel model plant) have revealed photoperiodism influence on flowering through the external coincidence model. This model explains that light must interact at appropriate time of the day with photoperiodic response of a cellular activity to confer photoperiodic responsiveness for flowering (Snape et al., 1996; Weller et al., 1997; Koornneef et al., 1998).

There is no information on the inheritance pattern of photoperiodism and genes involved to control this phenomenon in runner beans. However, in other *Phaseolus* species like common bean, a clear inheritance pattern of photoperiodism was reported by Kornegay et al. (1993) who found out that photoperiod response in common bean is controlled by two dominant genes which act in a recessive epistasis. Moreover, this pattern of inheritance was identical for crosses made within Andean and Meso- American germplasm and a test of allelism showed no difference between the two gene pools. The two genes were designated as A and B. It was noted that gene A codes for the production of a product which promotes sensitivity to long-day lengths and thus inhibits flowering of common bean under long-day conditions, while gene B enhances the photoperiod effect.

White et al. (1996) later identified gene A as 'Ppd' and B as 'Hr'. Ppd was the primary dominant gene responsible for photoperiod sensitivity, while the second dominant Hr gene increased the sensitivity to photoperiod. Further studies in common bean using DNA markers have confirmed the previously defined primary locus Ppd at which the dominant allele confers sensitivity and the secondary locus which influences the degree to which a plant responds to photoperiod (Gu et al., 1998). These studies therefore reveal the presence and possibility of transfer of genes controlling photoperiodism.

2.6 Methods used in determining inheritance of plant traits

Several biometrical methods have been used to estimate components of phenotypic variation. Widely used techniques include North Carolina mating designs, diallel crossing systems, line x tester and generation mean analysis. Amongst these designs, generation mean analysis (GMA) has been identified as the most effective since it provides information on estimates of the main gene actions (additive and dominance) and their digenic and trigenic interactions (Ganesh and Sakila, 1999). The concept of generation mean analysis was developed by Hayman (1958); Jinks and Jones (1958) for the estimation of genetic components of variation.

There are three models for estimating gene effects and variances from generation means; 6-parameter model, 5- parameter model and 3- parameter model based on the generations included in the study (Bankar et al., 2011). The five parameter model is based on five generations; Parents (P_1 and P_2) F_2 and F_3 while the three parameter model comprises of three generations; F_2,F_3 and F_1.The six parameter model is based on six generations P_1, P_2, F_1, F_2, BC_1P_1 and BC_1P_2 (Mather and Jinks, 1982). Information generated from these populations through data analysis helps in determining gene action. GMA has been extensively used in most crops like common bean (Checa et al., 2006), maize (Sher et al., 2012), eggplant (Sabolou et al., 2014) and lentils (Khodambashi et al., 2012). While using GMA, Checa et al. (2006) studied the inheritance of climbing ability in common beans. They reported that inheritance of plant height and internode length was greatly influenced by additive effect compared to the dominant-additive genetic effect. They therefore concluded that inheritance of plant height and internode length was relatively simple and thus selection for these phenotypic traits was highly effective.

Khodambashi et al. (2012) studied inheritance of grain yield and related traits in lentils using GMA. They concluded that inheritance of these traits was influenced by additive, dominance and at least one epistatic effect. Most of the traits studied showed low narrow sense heritability of 10 to 59% coupled with presence of greater non-additive effects. They further reported that selection for such traits would be difficult when using conventional methods in the early generations. Despite the expansive use of GMA, there is no report on the use of this technique in understanding gene effects in the control of flowering in runner beans. Therefore, use of this method will reveal the inheritance pattern of genes influencing photoperiodism in runner beans.

2.7 Snap bean production in Kenya

Snap bean (*Phaseolus vulgaris* L.) is one of the most widely cultivated vegetable crops. Production of snap bean is done by smallholder and few large-scale farmers in central, Eastern, western, and coast regions of Kenya (Chemining'wa et al., 2012). However, a higher percentage of production is mainly by smallholder farmers. Snap bean enterprise creates on-farm employment opportunities for the rural community. The total production of snap bean in 2013 was 38,398 metric tonnes and valued at Kshs 1.8 billion (Table 2.1). In 2013, area under snap production, yield and value increased by 7.1%, 14.6% and 43.3% respectively. The leading snap bean producing counties were Kirinyaga, Murang'a, Taita Taveta, Meru and Machakos accounting for 39.6%, 12.3%, 9.2%, 8.7% and 6.3% of the total production respectively from 2011 to 2013 (HCDA, 2013). About 90% of the crop produced in Eastern Africa is exported to regional and international markets (ASARECA, 2012).

More than one million people benefit from the snap bean sub-sector in Kenya (CIAT, 2006). According to Kelly and Scott (1992), snap bean is rich in ascorbic acid, iron, calcium, vitamin A,

and dietary fibre and hence can contribute nutritionally in various mixed diets. Snap bean thrives well in optimum temperature range of 20-25°C, but can be grown in temperatures ranging between 14^0C and 32°C. Extreme temperatures result in poor flower development and poor pod set. However, snapbeanmatures faster in warmer areas and can be grown between 1000 and 2100 m above sea level. Rain fed cultivation is possible in areas with well distributed, medium to high annual rainfall (900-1200 mm), but to maintain a continuous production especially during the dry season, irrigation is essential. Snapbean grows best on well drained, silty loams to heavy clay soils high in organic matter with pH 5.5-6.5 (Infonet Biovision, 2013).

2.8 Constraints to snap bean production in Kenya

Production of snap bean by smallholder farmers is low compared to large scale farms due to numerous challenges. Monda et al. (2003) reported that the major constraints to snap bean production in order of importance are marketing, poor infrastructure and pests and diseases. Abiotic factors like low nitrogen, aluminum and manganese toxicity and drought in snap bean production areas also affect production. Soil analyses conducted in Mwea indicated that nitrogen is very low (0.09-0.12%) even though phosphorous is sufficient (44-57ppm) (Kamanu et al., 2012). Lack of good quality seed of locally adapted varieties is another constraint to snap bean production in Kenya (Ndegwa et al., 2009). This has resulted on over-dependency on few imported snap bean varieties which are expensive and inaccessible to smallholder farmers. Muchui et al. (2001), identified post-harvest losses and quality characteristics conforming to target markets among other challenges affecting snap bean production.

The major insect pests affecting snap bean production in Kenya are bean stem maggot, bean flower thrips, western flower thrips, common blossom thrips, bean aphids, red spider mites, the African bollworm, the legume pod borer and white flies (Nderitu et al., 2007). Field experiments and surveys have ranked bean rust as a major foliar disease in snap bean in Kenya (Monda et al., 2003; Wahome et al., 2011). Over time, application of fungicides and use of cultural methods have been employed in managing the diseases (Wahome et al., 2011). However, management strategies have been severely constrained by high cost of chemicals, pathogen diversity for virulence and ability of pathogens to stay in the soil for a long time (Deeksha et al., 2009). Breeding programmes in eastern Africa aim at accumulating several resistance sources in a variety as a way of developing broad and durable resistance (Muthomi et al., 2011).

2.9 Major diseases of snap bean

Snap bean is affected by various diseases with the major foliar diseases of importance being rust, angular leaf spot, common bacterial blight, bean common mosaic virus and anthracnose.

Rust caused by a fungus *Uromyces appendiculatus* is a severe disease causing losses ranging from 18 to 100% in grain yield and reduction in pod quality in snap bean (Kimani, 2002, De Jesus et al., 2001; Lindgren et al., 1995). Bean rust has been ranked as a major foliar disease of snap bean in Kenya (Wahome et al., 2011). Bean rust results in reduction of maximum leaf area, leaf shrivelling and defoliation thereby decreasing the photosynthetic area of the crop (Mersha and Hau, 2008). The initial symptoms of this disease appear as small chlorotic leaf spots that first develop on leaves which enlarge to form orange to brown pustules called uredinia. The pustules are usually bordered with a chlorotic halo. Rust epidemics develop after flowering and severe infections result in leaves curling upward, dry up and drop prematurely hence reducing pod set, pod fill and seed size (Koike et al., and Harveson et al., 2007). Bean rust pathogens is highly virulent and possess more than 300 races (Araya et al., 2004).

Several resistant genes to rust have been identified, named and grouped as *ur-4,ur-6,ur-9,ur-12* and *ur-13* originating from the Andean genepool, while *ur-3,ur-5,ur-7* and *ur-11* from the middle American genepool (Lienbenberg et al., 2006).The most effective rust resistance genes to races from Kenya have been identified as *ur-5,ur-11* and *ur-CNC* (Arunga et al., 2012). Nonetheless, ur-11 gene has been reported to be resistant to about 89 races out of 90 races maintained at United States Department of Agriculture (Pastor-Corrales, 2002).

The most predominant race of rust found in Central Kenya (Embu, Mwea, Meru and Thika) and western region (Eldoret, Kisii, Kitale and Naivasha) is 29-1(Arunga et al., 2012). They further, found out that that the Mesoamerican genes confer resistance to most of the Kenyan races and could be exploited as valuable sources of resistance. Among resistant lines, BelDakMi, BelMiNeb and Beltgrade lines developed by Grafton and Stavely (2012); Pastor Corrales et al. (2001) possess *ur-3, ur-4, ur-5, ur*-6 and *ur-11* genes for rust resistance.

Angular leaf spot caused by *Phaeoisariopsis griseola* produces typical symptoms of angular shaped spots on leaves. Symptoms on pods consist of circular to elliptical red-brown lesions, while leaf lesions start as small, brown or grey spots that become angular and necrotic, being confined by leaf veins. Lessions on the leaf eventually coalesce, causing premature defoliation (Saettler, 1991). Stenglein et al. (2003) reported that angular leaf spot causes serious and premature defoliation resulting in shriveled pods, shrunken seeds and yield losses of up to 80%.

Disease development occurs over a wide range of temperature with optimum development temperature being at 24°C in humid conditions (Bassanezi et al., 1998). Several sources of resistance to angular leaf spot have been identified in cultivars such as AND 277, G5686 and

Mexico 54 (Nietsche et al., 2001; Pastor-Corrales et al., 1998; Aggarwal et al., 2004). In Africa, resistance has been found in GLP24, GLP X-92, GLP 806 and GLP 77(CIAT, 1984).

Inheritance of resistance to angular leaf spot is complex due to reports of resistance being qualitatively or quantitatively controlled. Dominant monogenic resistance has been reported by Carvalho et al. (1998); Sartorato et al. (2000); Nietsche et al. (2000); Ferreira et al., (2000). Lopez et al. (2003) ; Mahuku et al. (2009, 2011) reported quantitative inheritance pattern using quantitative trait loci (QTLs). However, consolidated reports reveal that angular leaf spot resistance depends very much on resistance genes; *Phg 1*, *Phg 2*, *Phg 3*, *Phg 4*, *Phg 5* and *Phg 6* genes which occur in AND 277, Mex 54 and Mar 2 lines (Carvalho et al., 1998; Sartorato et al., 2000; Oblessuc et al., 2012).

Bean anthracnose (*Colletotrichum lindemuthianum*) is a major disease in susceptible snap bean varieties and can cause of up to 100% loss if the environmental conditions are favorable (Fernandez et al., 2000). Symptoms appear as red to dark brown lesions on stems, leaf petioles and veins on the undersurface of the leaf. Lesions appear sunken and circular on pods. Anthracnose is favoured by cool temperatures of about 16^{o}C. The fungus can survive season to season on infected plant debris or seed (Hagedorn et al., 1986).

Resistance to anthracnose in common bean is conditioned mostly by single independent genes. Several anthracnose genes have been characterized in common bean and classified as *Co-2,Co-3,Co-3*^{2}*,Co-4,Co-4*^{3}*, Co-5,Co-6,Co-7,Co-8,Co-9,Co-10* and *Co-11* from the middle American gene pool, and *Co-1,Co-12* from the Andean gene pool (Kelly and Vallejo, 2004 ; Bassett, 2004). Resistance genes have been identified in a common bean line G2333 which was evaluated under field conditions in Brazil, Argentina, Peru, Colombia, C. America, Mexico and in several African countries and showed resistance (Pastor Corrales et al., 1994). Due to these resistance genes, G2333 line was released as a commercial cultivar in Rwanda where it's commonly known as "*Umubano*".

2.10 The importance of multiple disease resistance

Breeding for improved cultivars to a biotic and biotic stresses has been a primary goal in the integrated disease management strategies. Host resistance in particular is the most effective strategy and sustainable method for controlling bean diseases (Miklas et al., 2006; Oliveira et al., 2008). Resistant varieties provide the potential for achieving higher productivity even when the crop is under disease pressure (Mooney, 2007). The term multiple disease resistance (MDR) refers to host plant resistance to two or more diseases. The use of genotypes with multiple disease resistance in small scale holders is believed to be the most economical, adoptable and environmental friendly method (Nene, 1988).

The concept of MDR in crops dates back to 1902 when cowpea cultivar 'Iron' was found to be resistant to root knots and wilt (Orton, 1902; Webber et al., 1902). Since then ,this concept has been utilized and successful multiple disease resistance has been reported in crops such as snap bean (Wahome et al., 2011), common bean (Fininsa and Tefera, 2006), and cucumber (Barnes 1961).Fininsa and Tefera (2006) reported that 26 genotypes of common bean were resistant to common bacterial blight, angular leaf spot and anthracnose. According to Wahome et al., (2011), advanced lines of snap bean like HAB 501, SB 10W, SB 10 BR, HAV130, HAV131, HAV132, HAV133 HAV134 and HAV135 showed multiple resistances to rust angular leaf spot and anthracnose. These nine lines also showed a decrease in severity of angular leaf spot, anthracnose and rust by 17, 16 and 36%, respectively, compared to the commercial bush varieties.

Variety TY 3396-12 is a multiple disease resistant and high yielding common bean that is used for production in relatively high rainfall receiving areas of eastern and western Hararghe in Ethiopia. TY 3396-12 has also shown up to 28% yield advantage over the currently available common bean varieties such as Ayenew and Roba-1 in the region (Fininsa and Tesso, 2006).As revealed in previous studies, multiple resistance to diseases is conceivable and is an efficient way of developing resistant snap bean cultivars. However, a combination of yield potential, desirable pod characteristics alongside with this combined resistance is a major consideration in improvement of snap beans.

2.11 Runner bean and snap bean breeding in East Africa

Snap bean improvement in Kenya started in 1998 at Kenya Agricultural Research Institute (KARI)-Thika (currently referred to as KALRO) with support from the International Center for Tropical Agriculture (CIAT) and the Eastern and Central Africa Bean Research Network (ECABREN) as a regional activity. Kutuless (J12) line which was resistant to rust, had good snap ability and formed extra fine pods was developed but it was not released (Chemin'gwa et al., 2012). In 2000, ECABREN recognised snap bean as one of the seven most important regional bean classes (CIAT 2004). The network selected the national agricultural research systems (NARS) of Kenya and Uganda to lead snap bean breeding based on their comparative advantage and the importance of the crop in these countries.

In 2001 a regional snap bean programme was initiated to develop improved snap bean varieties with high yield potential, resistant to biotic stresses, and high pod quality for smallholder producers (Kimani, 2006). This programme was located in Kawanda Agricultural Research Institute in Uganda, Moi University in Eldoret (Kenya), the National Horticultural Research Centre of KARI-Thika, and the Department of Plant Science and Crop Protection, University of Nairobi. After four years of screening snap bean varieties with farmers at Kawanda in Uganda HAB 433, J12 and L3 varieties were selected. In Rwanda, two commercial varieties namely Saxa

and Loiret were produced for European markets, but later succumbed to disease pressure (Nyabyenda 1991).

The University of Nairobi snap bean breeding programme focused on pod shape, size and texture; resistance to rust, angular leaf spot, anthracnose, root rots and common bacterial blight; and bush and climbing habit. The efforts at the University of Nairobi breeding activities led to development of populations form crosses between resistant varieties and susceptible commercial varieties and evaluation of advanced bush and climbing bean lines. Forty-four bush breeding lines, 15 climbing lines, and 15 varieties of snap bean, including both fresh market and canning types, were identified and evaluated. The lines were further evaluated for reaction to inoculation with rust, angular leaf spot and anthracnose in trials conducted at Mwea and Thika.

More than 30 populations were developed between diverse sources of resistance to rust, angular leaf spot and anthracnose and advanced to F_5 generation as population bulks. The F_5 lines were artificially inoculated with the three diseases and selections combining multiple resistances to these diseases and preferred pod characteristics were made in 2010(Wahome et al., 2011). However, the selected lines have not been validated to possess multiple disease resistance and preferred pod traits in the market.

The need for runner bean improvement was first identified in 2004 as documented in PABRA report of 2005 when this crop was identified as a high value export and grain legume crop (Kimani et al., 2005b). However, the underlying problem in runner bean production was lack of flowering of the imported commercial variety under the short-day conditions. Therefore, the large scale companies were forced to install artificial lighting which was expensive for smallholder farmers. To try and solve the problem it was suggested that populations be developed from local short-day cultivars and introduced long-day varieties from which short-day vegetable and grain lines can be selected (Kimani et al., 2005a). This work was then started by the University of Nairobi Bean program and populations were developed. These populations were advanced through a series of bulk selections up to $F_{6.7}$ generations where single plant selections were made (Kimani et al., 2005b).However, evaluation of these lines for short-day adaptation, increased grain yield and vegetable pod characteristics has not been done.

Participatory variety selection (PVS) is an approach to provide choices of varieties to the farmers for increasing production in their diverse socioeconomic and agro-ecological condition.The Support for Participartory Variety Selection (PVS) emerged from the dissatisfaction over the slow pace of varietal change in many agricultural regions in developing countries. It was therefore important to involve farmers and key stakeholders along the value chain in improvement of crops. This strategies were adopted by Pan-African Bean Research Alliance (PABRA) bean reseachers in

sub –saharan Africa to focus research on specific client needs and to hasten the uptake of breeding products (Buruchara et al ., 2011).

Improved bean varieties in East Africa are probabaly the best known example of successful application of PVS which has fueled bean improvement in several countries including Tanzania, Uganda, Kenya, Rwanda and Malawi (Weltzien et al., 2003).There are reports of increased adoption of varieties when farmers are involved in variety development (Gressel et al.,2004).According to CIAT report 2013, use of participartory approaches has resulted in improved bean varieties being adopted on about 56% of bean area in Ethiopia, Malawi, Tanzania, Rwanda, Mozambique, Burundi, Democratic Republic of Congo and Kenya. This reveals the need of adopting partcipartory selection in improvement of these crops.

The work at the University of Nairobi on grain runner bean improvement was based on breeder's objectives. Consequently, selection of the runner bean lines was advanced based on the selection criterion of the breeder. Farmers were not involved in earlier stages of runner bean improvement. Therefore, it is necessary to determine the selection criteria of farmers to facilitate adoption of the improved grain runner bean lines.

CHAPTER THREE

GENETIC ANALYSIS OF PHOTOPERIOD SENSITIVITY AND FLOWERING IN RUNNER BEAN

Abstract

Breeding short-day tropically adapted vegetable runner bean is constrained by lack of information on the mode of inheritance of photoperiod sensitivity. The objective of this study was to determine the inheritance of photoperiodism in runner beans. 7 single crosses (White Emergo x Kin1, White Emergo x Kin 2,White Emergo x Kin 3,White Emergo x Nyeri, White Emergo x Dwarf 1,White Emergo x Dwarf 2 and White Emergo x Dwarf 3) were developed between long-day variety (White Emergo) and seven local landraces. For each cross, the F_1's were advanced to F_2 and backcrossed to both parents. The parents (P_1 and P_2), F_1, F_2 and backcrosses were evaluated at Kabete (1820 m.a.s.l) and Ol Joro-Orok (2300 m.a.s.l). Data was collected on days to 50% flowering, number of racemes and pods per plant. Components of phenotypic variance were determined using generation mean analysis. Analysis of variance showed that there were significant differences in days to 50% flowering, number of racemes at first and second flowering and number of pods in all crosses at both sites. The results showed that in all crosses, short-day parents (P_2) flowered earlier (within 40-48 days) and formed more racemes (on average 10 racemes/plant) and pods (at least 25 pods/plant) than long-day parent (P_1) which had 2 racemes on average and flowered within 54-58 days at both sites. Each raceme contained 15-20 single flowers. The backcrosses' showed means that were close to their recurrent parents where BC_1P_1 flowered late within 51-55 days, had fewer racemes (4-9 racemes /plant) and pods (9-22pods/plant) while BC_1P_2 formed on average 8-14 racemes/plant,13-30 pods/plant (and flowering early within 44-59 days at both locations. Mean duration to 50% flowering and number of racemes at first flowering of the F_1 and F_2 occurred within the range of the parental values in all crosses at both locations. However, in the crosses of White Emergo x Dwarf 1, Dwarf 2, Dwarf 3 and White Emergo x Kin 1,White Emergo x Kin 2 and Kin 3 the means of F_1 and F_2 were higher than the better parent(P_2) for number of racemes at second flowering and pods. The additive-dominant model was found adequate for genetic analyses of traits studied. Additive gene effects accounted for about 90% of the genetic variation for all the traits. Broad sense heritability was relatively high (64.2%-93.2%) for all traits. These results indicate that improvement of this crop for short-day adaptation can be easily achieved through selection methods such as single seed/pod descentand pedigree methods.

Key words: *Phaseolus coccineus*, day length, additive and dominance effects

3.1 Introduction

Runner bean has been traditionally grown in Kenya as a grain legume crop. The traditional grain type runner bean (butter bean) flowers easily under short-day conditions (12h). In contrast, vegetable runner bean grown by large scale fresh produce companies mainly for export do not flower under natural 12h day length unless there is an additional artificial light of 4h. These varieties are imported from temperate countries especially Europe and therefore are not adapted to short-day tropical conditions (Caiger, 1995).Therefore, breeding short-day varieties of runner bean can reduce production costs associated with additional lighting, facilitate local seed production and enhance production of fresh produce by smallholder farmers. However, breeding short-day grain and vegetable type runner bean is constrained by lack of information on the inheritance of photoperiod sensitivity in runner beans.

Photoperiodism has been identified to majorly influence flowering (Sumin et al., 2013)**.** Photoperiodism is the ability to flower in response to changes in relative lengths of day and night (Thomas and Vince-Prue, 1997). Garner and Allard (1920) first documented the importance of day length in flowering by using controlled photoperiodic conditions on tobacco and soybean. Thomas and Vince (1975) categorizes plants as short-day, long-day or day-neutral based on their response to day length and further sub-groups them as obligate (qualitative types) and facultative (quantitative types). In the quantitative crops, a particular day length accelerates flowering but it's not essential for flowering, whereas in qualitative types response to a specific day length is essential for flowering and thus in absence of a promotive day length the crop will not flower. Such clear categorization on the basis of photoperiod response is unknown in runner bean and the crop is thought to be long-day or short-day depending on area of adaptation (Purseglove, 1987; Martin, 1984). Furthermore, there is no information on nature of genes and gene action involved in influencing photoperiod inheritance in runner bean. However, genetic studies on photoperiod sensitivity in common bean (*Phaseolus vulgaris*) revealed that the basic photoperiod inheritance is controlled by two dominant genes (*Ppd* and *Hr*) genes which act in a recessive epistatic manner (Kornegay et al., 1993).

In an attempt to determine nature of gene action influencing flowering in runner bean, generation mean analysis method was adopted because it provides information on estimates of the main gene actions (additive and dominance) and epistatic effects (Ganesh and Sakila, 1999). Therefore, the objective of this study was to determine the inheritance of photoperiod sensitivity through the use of generation mean analysis in crosses between long-day and shortday runner beans.

3.2 Materials and Methods

3.2.1 Plant materials

Seven short-day grain type local landraces namely Nyeri, Kin 1, Kin 2, Kin 3, Dwarf 1, Dwarf 2, and Dwarf 3 were crossed as male parents to a long-day female parent, White Emergo. The seven short-day grain type parents were local landrace collections from farmers in Nyeri, Kinangop and Ol Joro-Orok in Kenya and hence the designation of the names. White Emergo is a long-day imported variety with straight, tender and very long pods preferred by exporters and consumers. However, it can only flower under additional artificial light in short-day conditions in Kenya. Kin 1, Kin 2, Dwarf 1 and 2 have violet-black speckled seeds; Kin 2 has black seeds while White Emergo and Dwarf 3 are white seeded (Fig 3.1). The growth habit of all parents was climbing vines except for dwarf parents which had a type II growth habit. The male and female parents had hypogeal germination, extrose type of stigma with a lanceolate leaf shape. White Emergo and Dwarf lines have white flowers which are associated with the white colour of the flower standard. However, Kin 1, Kin 2, Kin 3, Nyeri, Dwarf 1 and Dwarf 2 have red flowers mainly because of the scarlet colour of the standard. All the local landraces always flower easily under natural 12h day length unlike White Emergo which has delayed flowering and need artificial light to trigger flowering.

Figure 3.1: Seed colour of parental runner bean genotypes used in this study

3.2.2 Trial sites

Population development was done in an insect proof screen house at Kabete Field Station. Populations were evaluated in the field at Kabete and KALRO- Ol Joro-Orok. With limitations of long-day varieties not flowering under short-day conditions, the populations were evaluated under short-day conditions to evaluate their adaptation to this climatic condition. This will enhance adaptability of runner bean to tropical conditions.

Kabete Field Station is located in Nairobi County at an altitude of 1840m above sea level. It is in agro-ecological zone (AEZ) III (900-1860m.a.s.l) with a bimodal rainfall pattern with peaks in April and November. The annual rainfall is about 1000mm which is received during long rains (March to May) and short rains (October to December).The site has a maximum and a minimum mean temperature of 24.3^{o}C and 13.7^{o}C respectively. The dominant soils are humic nitisols soils which are very deep, well drained, dark reddish, deep friable clay type resistant to erosion (Jaetzold et al., 2006).

Ol Joro-Orok- KALRO station is located in Nyandarua County at an altitude of 2300 m a.s.l. The site is in AEZ II (highland areas at altitude of 1980 to2700 m.a.s.l). The mean annual rainfall is 1000mm with reliability of rains being from September to October. The mean maximum temperatures are 22^{o}C and mean minimum temperatures are 10-16^{o}C. The dominant soils are planosols. These soils are deep, imperfectly drained, firm and very dark greyish brown in colour (Jaetzold et al., 2006).

3.3 Methods

3.3.1 Characterization of parental lines used in crossing

Little is known about the parental lines used in this study. The male parents were local landraces collected from farmers who use them in making local dishes or for sale in local markets. White Emergo is only known to be an imported long-day variety mostly used by large scale companies for production of vegetable pods for export. There is no published information on the phenotypic attributes of these lines. Therefore, it was necessary to characterize these materials so as to determine phenotypic characteristics that distinguish the accessions to facilitate genetic analyses of target traits and an effective breeding process. Characterization was based on *Phaseolus coccineus* descriptors published by the International Board of Plant Genetic Resources as shown in Table 3.1 (IBPGR, 1983), currently known as Biodiversity International. The parental lines were planted on sterilized soil in18 inch diameter pots under a netted green house to minimize out crossing. Each accession had 5 pots with 2 plants per pot replicated three times hence giving a total of 30 plants per accession. Supplementary irrigations and crop protection measures were used when necessary. The parental lines were characterized for type of germination, hypocotyl or epicotyl colour, leaflet

shape, growth pattern, size of bracteole, shape of bracteole, colour of standard, shape of stigma, pod pattern, pod shape, colour of pod pattern, and seed colour and shape as described in Table 3.1 below.

Table 3. 1: Descriptors used in characterizing runner bean lines in this study

Trait	**Phenotypes**
Germination	Hypogeal, epigeal
Hypocotyl/epicotyl colour	Green , red, purple or mixed
Leaflet length	short (4-5cm), intermediate (8-9cm) or long (12-13cm)
Leaflet shape	Round (< 1.5cm), ovate (1.5-2cm), ovate-lanceolate (2-3cm), lanceolate (3-6cm) or hastate (>6cm)
Growth pattern	Small bush, large bush, semi-vine short runner, semi-vine long runner, climbing vine-medium size or climbing vine-large size
Colour of standard	Pure white, white with pink nervation, pink, orange, scarlet, violet, purple or mixed
Shape of stigma	Introrse, terminal or extrorse
Flower bud shape	Globular, intermediate or long
Pod pattern	Absent or present
Colour of pod pattern	Pod pattern absent, red, violet or black
Pod shape	Straight, slightly curved or markedly curved
Seed coat pattern	Seed pattern absent, mono-coloured pattern, bicolored pattern or mixture of different colours
Type of seed coat pattern	Seed pattern absent, flecked, striped, intensively striped, almost continuous or speckled
Background colour of the seed coat	White, off- white, grey, buff, brown, red, violet, dark violet, black or mixed

Source: Information based on International Board of Plant Genetic Resources (IBPGR descriptors (1983)

3.3.1 Population development

F_1, F_2 and backcrosses were developed from crosses between seven male short-day traditional grain type parents namely; Nyeri, Kin 1, Kin 2, Kin 3, Dwarf 1, Dwarf 2 and Dwarf 3 and one female long-day variety, White Emergo, at Kabete Field Station. This experiment was done in an insect-proof green house to minimize outcrossing. Seed of parental lines were planted in polythene

sleeves. For each parental line; 20 female and 25 male plants were sown in pots for each cross and this was replicated twice. Four seeds were sown in each pot and thinned to two plants per pot. The potting media was sterilized soil. At planting 5g of diammonium phosphate was thoroughly mixed with sterilized soil. The eight parental lines were planted at one week intervals to ensure synchronization of flowering in the greenhouse and availability of adequate pollen during pollination. The adjacent security light to the green house was utilized to provide additional light to enhance flowering of White Emergo (long-day variety).This ideally provided the extended light of 4 hours as applied in large scale production fields. Pots were irrigated manually in the morning and evening using watering cans.

A table spoon (5g) of calcium ammonium nitrate was applied once after 4weeks from planting to boost the vigor of plants. Whiteflies, aphids, spider mites and leaf miners were controlled by alternate application of Cyclone® (10% cypermethrin + 35% chlorypriphos) and Confidor® (imidacloprid) at the rate of 1.5ml L^{-1} after every two months.

Seven crosses were made (White Emergo x Nyeri), (White Emergo x Kin 1), (White Emergo x Kin 2), (White Emergo x Kin 3), (White Emergo x Dwarf 1), (White Emergo x Dwarf 2), and (W. Emergo x Dwarf 3). The seven short-day parental lines were used as male parents and crossed with White Emergo (female long-day parent) to obtain F_1 progeny. The six generations were developed through a stepwise crossing from December 2012 to December 2013. The F_1 plants were advanced to F_2 and part of it also back-crossed to long-day and short-day parents hence creating BC_1P_1 and BC_1P_2 respectively.

3.3.2 Hybridization of parental lines

The study populations were developed following standard hybridization procedures described by Bliss (1980); CIAT (1987). Fine-tipped forceps, small bottle of alcohol for rinsing forceps, tags to be attached around flower peduncle and magnifying lens were the equipment used to achieve hand pollination. Flower buds which were plump, showed scarlet or white colour depending on the population and seemed ready to open the following day were chosen from the female parent for pollination. The bud from the female parent was held between the thumb and fore finger of one hand with forceps in the other finger.

The standard was opened by inserting the point of the forceps into the suture and pushing from side to side. The wings were carefully removed with forceps to expose the coiled keel. The keel was then removed to expose anthers and the stigma. After the keel was pulled off, stamens were removed carefully so as not to rapture anther sacs and cause self-pollination. The forceps was dipped periodically in alcohol to prevent contamination. The pollination was done early morning before sunrise and late in the evening. The opened flowers from male parents were picked and

placed in a small tray. Both rubbing and hooking methods were used whereby the pollinated stigma of the male parent was pulled out and rubbed onto the female parent's stigma or just hooked. The freshly pollinated stigma was closed gently after pollination and the bud carefully enclosed to avoid contamination by other pollen .A tag with details of male and female parent and date of pollination was placed around pedicel of female flower for identification. A total of 250 pollinations were done for each cross. The pods were left to dry in the field while on the plant. Seeds were harvested from dry pods then dried in the sun and treated with fungicide and insecticide.

3.3.3 Experimental design

The six generations of each population were planted as a separate experiment. The experiment was laid out in a complete randomized bock design with two replications. Rows in a plot were 3m long. Number of rows per plot varied with treatments. Backcrosses (BC_1P_1 and BC_1P_2) were planted in plots with two rows. F_1, parent 1(P_1), parent 2 (P_2) were on a 3-row plot, while F_2 populations were planted in a 4-row plot. The intra-row spacing was 20cm. Inter-row spacing was 50cm. The number of plants evaluated varied depending on the treatment whereby BC_1P_1 and BC_1P_2 had 5 to 10 plants, F_1, P_1 and P_2 had 5 to 15 plants and F_2 had 10 to 20 plants per replication.

3.3.4 Crop husbandry

The parents, their F_1, F_2 and backcross progenies were planted under natural 12 hour day-light in the field at Kabete and KALRO- Ol Joro-Orok. The materials were planted during the long rains and evaluated for days to 50% flowering, number of racemes per plant and number of pods. Diammonium phosphate fertilizer was used during planting at a rate of 60kg ha^{-1}. Calcium ammonium nitrate (26% N) was applied once at flowering at a rate of 5g per plant. Stakes were used to support each individual plant was supported by stakes at Ol Joro-Orok while at Kabete a string was tied at the base of the plant to a top placed heavy weight wire suspended horizontally across the row. The wire was supported by sturdy wooden poles on each side of the row. Insect pests were controlled by alternate application of Cyclone® (10%cypermethrin + 35% chlorypriphos) and Confidor® (imidacloprid) at the rate of 1.5ml L^{-1} after every two months. Manual weeding and supplementary irrigation was done when necessary.

3.3.5 Data collection

Data was collected on duration to 50% flowering, number of racemes, flowers per raceme and number of pods per plant. Duration to 50% flowering was recorded as the number of days after planting to the date when 50% of plants had one or more open flowers. Number of racemes were

counted on a single plant basis during the 1st flush and 2nd flush of flowering at both sites. Pods from each plant were counted when the plants had reached physiological maturity of 270 days at Ol Joro-Orok and 150 days at Kabete.

3.3.6 Statistical Analysis

Data for each cross and location was analyzed separately. Analysis of variance (ANOVA) was conducted using Genstat statistical software13th edition (VSN international, 2011).Where the F test showed significant differences among generations, Tukey's test was used to separate the means at ($P \leq 0.05$). Analysis of variance was performed to determine the significance of genotypic effect followed by genetic analyses.

3.3.7 Genetic analyses

The traits that showed significant differences in the ANOVA were then subjected to generation mean analysis using the methodology proposed by Mather and Jinks (1971):

1. For each given trait, location and cross, each generation means was expressed in terms of its genetic effects using the equation below;

$\mathbf{g}_k = \mathbf{m} + (\alpha_k)\mathbf{a} + (\delta_k)\mathbf{d} + (\alpha_k)2\mathbf{aa} + (\alpha_k\delta_k)\mathbf{ad} + (\delta_k)2\mathbf{dd}$. Where

g_k = mean of generation k

m = mean of the parental homozygotes

α_k and δ_k = coefficients determined by the degree of relationship of generation k

a = additive gene effects

d = dominant gene effects

aa = epistatic effects of additive x additive type

ad= epistatic effects of additive x dominant type

dd= epistatic effects of dominant x dominant type .

Table 3.2: Coefficients of α_k and δ_k utilized for the construction of different models in generation mean analysis based on Mather and Jinks, 1971.

	Genetic effects					
Generation	**m**	**a**	**d**	**Aa**	**ad**	**dd**
P_1	1	-1	0	1	-1	0.25
P_2	1	1	0	1	1	0.25
F_1	1	0	1	0	0	0.25
F_2	1	0	0.5	0	0	0
BC_1P_1	1	-0.5	0.5	0.25	0	0
BC_1P_2	1	0.5	0.5	0.25	0	0

Where **m**-mean effect of parental homozygotes, **a**=additive effects**, d**=dominance effect, **aa=** additive x additive effects, **ad**=additive x dominant effects and **dd**= dominance x dominance effects.

2. The above coefficients shown in Table 3.2, means and the variances of each of the six generations and for each site were then submitted to regression analysis. Linear regression analysis was carried out using the statistical package Genstat 13th edition by weighting based on the inverse of the variance of means and the matrix of coefficient of genetic effects (Mather and Jinks, 1971).
3. Both the 3 and 6 parameter models were tested. Mather and Jinks (1982) scaling tests were employed to determine the adequacy of a 3-parameter model (m+a+d) as described by Hinkosa et al., (2013); Zdravkovic et al., (2011).The scaling test was done based on Mather and Jinks (1982) as follows;

   $A= 2\,\overline{BC_1P_1} - \overline{F_1} - \overline{P_1}$ and $V_A=4V_{BC_1P_1} + V_{P_1} + V_{F_1}$

   $B = 2\,\overline{BC_1P_2} - \overline{F_1} - \overline{P_2}$ and $V_B= 4V_{BC_1P_2} +V_{P_2} + V_{F_1}$

   $C = 4\,\overline{F_2} - 2\,\overline{F_1} - \overline{P_1} - \overline{P_2}$ and $V_C= 16V_{F_2}+ 4V_{F_1}+ V_{P_1} +V_{P_2}$

   WhereV_{P_1},V_{P_2},V_{F_1},V_{F_2},$V_{BC_1P_1}$ and $V_{BC_1P_2}$ were the variances estimated according to Scheffe (1959).

   The values of T- test were calculated as follows:

$$\pm t = \frac{\text{Deviation}}{\text{standard error}} = \frac{\text{Deviation (Values of A or B or C)}}{\sqrt{\text{Variation of deviation}}}$$

$$\pm t_A = \frac{A}{\sqrt{V_A}} \text{ and } t_B = \frac{B}{\sqrt{V_B}} \text{ and } t_c = \frac{C}{\sqrt{V_C}}$$

   In each test, the degree of freedom is sum of the degrees of freedom of various generations involved in each location and the t test was done at 5% and 1% probability levels. If at least one value from A, B or C set were statistically significant then the 3-parameter model (m+a+d) was declared inadequate therefore indicating the presence of non- allelic or epistatic effect which were calculated using a six parameter model (m+a+d+aa+ad+dd) (Singh and Chaudhary, 1985).
4. After identifying the most appropriate model, the significance of each genetic estimate (effect) either additive, dominance or epistatic effects in that model were evaluated by utilizing the significance of the t test at 5% significance level (Singh and Roy, 2007).
5. In addition to generation mean analysis, environmental, genotypic, additive and dominance components of the phenotypic variance were also estimated using the formula of Mather

and Jinks (1971).The variances for each location were computed separately for each cross. The components of phenotypic variance were computed for F_2 generation of each population based on the following formula:

Environmental variance or error: $\sigma^2_e = ¼\{(\sigma^2P_1 + \sigma^2P_2 + (2\sigma^2F_1)\}$

Genotypic (G) variance: $\sigma^2G\ (F_2) = \sigma^2F_2 - \sigma^2_e$

Additive (A) variance: $\sigma 2A\ (F_2) = (2\sigma^2F_2) – [\sigma^2BC_1\ P_1 + \sigma^2BC_1P_2]$

Dominance variance (D): $\sigma^2D\ (F_2) = \sigma^2G\ (F_2) - \sigma^2A\ (F_2)$

6. Heritability of the traits was also calculated as follows:

Broad sense heritability: $H_{BS} = 100(\sigma^2G_{(F2)} / \sigma^2\ (F_2))$

Where: σ^2P_1 = variance of parent 1; σ^2P_2 = variance of parent 2; σ^2F_1 = variance of F_1; σ^2F_2 = variance of F_2 generation; $\sigma^2BC_1P_1$ = variance of backcross to parent 1 and $\sigma^2BC_1P_2$ = variance of backcross to parent 2.

7. Better parent heterosis (BPH) was calculated as;

BPH (%) = $((F_1 – BP)/ BP)*100$

Where Where, F_1 = Mean value of the F_1 progeny and BP = Mean value of the better parent

3.4 Results

3.4.1 Characterization of parental lines

Results on characterization are presented in Table 3.3. From the results there was no variation for the mode of germination and colour of hypocotyls among the test lines. All the eight parental lines showed hypogeal germination with green hypocotyls. The leaflet length of all the eight lines when taken at 6 weeks after planting was intermediate (8 to 9cm) with a lanceolate leaf shape. Growth habit varied among the lines. White Emergo and short-day lines Kin 1, Kin 2, Kin 3 and Nyeri growth habit was a large climbing vine. However, the short-day dwarfs grew into a small bush (Table 3.3). The leaf colour based on the intensity of the green colour after 6 weeks of planting varied from pale green as observed in White Emergo, intermediate green for Kin 1,Kin 2, Kin 3 and dwarfs to dark green leaf colour of Nyeri.

The long-day White Emergo and short-day Dwarf 3 lines had white flowers while the rest of short-day lines had red flowers. The flower colour was associated with the colour of the standard since the white flowered lines had white standards, while the lines with red flowers had scarlet standards (Table 3.3). However, the local landraces (male parents) showed mixture of both white and red flowers hence the dominant colours were selected.

The flower bud shape was found to be globular for Kin 1 and Dwarf 1 but intermediate for White Emergo, Kin 2, Kin3, Dwarf 2, Dwarf 3 and Nyeri. All the parental lines were found to possess an extrose stigma. Among the short-day parents, Kin 2 and Nyeri pods had a violet pod pattern which

persisted until pod maturity. Nonetheless, White Emergo, Kin 1, Kin 3, and the Dwarfs didn't show any pod pattern at pod stage and at pod maturity. All the parental lines had slightly curved pods except for the dwarf parents which had markedly curved pods. The seed colour of parents was either mono-coloured as observed in White Emergo, Dwarf 3 and Kin 3 or bicoloured as it was the case in Kin 1, Kin 2, Dwarf 1, Dwarf 2 and Nyeri. White Emergo and Dwarf 3 had white seeds while Kin 2 had black seeds. Among the bicoloured seeds the pattern of the secondary seed colour was either speckled or flecked. For instance, Kin 1, Nyeri, Dwarf 1 and Dwarf 2 had violet and black speckled seeds while Kin 3 had violet and black flecked seeds as shown in figure 3.1 and Table 3.1.

Table 3.3: Morphological characteristics of parental runner bean lines used in this study

Variety	Germination type	Hypocotyl colour	Leaflet shape	Growth habit	Leaflet length	leaf colour
White Emergo	Hypogeal	Green	Lanceolate	climbing vine (large size)	Intermediate	pale green
Kin 1	Hypogeal	Green	Lanceolate	climbing vine(large size)	Intermediate	intermediate green
Kin 2	Hypogeal	Green	Lanceolate	climbing vine (large size)	Intermediate	intermediate green
Kin 3	Hypogeal	Green	Lanceolate	climbing vine large size)	Intermediate	intermediate green
Nyeri	Hypogeal	Green	Lanceolate	climbing vine (large size)	Intermediate	dark green
Dwarf 1	Hypogeal	Green	Lanceolate	small bush	Intermediate	intermediate green
Dwarf 2	Hypogeal	Green	Lanceolate	small bush	Intermediate	intermediate green
Dwarf 3	Hypogeal	Green	Lanceolate	small bush	Intermediate	intermediate green

Characterization was based on *Phaseolus coccineus* descriptors from the International Board on Plant Genetic Resources (IBPGR, 1983)

Table 3.3 (continued)

Variety	Flower colour	Flower bud shape	Colour of the standard	Stigma shape	Pod pattern	Colour of pod pattern	Pod curvature	Leaf persistence (when 90% of pods are ripe)	Seed coat pattern	Type of seed coat pattern	Background colour of seed coat	Seed colour
White Emergo	White	Intermediate	pure white	Extrorse	Absent	Absent	slightly curved	Few leaves remaining	seed coat pattern absent	seed pattern absent	White	white
Kin 1	Red	Globular	scarlet	Extrorse	Absent	Absent	slightly curved	Intermediate	Bicoloured pattern	speckled	Violet	Violet-black speckled
Kin 2	Red	Intermediate	scarlet	Extrorse	Present	Violet	slightly curved	Intermediate	Mono-coloured	seed pattern absent	Black	black
Kin 3	Red	Intermediate	scarlet	Extrorse	Absent	Absent	slightly curved	Intermediate	Bicoloured pattern	speckled	Violet	Violet-black spotted
Nyeri	Red	Intermediate	scarlet	Extrorse	Present	Violet	slightly curved	Intermediate	Bicoloured pattern	speckled	Violet	Violet-black speckled
Dwarf 1	Red	Globular	scarlet	Extrorse	Absent	Absent	markedly curved	Few leaves remaining	Bicoloured pattern	speckled	Violet	Violet-black speckled
Dwarf 2	Red	Intermediate	scarlet	Extrorse	Absent	Absent	markedly curved	Few leaves remaining	Bicoloured pattern	speckled	Violet	Violet-black speckled
Dwarf 3	White	Intermediate	white	Extrorse	Absent	Absent	markedly curved	Few leaves remaining	seed coat pattern absent	seed pattern absent	White	White

Characterization was based on *Phaseolus coccineus* descriptors from IBPGR, 1983

3.4.2 Statistical analysis

Analysis of variances (ANOVA) was done separately for each location and cross (Appendix 1). Significant differences ($P \leq 0.05$) for days to 50% flowering, number of racemes at 1st and 2nd flush of flowering, and number of pods plant^{-1} were recorded in all crosses except for number of racemes at first flowering of the cross (White Emergo x Kin 3) at both sites (Appendix 1). Therefore, this trait for the cross (White Emergo x Kin 3) was excluded from further genetic analysis. Based on the ANOVA results, the expected classical ratio could not be defined when the frequency distribution of the F_2 (segregating populations) were analysed in all crosses and traits. The frequency distributions obtained from ANOVA results were normally distributed; a typical indication that the studied traits were quantitatively inherited (Appendix 18). Therefore, generation mean analysis was performed in crosses which were significant for studied traits.

3.4.2.1 Mean Days to 50 % flowering

Anova results showed that the parents showed differences in number of days taken to flower at both locations (Appendix 1). In all crosses, parent 2 (short-day) flowered earlier than the parent 1 (long-day). The duration to 50% flowering for all crosses and at all sites in the F_1 progeny occurred within the range of their parents (Table 3.4). Despite that, the F_1 took longer days to flower at Ol Joro-Orok than at Kabete. The mean value of F_2 was also between the parental values for days to flowering at both sites. Duration to flowering of the backcross populations was influenced by the parent to which the F_1 was backcrossed to. Thus, backcrosses to White Emergo tended to flower late, while those backcrossed to local landraces tended to flower early (Table 3.4). This trend was consistent at both sites. Among the male parents (P_2), the dwarfs flowered earliest in 38 days at Kabete (Table 3.4).

Table 3.4: Days to 50% flowering ofseven runner bean populations grown at two locations.

	Days to 50% flowering													
Population	**W x Kin 1**		**W x Kin 2**		**W x Kin 3**		**W x Nyeri**		**W x Dwarf 1**		**W x Dwarf 2**		**W x Dwarf 3**	
	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ
P_1	53.7	55.7	54.5	53.9	54.8	56.5	55.0	57.7	54.4	54.5	53.8	53.5	53.6	56.8
P_2	43.6	46.7	43.5	47.5	42.4	46.5	41.4	47.5	37.7	46.5	41.0	46.3	40.0	45.7
F_1	47.0	48.8	47.0	50.0	44.9	49.6	45.0	48.3	47.5	50.5	43.5	48.3	43.9	49.6
F_2	48.3	50.0	48.1	51.1	47.1	49.4	46.3	51.2	47.0	50.7	46.4	50.6	46.5	51.9
BC_1P_1	52.5	53.8	54.4	53.6	54.0	55.0	51.5	53.9	53.0	53.6	51.5	53.4	50.8	54.0
BC_1P_2	45.8	46.5	47.4	47.0	45.4	48.3	44.9	47.2	46.4	47.6	43.9	47.0	45.6	49.1
Mean	48.5	50.1	49.4	50.2	51.0	50.9	47.4	50.9	46.3	50.5	46.3	49.6	46.6	50.9
CV (%)	7.1	3.8	7.5	3.0	7.5	7.3	6.0	5.4	6.1	5.5	6.7	5.2	5.6	5.1
$LSD_{0.05}$	4.2	6.5	4.7	5.5	4.5	4.3	2.7	2.3	3.2	2.8	3.4	2.9	3.0	2.9

P_1= female parent (White Emergo), P_2= male parents (Kin 1, Kin 2, Kin 3, Nyeri, Dwarf 1, Dwarf 2 and Dwarf 3), BC_1P_1 =backcross to female parent, BC_1P_2 = backcross to male parent, KAB= Kabete, OJ = Ol Joro-Orok , LSD= least significance difference at 5%

3.4.2.2 Mean number of racemes during first flush of flowering

The parents and generations differed significantly in number of racemes formed at first flush of flowering (Appendix 1). Parent 2 which was Kin 1, Kin 2, Kin 3, Nyeri, Dwarf 1, Dwarf 2 and Dwarf 3 had more racemes per plant than White Emergo in all crosses and at both sites (Table 3.5). The number of racemes formed by shortday parents ranged from 9 to17 racemes and 1 to 7 racemes for White Emergo at both sites. The racemes of $F_1$and F_2 generations were between the two parents at both sites and for all crosses but two crosses (White Emergo x Kin 3 and White Emergo x Dwarf 2) had more racemes than the parents (Table 3.5). In all crosses, the backcrosses tended to have the same number of racemes as their respective parents. Therefore, the backcross to parent 1 had fewer racemes (4 to 9 racemes plant^{-1}) than backcross to parent 2 for all crosses and at both sites. In contrast, the backcrosses to male parent (Bc_1P_2) formed more racemes (average of 9-14 racemes per plant). The cross White Emergo x Nyeri had the highest racemes plant^{-1} at both sites (Table 3.5). This cross had an average of 9.5 racemes per plant at both sites.

Table 3.5: Means for number of racemes formed during the first flowering in seven crosses at two locations

	Number of racemes plant^{-1} during first flowering stage													
	W x Kin 1		W x Kin 2		W x Kin 3		W x Nyeri		W x Dwarf 1		W x Dwarf 2		W x Dwarf 3	
Populations	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ
P_1	3.1	4.1	3.3	3.0	3.8	6.7	2.7	1.0	4.0	3.2	2.5	1.9	2.7	2.9
P_2	13.5	9.6	10.3	10.0	9.0	13.5	17.4	14.4	9.6	11.5	9.1	8.9	8.2	9.4
F_1	7.3	9.3	9.9	7.3	9.6	8.4	12.1	7.7	5.6	8.6	9.3	8.9	7.6	8.0
F_2	9.7	10.3	8.4	9.0	8.9	11.5	9.8	8.5	8.4	10.2	6.4	9.4	7.4	9.1
BC_1P_1	4.8	8.0	6.1	6.6	8.2	8.5	8.1	7.0	5.5	8.6	6.8	7.3	6.8	4.5
BC_1P_2	9.8	12.8	11.2	9.5	10.8	9.0	13.6	12.0	8.2	12.1	8.6	9.6	9.0	9.1
Mean	7.9	8.7	7.8	7.7	7.8	9.5	10.2	8.57	7.3	8.7	6.9	7.39	6.6	7.5
CV (%)	38.2	52.7	52.9	48.0	64.7	51.7	40.7	41.9	46.9	41.5	51.5	46.3	48.4	45
$LSD_{0.05}$	3.6	5.4	4.3	4.1	5.4	5.7	3.5	2.9	3.9	3.6	3.9	3.7	3.7	3.8

P_1= female parent (White Emergo), P_2= Male parent, BC_1P_1 =backcross to female parent, BC_1P_2 = backcross to male parent, KAB= Kabete, OJ = Ol Joro-Orok, LSD = least significance difference at 5%

3.4.2.3 Mean number of racemes during second flowering

The results showed that more racemes were formed during the second flowering for all crosses than the first flush of flowering and across sites (Table 3.5 and 3.6).The mean number of racemes for parent 1 and 2 were significantly different from each other (Appendix 1). In all crosses and

sites, White Emergo (parent 1) had fewer racemes compared to Parent 2 in both locations. The numbers of racemes formed by F_1 was intermediate between the parental range for all crosses except for the crosses involving White Emergo x Dwarf 1 and White Emergo x Dwarf 2.Moreover, raceme formation was found to be higher at Kabete for the F_1 generation and the male parents (P_2) in all crosses (Table 3.6). The F_2 racemes were found to be between the parental range in all crosses and sites except in W x Kin 1. The number of racemes formed by female parent (P_1) varied from 2 to 7, compared to 3 to 18 for male parents (P_2). This was consistent in all crosses and sites. The backcrosses to parent 2 (BC_1P_2) formed more racemes (8 to 14 racemes plant $^{-1}$) than the backcrosses to parent 1 (BC_1P_1). Once more, the cross involving White Emergo and Nyeri formed more racemes (mean of 10 racemes plant-^{1}) in the second flowering than all other crosses at both sites (Table 3.6).

Table 3.6: Number of racemes formed by populations in seven crosses during second flush of flowering at two locations

	Number of racemes plant^{-1}during the second flowering													
	W x Kin 1		**W x Kin 2**		**W x Kin 3**		**W x Nyeri**		**W x dwarf 1**		**W x dwarf 2**		**W x dwarf 3**	
Populations	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ
P_1	4.1	3.1	2.6	2.6	6.6	3.4	3.1	2.9	2.6	2.1	3.9	1.9	4.0	3.1
P_2	13.1	11.1	12.3	11.9	16.1	16.1	18.0	13.8	2.5	9.5	7.4	6.0	6.7	5.3
F_1	12.6	8.4	8.6	7.2	10.8	8.9	12.2	8.8	5.5	5.3	12.5	7.1	6.9	4.7
F_2	14.1	8.7	10.0	8.6	10.5	12.9	9.5	10.6	13.2	8.0	10.0	9.1	9.5	7.6
BC_1P_1	5.3	5.3	7.0	6.6	7.3	7.3	5.8	7.9	7.0	6.2	7.0	6.5	6.8	5.5
BC_1P_2	10.3	10.0	10.4	14.3	10.6	9.7	13.6	14.3	6.4	8.7	8.0	10.7	11.2	8.6
Mean	10.2	7.9	8.2	8.2	10.2	9.3	10.2	9.8	6.7	6.5	8.2	6.4	7.2	5.7
CV (%)	43.8	47.8	48.6	4.8	49.3	36.3	35.1	43.4	59.6	52	52.6	44.5	62.4	51.0
$LSD_{0.05}$	5.4	4.5	4.1	3.8	5.9	3.9	3.2	1.8	4.6	3.4	4.7	3.1	5.2	3.2

P_1= female parent (White Emergo), P_2= Male parent, BC_1P_1 =backcross to female parent, BC_1P_2 = backcross to male parent, KAB= Kabete, OJ = Ol Joro-Orok and, LSD= least significance difference at 5%

3.4.2.4 Mean number of pods per plant

There was a big difference in the number of pods formed by the two parents in all crosses and sitesas shown in the results of Anova (Appendix 1). The male parents (P_2) formed 19 to 38 pods per plant while the female parent ($P_{1)}$ had 7 to 12 pods per plant in all crosses and at both sites (Table 3.7). The F_1 generation of the crosses White Emergo x Kin 1, White Emergo x Kin 3, White Emergo x Dwarf 1 and White Emergo x Dwarf 2 had number of pods within the parental range. On the contrary, the F_1 generation out yielded both parents at both sites and in crosses involving White Emergo x Kin 2, White Emergo x Kin 2, White Emergo x Kin 3 and White

Emergo x Dwarf 1 at Kabete. The male parent (P_2) and its respective backcrosses yielded more pods (13-38 pods plant^{-1}) than the female parent (P_1) and its backcross which had 5 to 22 pods per plant (Table 3.7). The F_2 population had pods between the parental values at both sites and crosses except for White Emergo x Kin 2. F_1population out yielded F_2in all crosses and sites. The cross White Emergo x Nyeri formed the highest number of pods (at least 24 pods per plant) at both sites. All the populations had more pods at Ol Joro-Orok than Kabete in all crosses.

Table 3.7: Means of number of pods for the populations in seven crosses at two locations

	Number of pods plant^{-1}													
	W x Kin 1		**W x Kin 2**		**W x Kin 3**		**W x Nyeri**		**W x Dwarf 1**		**W x Dwarf 2**		**W x Dwarf 3**	
Populations	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ	KAB	OJ
P_1	7.1	9.0	9.9	8.3	9.6	8.8	8.5	11.5	10.2	9.2	6.6	5.4	7.3	7.6
P_2	21.6	26.7	18.8	28.2	22.3	38.9	38.1	33.2	26.7	30.5	24.3	28.2	32.4	24.7
F_1	28.7	23.7	23.8	31.5	31.1	32.5	27.5	29.8	30.1	23.7	27.0	27.6	26.6	20.1
F_2	21.9	24.4	20.4	29.9	26.6	30.9	28.9	26.7	25.5	24.2	24.9	22.9	24.9	24.9
BC_1P_1	9.0	13.0	15.9	10.4	10.3	11.8	10.9	12.1	21.5	21.8	14.0	12.0	12.8	15.0
BC_1P_2	26.0	23.0	20.8	28.3	13.4	21.8	30.1	23.4	23.8	29.0	23.0	27.7	23.2	23.1
Mean	18.7	20.6	18.1	24.3	19.9	24.9	24.4	24.2	23.5	22.2	20.9	20.3	21.3	19.6
CV(%)	34.8	22.2	43.2	32.8	36.2	22.1	27.6	27.0	27.5	41.1	24.7	29.8	32.6	32.4
$LSD_{0.05}$	7.9	5.4	7.6	8.9	8.4	6.4	5.9	5.4	7.4	9.2	5.6	6.6	7.9	7.2

P_1= female parent (White emergo), P_2= Male parent, BC_1P_1 =backcross to female parent, BC_1P_2 = backcross to male parent, Kab= Kabete, OJ = Ol Joro-Orok, LSD = least significance difference at 5%

3.4.3 Generation mean analysis

Generation mean analysis tested the 3 and 6 parameter models for the best fit to explain genetic control of days to 50% flowering, number of racemes at first and second flowering and number of pods in seven crosses of runner beans. To first identify the adequacy of the 3 parameter model before conducting analysis for the 6 parameter model a joint scaling test was done. The joint scaling test results showed that the scale tests A, B and C were not significant for all crosses and for all traits at both sites (Table 3.8).This indicated the adequacy of the 3-parameter model (m+a+d) in influencing days to flowering, number of racemes at first and second flowering and number of pods. The non -significance of the scaling tests also revealed lack of epistatic influence on the traits. Therefore, the model m+a+d was chosen for genetic analysis of the four traits in the crosses involving White Emergo x Kin 1,White Emergo x Kin 2,White Emergo x Kin 3,White Emergo x Nyeri, White Emergo x Dwarf 1, White Emergo x Dwarf 2 and White Emergo x Dwarf 3 at two sites. The model (m+a+d) was found to be significant in all crosses and at all sites (Appendix 17).

Table 3.8: Scaling test for days to flowering, number of racemes and pods in seven runner bean crosses grown at two locations

		Scaling test					
		A		B		C	
Cross	Traits	Kabete	Ol Joro-Orok	Kabete	Ol Joro-Orok	Kabete	Ol Joro-Orok
White Emergo x Kin1	Days to 50% flowering	0.62ns	0.41ns	0.11ns	-0.33ns	0.08ns	0.12ns
	Number of racemes at first flowering	-0.11ns	0.27ns	6.64ns	0.60ns	0.39ns	0.30ns
	Number of racemes at second flowering	-0.58ns	-0.11ns	-0.51ns	0.06ns	0.51ns	0.36ns
	Number of pods	-1.15ns	-0.61ns	-2.76ns	0.42ns	0.01ns	0.59ns
White Emergo x Kin 2	Days to 50% flowering	1.00ns	0.5ns	0.57ns	-0.55ns	0.02ns	0.15ns
	Number of racemes at first flowering	0.13ns	0.33ns	0.25ns	0.19ns	0.08ns	0.35ns
	Number of racemes at second flowering	0.38ns	0.66ns	-0.01ns	1.07ns	0.33ns	0.22ns
	Number of pods	-0.14ns	-1.14ns	-0.06ns	-0.21ns	-0.12ns	0.39ns
White Emergo x Kin 3	Days to 50% flowering	0.95ns	0.22ns	0.39ns	0.06ns	0.06ns	-0.19ns
	Number of racemes at first flowering						
	Number of racemes at second flowering	-0.29ns	0.29ns	-0.45ns	0.65ns	-0.08ns	0.62ns
	Number of pods	-1.32ns	-1.33ns	-1.68ns	-2.19ns	0.27ns	0.29ns
White Emergo x Nyeri	Days to 50% flowering	0.49ns	0.43ns	0.48ns	0.28ns	-0.06ns	0.16ns
	Number of racemes at first flowering	0.17ns	0.69ns	-0.27ns	0.22ns	-0.19ns	0.14ns

	Number of racemes at second flowering	-0.45ns	0.50ns	0.70ns	1.57ns	0.34ns	0.28ns
	Number of pods	1.29ns	-1.81ns	0.36ns	-1.15ns	0.32ns	0.06ns
White Emergo x Dwarf 1	Days to 50% flowering	0.69ns	0.36ns	1.16ns	0.28ns	0.02ns	0.05ns
	Number of racemes at first flowering	0.18ns	0.8ns	0.16ns	0.55ns	0.43ns	0.39ns
	Number of racemes at second flowering	0.74ns	1.49ns	0.56ns	0.32ns	1.55ns	0.47ns
	Number of pods	0.19ns	0.78ns	-0.70ns	0.19ns	0.12ns	0.17ns
White Emergo x Dwarf 2	Days to 50% flowering	3.14ns	0.77ns	0.51ns	-1.36ns	0.21ns	0.36ns
	Number of racemes at first flowering	0.29ns	0.50ns	-0.16ns	0.18ns	0.23ns	0.43ns
	Number of racemes at second flowering	-0.29ns	1.24ns	-0.42ns	1.21ns	0.15ns	0.25ns
	Number of pods	0.53ns	-0.66ns	-2.26ns	-0.03ns	0.49ns	0.08ns
White Emergo x Dwarf 3	Days to 50% flowering	0.55ns	0.24ns	0.98ns	0.49ns	0.21ns	0.34ns
	Number of racemes at first flowering	0.39ns	0.24ns	0.27ns	0.1ns	0.18ns	0.39ns
	Number of racemes at second flowering	0.25ns	0.46ns	0.91ns	1.13ns	0.49ns	0.68ns
	Number of pods	-0.55ns	0.15ns	-0.78ns	0.09ns	0.16ns	0.68ns

ns=not significant at 5% and 1% probability levels based on t-test

3.3.3.2 Estimates of genetic effects in a 3 parameter model

Based on the joint scaling test, the model (m+a+d) was found adequate to explain inheritance of days to 50% flowering, number of racemes formed at first and second flowering and number of pods in all crosses and at both sites.The results of regression analysis showed that the model (m+a+d) was significant in all crosses, at both sites and for all traits (Appendix 17). Therefore, the Tables (3.9, 3.10, 3.11 and 3.12) derived from regression analysis were created to estimate the individual effect of each genetic component (additive or dominance) in the model (m+a+d).

Days to 50% flowering

Based on regression analysis, the model (m+a+d) for days to 50% flowering was significant in all crosses and at both locations (Appendix 17). There was a significant parental effect as presented by the mean estimate [**m]** in all the four traits, crosses and both sites (Table 3.9).The additive genetic effects [a] for days to 50 % flowering were significant in all crosses studied and at both sites. Dominance gene effects were significant at Kabete in the cross involving White Emergo x Dwarf 2 (Table 3.9). However, the rest of the crosses, the dominance estimate was non significant at both sites. The model (m+a+d) adjusted well for all crosses and at both sites as observed from the R^2 values accounting for 70% to 94% (Table 3.9).The dominance effects were negative in crosses involving White Emergo x Kin 2, White Emergo x Kin 3, White Emergo x Nyeri, White Emergo x Dwarf 2 and White Emergo x Dwarf 3 but positive in White Emergo x Kin 1 and White Emergo x Dwarf 1.

Number of racemes per plant during the first flowering

White Emergo x Kin 3 did not show significant differences in the analysis of variance and therefore was excluded from further genetic analysis. The 3 parameter model was found significant in all crosses at both locations based on regression analysis (Appendix 17). The populations of all other crosses showed a significant parental effect [m] in number of racemes formed at first flowering at both sites and crosses (Table 3.10).Additive gene effects [a] of racemes formed at first flush of flowering were significant at both sites except in White Emergo x Kin 1 at Ol Joro-orok and White Emergo x Nyeri at Kabete. Dominance estimates were not significant for most crosses although significant differences were recorded in White Emergo x Dwarf 2 at both sites and in White Emergo x Dwarf 3 at Kabete (Table 3.13). The additive effects were found to be negative in all crosses and at both sites. The coefficient of determination (R^2) ranged from 59% to 89% (Table 3.10). Therefore, the additive –dominant model (m+a+d) was effective in explaining first flowering for crosses studied.

Number of racemes per plant during the second flowering

From the regression analysis, the model (m+a+d) was significant in all crosses and at both locations (Appendix 17). The parental mean effect [m] and additive genetic effect [a] were significant in all crosses and across sites for the number of racemes formed during the second flush of flowering (Table 3.11) .Conversely, non-significant additive effects were recorded in the cross of White Emergo x Dwarf 2 at both sites. All crosses did not show significant differences in dominance effects at both sites apart from the cross of White Emergo x Dwarf 2 (Table 3.11).The coefficient of determination (R^2) varied from 46 to 57% in crosses involving the dwarfs and 65% to 88% in the rest of the crosses.

Number of pods per plant

The model (m+a+d) was found significant in all crosses and at both sites (Appendix 17). All the seven crosses showed that the mean and additive effect were significant at both sites for the number of pods per plant (Table 3.12). The dominance effects were found to be significant in White Emergo x Kin 2 and White Emergo x Dwarf 2 at both sites and in White Emergo x Kin 1 and White Emergo x Dwarf 1 at Kabete. Additive effects significantly influenced number of pods in crosses; White Emergo x Kin 1, White Emergo x Kin 2, White Emergo x Nyeri, White Emergo x Dwarf 2 and Dwarf 3. In all crosses, the dominant effects were positive while the additive effects were negative. The R^2 values ranged from 66% to 93% in all crosses studied and at both sites. This showed a better fit of the model (m+a+d) for number of pods in the crosses studied.Therefore, the additive and dominance effects were considered effective in influencing number of pods formed in the crosses evaluated (Table 3.12).

Table 3.9: Estimates of gene effects and standard errors when fitted to a 3parameter model for days to 50%flowering at two locations

	Days to 50% flowering													
	White Emergo x Kin 1		White Emergo X Kin 2		White Emergo x Kin 3		White Emergo x Nyeri		White Emergo x Dwarf 1		White Emergo x Dwarf 2		White Emergo x Dwarf 3	
Model														
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok
m	46.7±0.8*	51.1±0.6 *	49.7 ±0.8*	50.5±0.7 *	51.6±0.9 *	51.6±1.0 *	48.4±0.8 *	52.5±0.5 *	46.9±1.1 *	50.5±0.4 *	48.0±0.7 *	50.2±0.7 *	47.4±0.5 *	51.5±0.5 *
a	3.1 ± 1.8	4.9 ± 0.6*	5.8 ± 0.8*	3.8 ± 0.7*	5.4 ± 0.9*	5.4 ± 0.9*	6.3 ± 0.8*	5.4 ± 0.5*	7.9 ± 1.2*	4.3 ± 0.4*	6.7 ± 0.7*	4.2 ± 0.7*	6.8 ± 0.5*	5.5 ± 0.5*
d	2.0 ± 3.4*	2.2 ± 1.1	-1.3 ± 1.5*	-0.5 ±1.4*	-1.9 ± 1.7	-2.0 ± 1.8	-3.2 ± 1.6	-3.5 ± 1.0	1.9 ± 1.9*	0.1 ± 0.8	-3.3 ± 1.4*	-0.9 ± 1.3*	-2.6 ± 1.0	-0.9 ± 1.0
R^2 (%)	79	88	83	70	75	75	85	91	83	90	89	77	94	90

* indicates term is Significant based on t-test at $p \leq 0.05$, m = mid parent Value, a = additive gene effects, d = dominance gene effects

Table 3.10: Estimates of gene effects when fitted to a 3 parameter model for number of racemes during the first flowering in seven crosses at two locations

	Number of racemes plant^{-1} at first flowering											
	White Emergo x Kin 1		White Emergo x Kin 2		White Emergo x Nyeri		White Emergo x Dwarf 1		White Emergo x Dwarf 2		White Emergo x Dwarf 3	
Model												
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok
m	8.4± 0.6*	7.0±1.2 *	5.5 ±0.9*	7.0±0.6 *	4.4±15.3	8.2 ± 0.9*	7.3± 0.9*	8.3± 0.8*	5.9± 0.6*	5.9± 0.8*	5.9± 0.6*	6.5± 0.9*
a	-5.2 ± 0.6*	-1.9 ± 1.7	-4.3 ± 0.9*	-3.5 ± 0.6*	-10.3 ± 15.1	-6.3 ± 0.7*	-2.8 ± 0.8*	-4.2 ± 0.8*	-3.2 ± 0.6*	-3.3 ± 0.8*	-2.6 ± 0.6*	-3.3 ± 0.9*
d	-0.9 ± 1.2	2.6 ± 3.1	3.2 ± 1.6	1.3 ± 1.2	53.5 ± 28.4	0.7 ± 1.3	-0.6 ± 1.6	2.2 ± 1.5	3.1 ± 1.2*	4.1 ± 1.5*	2.8 ± 1.0*	2.3 ± 1.7
R^2 (%)	86	66	71	74	89	87	65	72	73	67	71	59

*indicates term is significant based on t-test at $p \leq 0.05$, m = mid parent value, a = additive gene effects,d = dominance gene effects

Table 3.11: Estimates of gene effects fitted to a 3-parameter model for number of racemes during the second flowering in seven crosses at two locations

	Number of racemes plant $^{-1}$ at second flowering													
	White Emergo x Kin 1		White Emergo X Kin 2		White Emergo x Kin 3		White Emergo x Nyeri		White Emergo x Dwarf 1		White Emergo x Dwarf 2		White Emergo x Dwarf 3	
Model														
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok
m	8.3± 1.6*	7.3± 0.9 *	7.8± 0.7*	8.3± 1.2 *	10.7± 0.7 *	9.9± 1.4 *	9.9 ± 0.6*	9.2± 0.9*	4.9± 1.7 *	7.4 ± 0.8*	5.3± 0.8*	5.1± 1.0 *	6.5± 1.2*	5.2± 1.0*
a	-4.7±1.6 *	-3.9±0.9*	-4.5±0.7*	4.9±1.2*	-4.5±0.7*	-5.6±1.4*	-7.5±0.6*	-5.6±0.9*	-0.5±1.7	-2.6±0.8*	-1.8±0.8*	-2.5±0.9*	-2.1±1.2	-1.5±1.0
d	3.8±3.0	1.3±1.8	1.7±1.2	0.9±2.3	-1.1±1.4	-0.5±2.3	0.9±1.1	1.4±1.7	4.1±3.2	-1.0±1.5	6.5±1.6*	4.4±1.9*	2.6±2.2	1.7±1.9
R^2 (%)	88	68	81	57	77	58	94	77	63	46	65	47	48	51

* indicates term is significant at based on t-test at $p \leq 0.05$, m = mid parent value, a = additive gene effects, d = dominance gene effects

Table 3.12: Estimates of gene effects fitted to a 3parameter model for number of pods formed by seven crosses at two locations

	Number of pods plant^{-1}													
	White Emergo x Kin 1		White Emergo X Kin 2		White Emergo x Kin 3		White Emergo x Nyeri		White Emergo x Dwarf 1		White Emergo x Dwarf 2		White Emergo x Dwarf 3	
Model														
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok
m	13.3± 2.5 *	17.9±1.7 *	14.5±1.2 *	17.7±2.7 *	13.6±3.3 *	21.9±3.3 *	22.2 ±2.1*	20.3±2.2 *	18.4± 1.2*	20.5± 2.5*	15.8± 1.4*	16.2±1.1 *	18.8± 1.6*	17.2±1.6 *
a	-9.2±2.4*	-9.1±1.6*	-4.6±1.2*	-11.6±2.6*	-5.6±3.3	-14.6±3.2*	-15.3±2.1*	-11±2.2*	-6.8±1.2*	-9.6±2.5*	-9.0±1.3*	-12.2±1.1*	-12.2±1.5*	-8.5±1.6*
d	13.9±4.5*	5.13±3.1	9.5±2.2*	12.5±4.9*	12.9±6.2*	5.9±6.1	3.9±3.9	5.9±3.9	10.9±2.2*	4.4±4.6	11.4±2.5*	10.7±2.0*	5.6±2.96	4.9±2.9
R^2 (%)	66	74	74	69	63	64	83	71	84	56	86	93	85	72

*indicates term is Significant based on t-test at $p \leq 0.05$, m = mid parent value, a = additive gene effects, d = dominance gene effects

3.3.3.3 Components of phenotypic variance

Population variances were first calculated followed by phenotypic components of variance. The population varainces are presented in Appendix 1b and the phenotypic variance components in Table 3.13. From the population variances, the F_2 variance was higher than the variances of F1, both parents (P_1 and P_2) and backrosses. On the other hand, the components of phenotypic variance varied considerably across crosses, locations and traits studied (Table 3.13). The additive genetic component was the highest in all crosses evaluated for days to 50% flowering, number of racemes at 1^{st} and 2^{nd} flush and in number of pods for all crosses and at both sites (Table 3.13). On the other hand, the dominant component was the least and had negative values for all traits studied in all crosses and locations. The additive variance exceeds the genotypic variance because the dominance variance is negative. Therefore, the negativity of dominance variance reduces the value of additive variance because of complementarity of the two factors to make up the genetic varaince. The environmental effect was much lower in all crosses and sites though slightly higher than the dominance effect in all traits (Table 3.13). In general, the magnitude of additive variance was immensely greater than dominance and environmental variance for all crosses.

3.3.3.4 Heterosis

Better parent heterosis (BPH) varied from negative to positive among crosses, traits and locations (Table 3.13). At both sites and all crosses, heterosis ranged from 3.2% to 93.4% in days to 50% flowering, -6.0% to 40.4% in racemes formed at first flowering, 2.9% to 88.3 in racemes formed during second flowering and 18% to 99% in number of pods. For days to 50% flowering, better parent heterosis was positive in the crosses; White Emergo x Kin 3 and negative in White Emergo x Kin 1 at both sites. However, in the crosses White Emergo x Kin 2, White Emergo x Nyeri, White Emergo x Dwarf 1, White Emergo x Dwarf 2 and White Emergo x Dwarf 3 positive heterosis in days to flowering was observed at Ol Joro-Orok and negative heterosis at Kabete. All crosses showed negative heterosis in number of racemes formed at first flowering except in White Emergo x Kin 2 at both sites and in White Emergo x Dwarf 1 and White Emergo x Dwarf 2 at Ol Joro-Orok (Table 3.13). For number of racemes formed during the second flowering, positive heterosis was at least recorded in all crosses at either location apart from White x Dwarf 1 and White Emergo x Kin 2 at both locations. Remarkably, positive heterosis was observed in all crosses and at both sites for number of pods formed on a plant (Table 3.13).

3.3.3.5 Heritability

Heritability is the ratio of genetically variation to total variation in a population.It therefore shows the proportion of a trait that is heritable. In this study, broad sense heritability was calculated in each cross, site and trait. From the results, broad sense heritability was relatively high for all traits

and ranged from 69.9-91% in days to flowering,(71-89%) racemes at first flowering,(68-93%) racemes at second flowering and (64-81%) in number of pods as shown in Table 3.13. In all crosses heritabilty was found to be consistent at both sites and only differed by 5 to 10 % between sites.

Table 3.13: Different components of phenotypic variance, heterosis and heritability estimates of traits studied.

Cross		Days to 50% flowering						Number of racemes formed at first flowering					
	Location	V_E	V_{GF2}	V_{AF2}	V_{DF2}	HBS	BPH (%)	V_E	V_{GF2}	V_{AF2}	V_{DF2}	HBS	BPH (%)
W x Kin 1	KAB	5.71	25.54	36.56	-11.03	81.74	-41.5	5.51	15.39	23.97	-8.58	73.65	-30.4
	OJ	5.24	18.99	24.57	-5.59	78.39	-13.8	9.22	42.28	54.75	-12.47	82.09	-39.9
W x Kin 2	KAB	5.96	21.83	33.97	-12.15	78.56	-3.2	8.84	23.99	39.84	-15.85	73.08	24.1
	OJ	3.08	18.54	23.92	-5.39	85.77	203	5.46	27.46	31.87	-4.41	83.42	-6
W x Kin 3	KAB	7.43	25.18	33.19	-8.01	77.22	93.4	_	_	_	_	_	_
	OJ	11.05	22.07	38.24	-16.17	66.63	56.9	_	_	_	_	_	_
W x Nyeri	KAB	5.01	17.80	28.32	-10.53	78.05	-36.1	9.46	34.25	66.19	-31.94	78.36	-15.7
	OJ	2.00	20.24	33.51	-13.27	91.02	29.9	5.07	25.72	32.62	-6.9	83.54	-44.5
Dwarf 1	KAB	3.59	14.24	19.69	-5.45	79.88	-6.7	6.71	16.55	24.65	-8.1	71.15	-19.6
	OJ	4.58	12.14	17.83	-5.7	72.62	10.4	6.35	22.68	32.62	-9.94	78.13	40.4
Dwarf 2	KAB	4.10	14.03	21.16	-7.13	77.39	-39.7	4.36	19.47	25.35	-5.89	81.72	-36.1
	OJ	3.36	12.6	16.45	-3.85	78.95	12.9	6.52	18.27	26.51	-8.25	73.71	24.1
Dwarf 3	KAB	5.35	21.92	30.32	-8.4	80.38	19.9	3.51	30.08	41.76	-11.68	89.54	-35.6
	OJ	4.80	11.17	17.12	-5.96	69.96	-31.8	6.98	17.46	26.23	-8.77	71.44	-18.4

Where KAB= Kabete, OJ= Ol Joro-Orok, V_E=environmental variance, V_{GF2}= genotypic variance, V_{AF2}=additive variance, V_{DF2}= dominance variance, HBS= broad sense heritability and BPH= Better parent heterosis

Table 3.13 (continued)

		Number of racemes plant^{-1} formed during second flowering						Number of pods plant $^{-1}$					
Cross	**Location**	**V_E**	**V_{GF2}**	**V_{AF2}**	**V_{DF2}**	**HBS**	**BPH (%)**	**V_E**	**V_{GF2}**	**V_{AF2}**	**V_{DF2}**	**HBS**	**BPH (%)**
W x Kin 1	KAB	11.76	31.22	44.79	-13.57	72.63	-20.9	32.27	57.87	103.61	-45.74	64.2	99.72
	OJ	7.55	27.7	38.25	-10.55	78.58	57.3	11.29	38.50	52.89	-14.4	77.33	32.72
W x Kin 2	KAB	5.72	27.28	37.84	-10.56	82.67	62.7	30.99	100.31	180.41	-80.1	76.4	65.33
	OJ	4.68	29.28	41.70	-12.42	86.22	5.7	37.69	110.41	208.98	-98.57	74.55	72.93
W x Kin 3	KAB	13.18	41.49	56.29	-14.8	75.89	12.6	30.15	88.55	146.85	-58.3	74.6	95.48
	OJ	6.51	24.47	34.24	-9.77	78.99	-6.5	19.76	56.08	87.26	-31.18	73.95	36.21
W x Nyeri	KAB	5.36	22.67	28.18	-5.51	80.87	88.3	23.57	83.93	152.25	-68.32	78.07	18.13
	OJ	3.57	48.91	62.85	-13.95	93.21	-67	22.70	76.68	123.18	-46.5	77.16	33.62
W x Dwarf 1	KAB	9.86	21.61	35.31	-13.7	68.67	1.6	24.19	65.42	109	-43.59	73.01	63.12
	OJ	5.09	19.63	28.0	-8.37	79.4	10.5	37.51	161.09	249.5	-88.41	81.11	19.39
W x Dwarf 2	KAB	7.05	28.05	38.67	-10.62	79.91	-2.9	15.52	33.14	58.43	-25.29	68.1	75.32
	OJ	5.07	11.13	16.73	-5.60	68.69	33.9	17.78	61.83	80.95	-19.12	77.67	64.33
W x Dwarf 3	KAB	11.12	30.66	42.92	-12.27	73.39	-12.1	27.96	72.54	107.22	-34.68	72.18	34.31
	OJ	4.65	14.54	20.73	-6.19	75.76	53	21.14	69.1	93.01	-23.92	76.58	24.19

Where Kab= Kabete, OJ= Ol Joro-orok, V_E= environmental variance, V_{GF2}= genotypic variance, V_{AF2}= additive variance, V_{DF2}= dominance variance, HBS= broad sense heritability and BPH= Better parent heterosis

3.4 Discussions

3.4.1 Parental characterization

The results showed that the male and female parents differed immensely in phenotypic traits evaluated in this study. This characterization provides a good understanding of phenotypic variations that exist between the local runner bean accessions and the imported varieties. The growth pattern, flower and grain colours varied significantly between the male and female parents revealing the variant diversity of *P. coccineus* as indicated by Zeven et al., (1993) and Santalla et al., (2004).These results also mirror Spataro et al., (2011) findings that high level of diversity exists among the world wide collections (domesticated, wild forms and landraces) of *P. coccineus.* They attributed these differences to adaptation to new environment, genetic drift and differential gene flow.

Grain and flower colour also varied significantly among the male parents (landraces) due to the out-crossing nature of this species. Giurca, (2009) in his study with runner beanalso noticed high rate of other grain colours being different from the original sample that was planted and associated the grain mixture to the higher degree of allogamy that exists in *P. coccineus*.

High variation in the phenotypic characteristics among the male parents is a clear indication of lack of agronomic stability that exists in landraces when they are planted in locations that are not the native environments (Gomez, 2004). These genetic differences reveal the underlying genetic diversity that exists among these materials and hence can be preserved in situ or ex situ for future breeding programs of improving Phaseolus species.

3.4.2 Mean analysis of generations

These ANOVA results showed that P_1 (female imported long-day variety) and P_2 (short-day male parents) were contrasting in the means of traits studied in all evaluated crosses indicating the considerable genetic diversity among the parents and their respective crosses. The results also confirms the correct choice of contrasting parents in respect to day length adaptation which is a prerequisite for generation mean analysis as proposed by Mather and Jinks (1971).

The male parents formed more racemes as well as pods and flowered earlier in all crosses indicating the superior adaptation of these materials to the short-day conditions. The occurrence of F_1 means of days to flowering, racemes formed at first and second flowering slightly more than Parent one but closer to parent 2 in all crosses demonstrated the presence of mid parent heterosis. From the results the parent Nyeri was selected as the best parent that flowers easily and abundantly hence giving high pod yield .This parent can be utilized in future breeding programs of runner

bean improvement. Among the parents, the dwarfs' accessions can also be used to develop early flowering and bush type runner beans.

3.4.3 Genetic components

3.4.3.1 Nature of gene action

No previous studies on the genetics of traits in runner bean were available for comparison. However, the results of this study were associated with findings from other crops. The results indicated that the mean effect (**m**) of each cross was significant for all characters which revealed the difference in inheritance of these traits among the local landraces vs. the imported variety. The results also showed that the evaluated traits were quantitatively inherited since the segregating F_2 populations could not be grouped into classical ratios.

Results also showed that additive-dominant model (m+a+d) was more acceptable in explaining days to 50% flowering, number of racemes and pods formed compared to the digenic interactions in all crosses. This shows that epistatic effects were not involved in the inheritance of traits studied in the crosses evaluated as indicated by the joint scaling test.In addition, the dominance parameter [d] was not significant for all of the evaluated traits in all crosses except in White Emergo x Kin 1 and White Emergo x Dwarf 2 in number of racemes and number of pods.Although the joint scaling test and t significance tests indicated the adequacy of the model (m+a+d) the R^2 values were not fitting exactly to 99% or 100% .This was attributed to high experimental error as revealed by Ceballos et al., (1998) that a genetic model fits best when experimental error is very low. The prevalence of additive or additive-dominant models other than epistatic effects has also been found by Kornegay and Temple (1986); Park et al., (1994) and Rainey and Griffiths (2005) in generation means analysis conducted for such traits in common beans.

When estimating each gene effect, the additive effects were found to majorly influence days to flowering in all crosses as opposed to dominance or epistatic effects concurring with the results of Arunga et al. (2010); Silva et al. (2004); Barelli et al. (1999) in their studies on snap bean. On the contrary, Mendes et al. (2008) found additive x dominance effects to influence days to 50% flowering but further revealed that the dominance effects were less important in controlling number of days to 50% flowering and their effect was to reduce the number of days to flowering.

The positive dominance effects in number of racemes at first and second flowering and number of pods indicated existence of partial dominance in the latter traits in all crosses. The results revealed that numbers of racemes formed at both flowering stages were significantly influenced by additive effects although the additive and dominance effects were important in the cross; White x Dwarf 2.

Das et al. (2014) also found that number of inflorescences per plant and numbers of buds per inflorescences in dolichos are predominantly influenced by additive genetic effects. Alam and Newaz (2005) however found the preponderance of both additive and non-additive gene effects for number of inflorescences per plant and number of flower buds per inflorescence in dolichos.

The results of this study of additive effects influencing number of pods per plant were similar to findings of Arunga et al.(2010) in snap bean, Weerapun et al. (2010) in common bean and Das et al.(2014)in dolichos. Nonetheless, Hinkossa et al.(2013); Khodambashi et al.(2012) and Singh et al.(2007) contradicts the results in this study by showing that non-allelic interactions are important in control of number of pods in common bean, lentil and mung bean respectively. Such variations in the results may arise from differences in the genetic backgrounds of the species or varieties used in the various studies and environment under which the studies were carried out.

Evidence that both additive and dominance gene effects are involved in the genetic control of the traits investigated implie that both gene effects should be considered when developing breeding schemes for the selection of superior runner bean lines. Consequently, selection of these traits will be useful to start at early segregating populations (Hinkossa et al., 2013).

3.4.3.3 Phenotypic components of variance

The estimates for genetic parameters calculated revealed that additive variance was the highest for all traits and crosses indicating the relative importance of fixable type of gene action in the inheritance of the traits (Vanda et al., 2013). The presence of a higher magnitude for additive variance in number of pods and days to flowering has been reported by Dickens (1967) in snap bean and Bicer and Sakar (2008) in chick pea. Therefore, selection of these characters will be very effective since this is the variance that responds to selection efficiently. The F_2 population variance was the highest than all variances of F_1, P_1, P_2 and backcrosses as it was expected. However, it was found that n phenotypic components, the additive variance was exceeding the genotypic variance in all traits and crosses due to the negative effect of dominance variance that reduced the value of additive variance. This is as a result of complimentarity of additive and dominance factors constituting to the genotypic variance hence there is an expected relation in the magnitude of the two sets of factors (dominance and additive). Generation mean analysis has been found to be effective on pure or inbred lines which are relatively homozygous (Hallauer et al., 2010), therefore the negative dominace variance reported in this study could also be attributed to the outcrossing nature of runner bean when grown in open fields. Similar, results of additive variance exceeding the genotypic variance when using generation mean analysis has also been reported in bread wheat by Magda, (2013). In her study, the additive variance was found to be more than the genotypic

varaiance when the dominance variance was negative as it was the case in the present study. Mendes et al. (2008) also found dominant genetic value to be negative in their study of genetic control of days to flowering in common beans. Consequently, the evaluated traits in this study can be improved through selection procedures such as pedigree and single seed methods (Kumar, 2005).However, modification of such methods is recommended to minimize outcrossing. Considering the results of means and variances, the evaluated traits showed a stronger gene association as they had significant values of additive effect [a] and high additive variance (V_{AF2}) which emphasizes that these studied traits are majorly controlled by additive effects.

3.4.3.4 Heritability

High broad sense heritability observed for all traits demonstrates that rapid progress can be made when using selection procedures that are dependent on the phenotype (Acquaah, 2007).According to Singh (1991) broad sense heritability for number of pods per plant was found to be 49% and 81% for n days to flowering respectively. Lumpkin and Mcclary (1994) after consolidating the findings of different authors concluded that heritability values in pure lines and segregating materials of adzuki bean ranged from 84 to 96% for number of days to 50% flowering and 9 to87% for number of pods per plant.

From these findings it was noted that heritability of number of days to flowering was high. However, the magnitude of heritability in number of pods was highly influenced by genetic materials and the environment where they were evaluated. Such high heritability observed for all crosses in this study indicates that selection based on studied traits would be successful in improving these traits.

3.4.3.5 Heterosis

Heterosis is the superior performance of of F_1 hybrids relative to the mid parent value (Wolfgang et al., 2008).Both positive and negative heterosis are useful in breeding depending on breeding objectives. Presence of positive heterosis that was observed in number of pods is a clear evidence of manifestation of hybrid vigor. This therefore indicates that the parents used in the crosses can be utilized for hybrid breeding of yield and selction should be based on number of racemes and pods which are the major yield contributing factors in runner bean. Nevertheless, crosses that showed negative heterosis in number of days to 50% flowering showed that such parents could be used in developing early flowering varieties (Turi et al., 2006).

3.5 Conclusion

This study was the first step in determining gene action and possible breeding implications in runner bean in Africa. Results from this study showed that additive and dominance gene action influenced days to flowering, number of racemes and number of pods in runner beans. This

implies that improvement of this crop will be easily achieved through selection procedures such as pedigree and single seed/pod descent and therefore breeders should use the methods to effectively select for phenotypic characters in runner beans. However, a modification of the methods is recommended to reduce outcrossing in runner bean grown in open field.

Additive variance was found to be higher in all traits and crosses of runner bean which indicate that days to 50% flowering, number of racems and number of pods in runner bean can be easily inherited.Also, a rapid progress is expected when selection procedures are based on these studied phenotypic traits because of high heritability levels revealed by the traits studied.

The study also gives an undersatnidng of significant differences that exist between the local landraces and imported runner bean varieties.This provides a good basis of genetic variation which can be utilized in developing improved runner bean varieties.

CHAPTER FOUR

SELECTION FOR SHORT-DAY ADAPTATION, POD QUALITY AND YIELD IN VEGETABLE RUNNER BEAN

Abstract

Runner bean (*Phaseolus coccineus* L.) offers considerable potential as a high value vegetable for domestic and export markets in eastern Africa. However, production and utilization of vegetable runner bean in Kenya is severely constrained by reliance on imported long-day varieties which require additional artificial lighting to trigger flowering and pod formation under tropical short-day conditions. The objective of this study was to select for short-day adaptation, market preferred pods and yield from runner bean bulk populations developed from crosses between long-day and short-day parental lines. One hundred and fourteen $F_{6.8}$ lines were evaluated in 2013 and 50 $F_{6.9}$ lines in 2014 at two locations (Kabete, 1800m and Ol Joro-Orok, 2300m) in Kenya. Data was collected on days to 50% flowering, number of racemes per plant, disease resistance, marketable pod yield, pod length and diameter. The fresh pods were categorized as Grade I (long, straight pods), II (long, slightly curved pods) and III (short and markedly curved pods) according to commercial standards. The numbers of racemes were counted during the first flush of flowers (85 days after planting) and second flush (110 days from planting). Analysis of variance showed that there were significant differences ($P<0.05$) for days to 50% flowering, the number of flowers formed during the first and second flush of flowers, number of pods and pod yield at both sites and seasons. The numbers of racemes per plant were higher during the cooler second flush at both sites, suggesting better adaptation of runner bean to cooler higher altitudes. The new lines formed flowers easily and produced significantly more racemes (20 racemes plant^{-1}) compared with the long-day check, White Emergo at both sites and seasons. The runner bean lines also had a mean marketable pod yield of 705 kg ha-^{1} per harvest in the first year, and 441 kg ha^{-1} per harvest in the second year. The long-day check variety failed to produce pods in first year, and had a mean pod yield of 25 kg ha-^{1} per harvest. Pod length of new lines varied from 18 to 25 cm. About 80% of total pod yield of the new lines was Grade I and II in both years. The results showed that it's possible to select for shortday adaptation and this can be exploited in breeding short-day varieties of runner bean which do not require additional lighting. Release and commercialization of the new short-day high yielding lines will facilitate local seed production, reduce costs of production and increase competitiveness of vegetable runner bean in domestic and export markets.

Key words: Racemes, pod yield, long-day, photoperiod sensitivity

4.1 Introduction

Runner bean (*Phaseolus coccineus* L.), is one of the cultivated species of genus *Phaseolus* in the large Papillionaceae (Fabaceae) family. It is ranked as the third most important species of Phaseolus economically and is mainly grown for dry seeds and immature fresh pods (Santalla et al., 2004). Archaeological evidence indicates that scarlet runner bean was a domesticated crop in Mexico around 900 AD. Currently, runner bean is cultivated in temperate countries and occasionally in highland areas of Central and South America, Africa and Asia (Brink, 2006). This crop is also very popular in the United Kingdom which appears to be the main grower and consumer of vegetable runner bean (Rodino et al., 2007).

The success of runner bean in Europe is also attributed to the fact that the crop is highly adapted to cool temperatures than common bean (*P.vulgaris*). In Africa, runner bean is cultivated in Ethiopia, Kenya and South Africa. In Kenya, grain runner bean is grown a high altitudes in Nakuru District, where white-seeded cultivars are most common. Caiger (1995) reveals production of runner bean in Zimbabwe and South Africa mainly for export. In Kenya, vegetable runner bean is grown by fresh produce companies in Naivasha, Nyeri and Timau on the slopes of Mt Kenya. Timau and Nyeri are cool high altitude areas with mean annual temperatures of 15.2^{o}C and 17.1^{o}C. Naivasha has warm and dry climate with temperatures up to 25^{o}C. The vegetable runner bean is ranked by major exporters to be among the highest quality green bean in the world (EPZA, 2005). Nyandarua and Meru Counties are the leading producers of vegetable runner bean and account for 87% of total production in the country (HCDA, 2013).

Fresh produce companies' rely on imported varieties which are adapted to long-day conditions. These varieties originate from temperate regions especially Europe and therefore they fail to flower under tropical conditions. The grain runner type that has been traditionally grown in highlands of Kenya flowers in short-day conditions (Kahuro, 1990). However, the grain type runner bean lacks the market preferred pod characteristics of the vegetable type. Scarlet runner bean seeds germinate 10–14 days after sowing and flowering starts 40–60 days after sowing (Brink, 2006). The most popular variety grown in Africa is White Emergo, although new varieties have been introduced (Caiger, 1995).To enhance flowering in long-day varieties, day length is increased by additional lighting to fit the short-day conditions in Kenya. Commercial large scale producers are forced to use artificial lighting which is expensive and limits smallholder production as well reducing area under production. It therefore necessary to develop short-day varieties that can flower and pod easily under shorter photoperiods to broaden production areas and facilitate smallholder production.

There is little information on runner bean production in Africa. No commercial vegetable or dry grain varieties of runner bean have been developed in Africa, partly because legume breeders have mainly focused on common bean (Kimani et al., 2005a). Vegetable runner bean earns higher prices in the export market and therefore improving its productivity in the tropical regions will enhance its competitiveness in the lucrative export and local markets. Runner bean improvement was birthed in 2004 as documented in PABRA report of 2005 where this crop was identified as a high value export and grain legume crop. However, the main constraint to improvement of this crop was photoperiod sensitivity. Therefore it was suggested that populations to be developed from local short-day cultivars and introduced long-day varieties from which short-day vegetable lines can be selected (Kimani et al., 2005b). This work was then started by the University of Nairobi Bean program where populations were developed. These populations were advanced through a series of bulk selections up to $F_{6.8}$ generations. However, little has been done on evaluating the runner bean materials for vegetable production. Therefore the objective of this study was to select for short-day adapted vegetable runner bean with market preferred pod yield and quality from advanced lines developed at the University of Nairobi.

4.2 Materials and Methods

4.2.1 Plant materials

The study materials were 114 $F_{6.8}$ lines which were initially developed in 2004 from crosses between five short-day local landraces (Kin 1, Kin 2, Kin 4, Kenya local and Nyeri) as male parents and one female imported variety; White Emergo (Kimani et al., 2005b).The local landraces were selections from farmers from Kinangop and Nyeri and hence the designation of names. Progenies from the crosses were advanced through bulk population method up to F_5 generation where selections began.

About 1154 single plant selections with good pod quality were selected from F_5 bulk populations which were grown at Ol Joro-orok, Subukia and Kabete Field Station during the 2009 long rain season. These single plant selections were used to establish progeny rows during the 2009 short rain season and families during 2010 long rain season (Kimani, 2009). Continuous selections were again done within and among families up to $F_{6.8}$ generation which then constituted into a working collection that was used in this study. The two hundred and sixty $F_{6.8}$ lines were evaluated during long rains at Kabete and OlJoro-Orok in the first season in 2013. About 50 $F_{6.9}$ lines that showed better adaptation to short photoperiod with market preferred fresh pods were selected for further evaluation during long rain season of 2014. Spacing between lines was one row to prevent outcrossing. 34 selected lines are presented in the table of results and the rest of the 114 lines are in appendix 3 and 4.

4.2.2 Trial sites

The experiments were conducted at Kabete Field Station and Dairy Research Institute- Ol Joro-Orok for the two seasons.Kabete Field Station is located in Nairobi County at an altitude of 1840m above sea level and agro-ecological zone III (900-1860m.a.s.l).The annual rainfall of about 1000mm which is received during long rains (March to July), and short rains (October to December). The site has maximum temperature of 24.3^0C and a minimum mean temperature of 13.7^oC. The dominant soils are humic nitisols which are very deep, well drained, dark reddish, deep friable clay type resistant to erosion (Jaetzold et al., 2006).

Dairy Research Institute- Ol Joro-Orok is located in Nyandarua County at an altitude of 2300m a.s.l. and agro-ecological zone II (highland areas with 1980-2700m.a.s.l). It has a mean annual rainfall of 1000mm which permits a continuous cropping between March and December. However, reliability of rains is high from April until November. The site has mean maximum temperatures of 22^oC, and mean minimum temperatures of 10 to 16^oC. Dominating soils are planosols. These soils are deep, imperfectly drained, firm and very dark greyish brown in colour (Jaetzold et al., 2006).

4.2.3 Experimental design and crop husbandry

The experiment was conducted for two seasons at both sites. Experiments were laid out in a randomized complete block design with two replicates. A plot size consisted of 2 rows of 3m in length.Intra row spacing was 30cm and inter row at 1 m. The 114 $F_{6.8}$ lines were planted using pod to progeny row method in 2013. Diammonium phosphate fertilizer was applied at a rate of 60kg ha^{-1} before planting at both sites. The crop was weeded when necessary at both sites. A trellis system was used to support the plants.

Individual plants were staked at Ol Joro-orok or tied with a string at Kabete (at the base of the plant) to a top placed heavy weight wire suspended horizontally across the row. The wire was supported by sturdy wooden poles on each side of the row. Insect pests were controlled by alternate application of Cyclone® (10% cypermethrin + 35% chlorypriphos) and Confidor® (imidacloprid) at the rate of 1.5ml L^{-1} after every two months. About 50 vegetable type single plants selections with straight and long pods were selected during the 2013 long rains and were advanced as pod to row in 2014. The pods from selected plants were left to dry in the field. Seeds were harvested on a single plant basis, threshed, cleaned and then treated with insecticides.

4.2.4 Data collection

Data was collected on duration to 50% flowering, plant vigor, number of flowers, diseases, marketable pod yield, pod length, pod diameter and market grades. Plant vigour was scored based

on plant height, vegetative growth and stem stability of the plant (Van Schoonhoven and Pastor-Coralles, 1987). Ten plants per plot were sampled and rated on a scale of 1 to 9, where 1=excellent vigor, 3=good vigor, 5=intermediate vigor, and 7=very poor vigor.Duration to 50% floweringwas recorded as the number of days from sowing to the date when 50% of plants in a plot had one or more open flowers.

Numbers of racemes from each single plant was counted and average number of racemes computed. The counting of racemes was done during the first flush (85 days from planting) and second flush (110 days after planting) days. Counting of racemes during the second flush was done after the first flowers had formed pods. The genotypes were evaluated for the reaction to prevalent diseases using CIAT scale of 1-9 where 1-3=resistant, 4-6=intermediate resistance, and 7-9 = susceptible (Table 4.1). Prevalent diseases were powdery mildew, bean common mosaic virus, bean rust and common bacterial blight. Disease scoring was done at flowering.

To determine marketable pod yield, pods that had which were at least 18cm length and a diameter of < 20mm were harvested. Marketable pods were harvested on Monday and Thursday each week for a period of four weeks. The harvested pods were then graded according to commercial marketclasses (Sunripe Company, personal communication 2013) as shown in Table 4.2.

Table 4.1: Scale used to evaluate the reaction of vegetable runner bean germ plasm to fungal diseases

Rating	Category	Description	Comments
1-3	Resistant	No visible symptom or light symptoms (2% of the leaf)	Germplasm useful as a parent or commercial variety.
4-6	Intermediate	Visible and conspicuous symptoms (2-5% of the leaf) resulting only in limited economic damage.	Germplasm can be used as commercial variety or source of resistance to disease.
7-9	Susceptible	Severe to very severe symptoms (10-25% of the leaf) causing yield losses or plant death.	Germplasm in most cases not useful as parent or commercial variety

Source: van Schoonhoven and Pastor-Corrales, 1987.

Table 4.2: Description of commercial vegetable runner bean grades.

Grade	Description
I	whole green and young tender pods, flat, very straight pods of length 18-27cm,easily broken by hand, free from pests, diseases, no seeds and maximum curvature of 30mm
II	whole green tender pods, easily broken, flat, slightly curved, length of 18-27 cm with curvature of more than 30mm and free from pests and diseases
III	broken beans, bean have necks, aborted seeds, curvature of more than 30mm and length below 18cm
Rejects	over mature seedy pods, pods with pest/disease or mechanical damage, dehydrated/wrinkled bean or presence of chemical deposits

Source: Sunripe vegetable runner bean grading manual, 2014

4.2.5 Data Analysis

All data was subjected to analysis of variance using Genstat software, 13th edition (VSN International, 2011). Means were separated using Fisher's protected least significant difference at 5% probability level. The results showed the performance of 34 lines in Table 4.3 to 4.11 while the performance of the rest of the lines is in appendix 3 and 4.

Figure 4.1:Vegetable runner bean pod grading according to fresh produce Companies

4.3 Results

4.3.1 Weather conditions at experimental sites

The weather data was obtained from Kabete and Ol Joro-Orok meterological Stations. In both years (2013 and 2014) the mean temperatures were lower at Ol Joro-Orok than Kabete. In 2013, mean monthly temperatures ranged from 13-16^{o}C at Ol Joro-Orok, and 16-28^{o}C at Kabete from planting to pod maturity (Fig 4.2). In contrast, temperatures in 2014 were low at both locations and hence mean monthly temperatures ranged from 12 to 16^{o}C at Ol Joro-Orok, and 16 to 19^{o}C at Kabete (Fig 4.2). Flowering occurred between April and June. Within these 3 months, mean temperatures were 15 ^{o}C at both sites in 2014, while in 2013 the temperature at the two sites varied with Kabete having mean temperature of 24^{o}C and 15^{o}C at Ol Joro-Orok.

In 2013, Kabete received a total rainfall of 1,139.9 mm from planting to pod maturity, while Ol Joro-Orok received 1,516 mm (Fig 4.2). The highest rainfall in 2013 was recorded in the month of April (508mm) at Kabete, and 295mm at Ol Joro-Orok. During the second year (2014), the total rainfall decreased at both sites but was well distributed throughout the year. Kabete recorded a total of 793mm of rainfall compared with 823.4mm at Ol Joro-Orok. The highest rainfall in 2014 was experienced in the month of March at Kabete, and in July and August at Ol Joro-Orok (Fig 4.2). There was a dry spell from May to October in 2013 at Kabete. During this period less than 40mm of rainfall was received. From these observations, the total rainfall received at both sites in 2013 was found to be normal however in 2014 the rainfall was lower than the expected. Nonetheless, Ol Joro-Orok had normal mean temperatures in both years whereas Kabete had high mean temperature in 2013 than the normal and expected temperature in 2014.

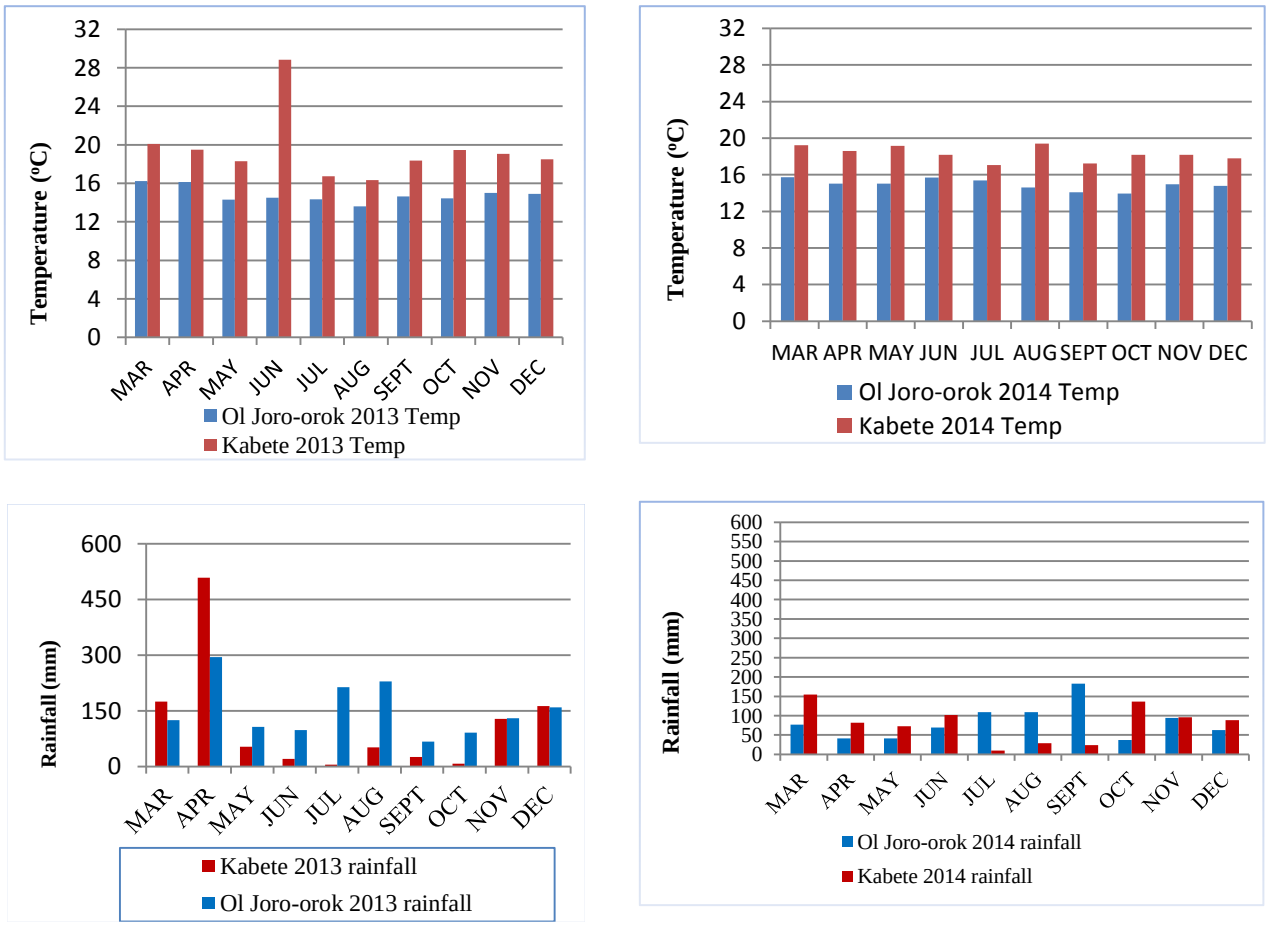


Figure 4.2: Mean monthly temperature and total monthly rainfall data for Kabete and Ol Joro-Orok in 2013 and 2014.

4.3.2 Plant vigor

There were significant differences in plant vigour among the genotypes at both locations in 2013 (Appendix 15). However, differences in vigor were not significantly different in 2014 (Appendix 16). In the first year, 22% of genotypes showed intermediate vigor (4-6) at Kabete, whereas 90% of genotypes had good vigor (1-3) at Ol Joro-Orok (Table 4.3). In the second year, all genotypes were very vigorous with a mean score of 2 at both sites. The check variety White Emergo showed good vigor (score of 3) at Kabete, but had intermediate vigor (mean of 4) at Ol Joro-Orok in both seasons. Genotypes were more vigorous in the second season than in the first year (Table 4.3). 60% of the tested genotypes were found to be more vigorous than White Emergo at Kabete and 90% at Ol Joro-Orok in both years.

Table 4.3: Plant vigour of selected vegetable runner bean lines at two locations for two years

	Plant vigor scores				
	2013			2014	
Genotypes	**Kabete**	**Ol Joro-Orok**	**Genotypes**	**Kabete**	**Ol Joro-Orok**
KAB-RB13-1-105	3.0	1.0	KAB-RB13-1-105/3	3.0	2.3
KAB-RB13-305-130	3.0	6.0	KAB-RB13-305-130/1	3.0	3.0
KAB-RB13-308-57	1.0	3.0	KAB-RB13-308-57/4	3.0	2.3
KAB-RB13-309-60	5.0	3.0	KAB-RB13-309-60/3	1.0	1.7
KAB-RB13-309-64	2.0	1.5	KAB-RB13-309-64/4	1.0	1.7
KAB-RB13-311-102	1.0	2.0	KAB-RB13-311-102/2	2.3	3.0
KAB-RB13-311-103	2.0	2.0	KAB-RB13-311-103/5	1.0	2.3
KAB-RB13-312-135	2.0	3.0	KAB-RB13-312-135/4	2.3	2.3
KAB-RB13-312-35	1.0	2.0	KAB-RB13-312-35/1A	1.7	1.7
KAB-RB13-312-36	1.0	2.0	KAB-RB13-312-36/1	3.0	3.0
KAB-RB13-318-34	5.0	1.0	KAB-RB13-318-34/1	2.3	2.3
KAB-RB13-326-59	4.0	1.0	KAB-RB13-326-59/4	1.7	1.7
KAB-RB13-331-66	3.0	3.0	KAB-RB13-331-66/2	1.7	1.0
KAB-RB13-336-28	1.0	3.0	KAB-RB13-336-28/4B	1.7	1.0
KAB-RB13-339-89	2.0	2.0	KAB-RB13-339-89/6	1.0	2.3
KAB-RB13-363-131	3.0	2.0	KAB-RB13-363-131/2A	1.7	2.3
KAB-RB13-380-55	3.0	1.0	KAB-RB13-380-55/1	1.7	2.3
KAB-RB13-446-5	4.0	1.0	KAB-RB13-446-5/2	1.7	1.7
KAB-RB13-46-22	4.0	1.0	KAB-RB13-46-22/2	1.0	2.3
KAB-RB13-46-23	2.0	3.0	KAB-RB13-46-23/1	1.0	1.7
KAB-RB13-470-72	2.0	1.0	KAB-RB13-470-72/3	2.3	2.3
KAB-RB13-470-8	2.0	2.0	KAB-RB13-470-8/4	1.0	2.3
KAB-RB13-649-70	1.0	3.0	KAB-RB13-649-70/2	1.7	2.3
OL-RB13-21-1	4.0	3.0	OL-RB13-21-1/4	2.3	3.0
SUB-RB13-114-77	2.0	3.0	SUB-RB13-114-77/2	1.0	2.3
SUB-RB13-117-68	1.0	3.0	SUB-RB13-117-68/1	2.3	3.0
SUB-RB13-133-10	2.0	3.0	SUB-RB13-133-10/4	1.7	2.3
SUB-RB13-178-123	4.0	1.0	SUB-RB13-178-123/3	1.0	2.3
SUB-RB13-240-125	4.0	1.0	SUB-RB13-240-125/5	2.3	1.7
SUB-RB13-240-126	2.0	1.5	SUB-RB13-240-126/2	1.7	1.7
SUB-RB13-271-78	1.0	2.0	SUB-RB13-271-78/3B	1.7	3.0
SUB-RB13-271-79	1.0	2.0	SUB-RB13-271-79/5	1.0	1.7
SUB-RB13-305-76	2.0	1.0	SUB-RB13-305-76/3	1.7	3.0
SUB-RB13-82-69	2.0	4.0	SUB-RB13-82-69/3	2.3	1.0
Check					
White Emergo	3.0	5.0	White Emergo	2.3	3.7
Mean	2.3	2.2	Mean	1.8	2.2
CV (%)	57.5	43.8	CV (%)	58.8	65.9
$LSD_{0.05}$	2.6	1.9	$LSD_{0.05}$	2.10	2.39

4.3.3 Days to 50% flowering

In the first year, genotypes differed significantly in number of days to 50% flowering at Ol Joro-Orok only (Appendix 15). Conversely, in the second year the genotypes showed significant differences for duration to flowering at both sites (Appendix 16). In the first year, the test lines took 48 to 51days to flower at Kabete and 50 to 53 days at Ol Joro-Orok. In the second year, genotypes took 30 to 45 days to flower at Kabete, and 51-59 days at Ol Joro-Orok. In both years, genotypes flowered earlier at Kabete than at Ol Joro-Orok (Table 4.4).

The check variety, White Emergo, flowered late with 55-59 days in first year and 51-62 days in second year at both locations. It was interesting to note that the interval of flowering time at Kabete and Ol Joro-Orok differed with only 2 days in the first year, while in the second season flowering was prolonged at Ol Joro-Orok with more than 7 days. Based on the second year (2014), the genotypes KAB-RB13-309/3, KAB-RB13-318-34, KAB-RB13-326-59, KAB-RB13-339-89, KB-RB13-46-22, and KAB-RB13-271-79 flowered early with less than 40 days at Kabete (Table 4.4).

Table 4.4: Number of days to 50% flowering of vegetable runner bean lines grown at two sites and in two years

Days to 50% flowering					
	2013			2014	
Genotypes	Kabete	Ol Joro-Orok	Genotypes	Kabete	Ol Joro-Orok
KAB-RB13-1-105	51.5	51.5	KAB-RB13-1-105/3	44.3	54.0
KAB-RB13-305-130	49.0	50.0	KAB-RB13-305-130/1	44.0	54.0
KAB-RB13-308-57	50.5	51.0	KAB-RB13-308-57/4	46.0	53.3
KAB-RB13-309-60	51.5	51.5	KAB-RB13-309-60/3	39.7	52.0
KAB-RB13-309-64	51.0	53.0	KAB-RB13-309-64/4	45.7	57.3
KAB-RB13-311-102	50.5	52.0	KAB-RB13-311-102/2	43.3	55.7
KAB-RB13-311-103	50.0	52.0	KAB-RB13-311-103/5	42.0	53.7
KAB-RB13-312-135	50.0	50.0	KAB-RB13-312-135/4	46.3	58.0
KAB-RB13-312-35	50.5	50.5	KAB-RB13-312-35/1A	46.0	57.3
KAB-RB13-312-36	47.5	52.5	KAB-RB13-312-36/1	46.7	58.7
KAB-RB13-318-34	50.0	50.0	KAB-RB13-318-34/1	39.3	57.0
KAB-RB13-326-59	49.5	51.0	KAB-RB13-326-59/4	35.7	53.7
KAB-RB13-331-66	50.5	50.5	KAB-RB13-331-66/2	47.3	55.3
KAB-RB13-336-28	48.5	51.0	KAB-RB13-336-28/4B	41.7	53.3
KAB-RB13-339-89	51.5	50.0	KAB-RB13-339-89/6	38.7	53.7
KAB-RB13-363-131	51.0	50.5	KAB-RB13-363-131/2A	45.0	53.3
KAB-RB13-380-55	48.5	49.5	KAB-RB13-380-55/1	45.0	54.3
KAB-RB13-446-5	50.0	52.0	KAB-RB13-446-5/2	42.0	54.7

Table 4.4

(continued)

Days to 50% flowering					
	2013			2014	
Genotypes	**Kabete**	**Ol Joro-Orok**	**Genotypes**	**Kabete**	**Ol Joro-Orok**
KAB-RB13-46-22	51.0	52.0	KAB-RB13-46-22/2	37.7	54.0
KAB-RB13-46-23	50.0	50.0	KAB-RB13-46-23/1	40.3	51.0
KAB-RB13-470-72	50.0	50.0	KAB-RB13-470-72/3	45.7	54.0
KAB-RB13-470-8	50.0	50.5	KAB-RB13-470-8/4	47.7	54.0
KAB-RB13-649-70	49.0	53.0	KAB-RB13-649-70/2	46.7	58.0
OL-RB13-21-1	50.5	52.0	OL-RB13-21-1/4	45.7	55.0
SUB-RB13-114-77	51.5	51.0	SUB-RB13-114-77/2	44.3	56.7
SUB-RB13-117-68	50.0	51.5	SUB-RB13-117-68/1	46.3	57.7
SUB-RB13-133-10	47.5	52.0	SUB-RB13-133-10/4	45.0	54.3
SUB-RB13-178-123	49.0	50.0	SUB-RB13-178-123/3	43.7	52.0
SUB-RB13-240-125	49.0	49.5	SUB-RB13-240-125/5	45.7	54.7
SUB-RB13-240-126	49.5	50.0	SUB-RB13-240-126/2	43.0	56.7
SUB-RB13-271-78	47.5	50.0	SUB-RB13-271-78/3B	30.0	54.3
SUB-RB13-271-79	50.0	50.0	SUB-RB13-271-79/5	37.7	53.3
SUB-RB13-305-76	51.0	50.5	SUB-RB13-305-76/3	43.3	54.3
SUB-RB13-82-69	49.5	50.0	SUB-RB13-82-69/3	39.3	56.7
Check					
White Emergo	54.5	58.5	White Emergo	51.3	61.7
Mean	49.6	50.8	Mean	43.7	55.0
CV (%)	12.4	2.1	CV (%)	8.6	5.0
$LSD_{0.05}$	2.06	2.2	$LSD_{0.05}$	6.1	4.5

4.3.4 Number of racemes in the first flush of flowering

The genotypes showed significant differences in formation of racemes during first flowering at both locations and years (Appendix 15 and 16). The number of racemes varied between 0 to 9 in the first year and 0 to 20 in the second year (Table 4.5). The numbers of racemes formed at first flowering were higher at Ol Joro-Orok than at Kabete. In both years, genotypes had few racemes at Kabete during the first season; almost 70% of genotypes hardly formed flowers. There was a strong location effect on flowering and thus test lines flowered better at Ol Joro Orok.

Results showed that 40% of genotypes formed less than 2 racemes per plant at Kabete, yet the same genotypes at Ol Joro-Orok had five times the number of racemes. Regardless of the poor flower set among genotypes at Kabete in the first season, the genotypes KAB-RB13-1-105, KAB-

RB13-308-57, KAB-RB13-311-102, KAB-RB13-312-36 and KAB-RB13-46-22 formed more than 5 racemes at both sites (Table 4.5). Twenty seven genotypes formed more racemes than White Emergo at Kabete and 24 at Ol Joro-Orok in 2013. In 2014, all genotypes had more racemes than White Emergo at Ol Joro-Orok while at Kabete only six had more racemes than the check variety.

Table 4.5:Number of racemes of vegetable runner bean lines during the first flowering at two sites for two years

Number of racemes plant^{-1} during the first flowering					
	2013			2014	
Genotypes	Kabete	Ol Joro-Orok	Genotypes	Kabete	Ol Joro-Orok
KAB-RB13-1-105	8.7	6.4	KAB-RB13-1-105/3	4.1	5.4
KAB-RB13-305-130	1.5	4.1	KAB-RB13-305-130/1	3.9	5.8
KAB-RB13-308-57	5.3	7.6	KAB-RB13-308-57/4	2.8	8.9
KAB-RB13-309-60	0.5	2.3	KAB-RB13-309-60/3	4.2	3.6
KAB-RB13-309-64	2.3	2.9	KAB-RB13-309-64/4	5.1	8.1
KAB-RB13-311-102	4.8	6.9	KAB-RB13-311-102/2	5.2	7.7
KAB-RB13-311-103	3.9	5.3	KAB-RB13-311-103/5	2.6	5.2
KAB-RB13-312-135	4.0	5.7	KAB-RB13-312-135/4	3.5	4.7
KAB-RB13-312-35	2.1	10.4	KAB-RB13-312-35/1A	3.4	5.7
KAB-RB13-312-36	7.0	10.5	KAB-RB13-312-36/1	5.0	4.6
KAB-RB13-318-34	3.8	13.0	KAB-RB13-318-34/1	6.9	7.1
KAB-RB13-326-59	0.8	4.8	KAB-RB13-326-59/4	8.6	7.8
KAB-RB13-331-66	3.0	6.7	KAB-RB13-331-66/2	2.6	6.8
KAB-RB13-336-28	2.0	6.8	KAB-RB13-336-28/4B	4.8	4.6
KAB-RB13-339-89	1.4	11.2	KAB-RB13-339-89/6	3.8	3.8
KAB-RB13-363-131	1.3	6.9	KAB-RB13-363-131/2A	3.3	7.1
KAB-RB13-380-55	3.9	7.0	KAB-RB13-380-55/1	7.4	12.5
KAB-RB13-446-5	2.0	6.9	KAB-RB13-446-5/2	5.6	8.9
KAB-RB13-46-22	7.8	4.4	KAB-RB13-46-22/2	4.3	6.3
KAB-RB13-46-23	3.5	8.4	KAB-RB13-46-23/1	5.4	8.3
KAB-RB13-470-72	4.0	8.8	KAB-RB13-470-72/3	3.1	5.9
KAB-RB13-470-8	0.8	12.1	KAB-RB13-470-8/4	3.7	9.1
KAB-RB13-649-70	1.4	7.4	KAB-RB13-649-70/2	1.6	7.8
OL-RB13-21-1	0.4	3.6	OL-RB13-21-1/4	3.6	3.6
SUB-RB13-114-77	5.5	4.2	SUB-RB13-114-77/2	1.5	4.3
SUB-RB13-117-68	3.8	5.8	SUB-RB13-117-68/1	5.5	4.0
SUB-RB13-133-10	2.9	13.2	SUB-RB13-133-10/4	6.1	7.1
SUB-RB13-178-123	0.3	3.8	SUB-RB13-178-123/3	3.8	3.2

Table 4.5

(Continued)

Number of racemes plant^{-1} during the first flowering					
	2013			2014	
Genotypes	Kabete	Ol Joro-Orok	Genotypes	Kabete	Ol Joro-Orok
SUB-RB13-240-125	2.0	5.9	SUB-RB13-240-125/5	3.6	3.9
SUB-RB13-240-126	1.6	10.0	SUB-RB13-240-126/2	7.1	3.4
SUB-RB13-271-78	1.9	6.4	SUB-RB13-271-78/3B	6.4	6.0
SUB-RB13-271-79	2.0	7.5	SUB-RB13-271-79/5	2.6	3.6
SUB-RB13-305-76	1.7	6.7	SUB-RB13-305-76/3	5.8	4.2
SUB-RB13-82-69	3.2	3.6	SUB-RB13-82-69/3	3.7	4.1
Check					
White Emergo	1.0	5.1	White Emergo	5.7	2.4
Mean	3.3	7.4	Mean	4.3	6.0
CV (%)	85.3	48.6	CV (%)	50.7	41.9
$LSD_{0.05}$	5.5	7.1	$LSD_{0.05}$	3.5	4.1

4.3.5 Number of racemes in the second flush of flowering

The genotypes showed significant differences in formation of racemes in the second flush of flowering at both sites and locations (Appendix 15 and 16). There were differences in raceme formation in years thus genotypes formed remarkably more racemes in 2014 than in 2013. In both years, genotypes formed more racemes during the second flowering at Ol Joro-Orok than at Kabete. Formation of flowers at Kabete was poor compared to Ol Joro-Orok in the first year (Table 4.6).

About 87% of genotypes formed more than ten racemes per plant at both sites in the second year. The number of racemes varied between 0 to 9 in the first year and 0 to 20 in the second year. White Emergo formed fewer racemes at both sites and years (Table 4.6). In the first year, twenty three genotypes at Kabete and thirty one genotypes at Ol Joro-Orok formed more racemes than White Emergo. Interestingly, in the second year all genotypes formed more racemes in second flowering than White Emergo at both sites.

Table 4.6: Number of racemes of vegetable runner bean lines formed during the second flowering at two sites for two years

Number of racemes plant^{-1} during the second flowering					
	2013			2014	
Genotypes	Kabete	Ol Joro-Orok	Genotypes	Kabete	Ol Joro-Orok
KAB-RB13-1-105	2.0	4.9	KAB-RB13-1-105/3	7.0	15.4
KAB-RB13-305-130	2.3	1.0	KAB-RB13-305-130/1	7.1	14.8
KAB-RB13-308-57	2.8	4.4	KAB-RB13-308-57/4	10.8	15.8
KAB-RB13-309-60	3.5	3.0	KAB-RB13-309-60/3	10.5	8.0
KAB-RB13-309-64	2.6	1.8	KAB-RB13-309-64/4	8.4	12.6
KAB-RB13-311-102	1.3	4.4	KAB-RB13-311-102/2	10.4	19.8
KAB-RB13-311-103	1.8	8.3	KAB-RB13-311-103/5	10.3	8.4
KAB-RB13-312-135	1.7	5.2	KAB-RB13-312-135/4	6.9	15.9
KAB-RB13-312-35	0.9	3.3	KAB-RB13-312-35/1A	8.7	9.8
KAB-RB13-312-36	0.2	3.1	KAB-RB13-312-36/1	13.9	10.1
KAB-RB13-318-34	1.4	6.0	KAB-RB13-318-34/1	9.4	14.9
KAB-RB13-326-59	1.3	2.0	KAB-RB13-326-59/4	10.9	19.7
KAB-RB13-331-66	3.3	4.4	KAB-RB13-331-66/2	13.7	10.4
KAB-RB13-336-28	2.1	2.8	KAB-RB13-336-28/4B	7.1	15.5
KAB-RB13-339-89	0.3	7.4	KAB-RB13-339-89/6	8.4	16.8
KAB-RB13-363-131	1.0	6.4	KAB-RB13-363-131/2A	13.1	10.6
KAB-RB13-380-55	1.6	9.5	KAB-RB13-380-55/1	13.5	15.6
KAB-RB13-446-5	0.6	3.0	KAB-RB13-446-5/2	7.5	19.8
KAB-RB13-46-22	4.8	1.2	KAB-RB13-46-22/2	5.8	8.2
KAB-RB13-46-23	0.3	2.9	KAB-RB13-46-23/1	15.1	16.5
KAB-RB13-470-72	2.6	3.7	KAB-RB13-470-72/3	15.9	14.2
KAB-RB13-470-8	2.0	3.5	KAB-RB13-470-8/4	15.2	19.3
KAB-RB13-649-70	0.2	5.6	KAB-RB13-649-70/2	12.4	18.0
OL-RB13-21-1	1.2	4.4	OL-RB13-21-1/4	8.8	18.3
SUB-RB13-114-77	1.4	3.2	SUB-RB13-114-77/2	9.9	13.2
SUB-RB13-117-68	1.9	2.6	SUB-RB13-117-68/1	5.2	9.3
SUB-RB13-133-10	5.9	4.6	SUB-RB13-133-10/4	9.4	16.8
SUB-RB13-178-123	2.4	7.4	SUB-RB13-178-123/3	8.2	14.9
SUB-RB13-240-125	1.0	4.6	SUB-RB13-240-125/5	7.6	10.9
SUB-RB13-240-126	0.6	6.5	SUB-RB13-240-126/2	9.3	4.8
SUB-RB13-271-78	1.0	9.0	SUB-RB13-271-78/3B	8.7	10.2
SUB-RB13-271-79	0.9	2.5	SUB-RB13-271-79/5	12.4	15.4
SUB-RB13-305-76	0.3	5.8	SUB-RB13-305-76/3	8.8	23.8
SUB-RB13-82-69	2.2	1.4	SUB-RB13-82-69/3	15.1	12.6
White Emergo	0.8	1.8	White Emergo	2.0	0.0
Mean	1.8	4.5	Mean	9.4	14.5
CV (%)	95.8	55.8	CV (%)	48.7	43.8
$LSD_{0.05}$	3.4	5.0	$LSD_{0.05}$	7.4	10.3

4.3.6 Cumulative number of racemes for both first and second flushes of flowering

Genotypes showed significant differences in cumulative number of racemes formed in both flowering stages at both sites in the first year and at Ol Joro-Orok in the second year.The genotypes formed more racemes in the second year (18 racemes plant^{-1}) than the first year (13 racemes plant^{-1}) at both sites (Figure 4.4).

In both years, genotypes had more racemes at Ol Joro-Orok than Kabete. Also, flowering in 2013 was poor at Kabete than Ol Joro-Orok as indicated earlier. White Emergo had the least number of racemes (on average 3 racemes plant-^{1}) in 2013, and 5 racemes plant-^{1} in 2014. Based on the second year; all test lines had more than 10 racemes per plant at both sites which is an equivalent of 150 single flowers per plant (Table 4.7). Similarly, all test lines formed more than 150 flowers plant-1 in both flowering stages during the second year at both sites and in the first year at Ol Joro-Orok.

Table 4.7: Cumulative number of racemes of vegetable runner bean lines grown at two locations for the two flushes of flowering

Cumulative racemes plant^{-1} for two flushes of flowering					
	2013			2014	
Genotypes	**Kabete**	**Ol Joro-Orok**	**Genotypes**	**Kabete**	**Ol Joro-Orok**
KAB13-1-105	10.7	11.3	KAB-RB13-1-105/3	11.1	20.7
KAB13-305-130	3.8	5.1	KAB-RB13-305-130/1	11.0	20.6
KAB13-308-57	8.1	12.0	KAB-RB13-308-57/4	13.6	24.7
KAB13-309-60	4.0	5.4	KAB-RB13-309-60/3	14.8	11.5
KAB13-309-64	4.9	4.8	KAB-RB13-309-64/4	13.4	20.7
KAB13-311-102	6.0	11.3	KAB-RB13-311-102/2	15.6	27.5
KAB13-311-103	5.7	13.6	KAB-RB13-311-103/5	12.9	13.5
KAB13-312-135	5.7	10.9	KAB-RB13-312-135/4	10.4	20.6
KAB13-312-35	3.0	13.8	KAB-RB13-312-35/1A	12.1	15.5
KAB13-312-36	7.2	13.6	KAB-RB13-312-36/1	19.0	14.7
KAB13-318-34	5.5	19.0	KAB-RB13-318-34/1	16.4	22.0
KAB13-326-59	2.0	6.8	KAB-RB13-326-59/4	19.4	28.3
KAB13-331-66	6.3	11.2	KAB-RB13-331-66/2	16.3	20.1
KAB13-334-28	4.9	4.3	KAB-RB13-336-28/4B	11.9	20.6
KAB13-339-89	1.7	18.5	KAB-RB13-339-89/6	12.3	17.7
KAB13-363-131	2.2	13.3	KAB-RB13-363-131/2A	16.3	16.8
KAB13-380-55	5.5	16.5	KAB-RB13-380-55/1	21.0	28.7
KAB13-446-5	2.5	10.0	KAB-RB13-446-5/2	13.2	14.5
KAB13-46-22	12.6	5.6	KAB-RB13-46-22/2	10.1	24.8
KAB13-46-23	3.8	11.2	KAB-RB13-46-23/1	20.5	19.9
KAB13-470-72	6.6	12.5	KAB-RB13-470-72/3	19.0	28.4
KAB13-470-8	2.8	15.6	KAB-RB13-470-8/4	18.9	25.8
KAB13-649-70	1.6	13.0	KAB-RB13-649-70/2	14.0	17.6
OL13-21-1	1.6	7.9	OL-RB13-21-1/4	12.4	22.0
SUB13-114-77	6.9	7.4	SUB-RB13-114-77/2	11.4	17.5

Table 4.7
(Continued)

Cumulative racemes plant^{-1} for two flushes of flowering					
	2013			2014	
Genotypes	**Kabete**	**Ol Joro-Orok**	**Genotypes**	**Kabete**	**Ol Joro-Orok**
SUB13-117-68	5.7	8.4	SUB-RB13-117-68/1	10.7	13.3
SUB13-133-10	8.8	17.8	SUB-RB13-133-10/4	15.4	23.9
SUB13-178-123	2.6	11.2	SUB-RB13-178-123/3	11.9	18.1
SUB13-240-125	3.0	10.5	SUB-RB13-240-125/5	11.2	14.8
SUB13-240-126	2.2	16.5	SUB-RB13-240-126/2	16.4	8.2
SUB13-271-78	2.9	15.3	SUB-RB13-271-78/3B	15.1	16.2
SUB13-271-79	2.9	10.0	SUB-RB13-271-79/5	15.0	19.0
SUB13-305-76	2.0	12.5	SUB-RB13-305-76/3	14.5	28.0
SUB13-82-69	5.5	5.0	SUB-RB13-82-69/3	18.8	16.7
White Emergo	1.8	6.8	White Emergo	7.7	2.4
Mean	4.9	11.9	Mean	13.7	20.5
CV (%)	67.5	3.9	CV (%)	38.0	39.3
$LSD_{0.05}$	6.66	9.2	$LSD_{0.05}$	6.66	13.1

4.3.6 Reaction of genotypes to rust

The mean rust scores are presented in Table 4.8.There was a significant difference in genotypes' reaction to rust infection at both sites and years (Appendix 15 and 16). Susceptibility to rust was not observed in 2013 at both sites however KAB-RB13-312-36/1 and White Emergo were found susceptible at Kabete in 2014. In 2013, 30 genotypes at Kabete and 22 genotypes at Ol Joro-Orok were resistant. Similarly, in 2014, 24 genotypes at Kabete and 30 genotypes at Ol Joro-Orok were found to be resistant (Table 4.8). These resistant lines had mean disease scores ranging from 1 to 3.About 40% of genotypes showed intermediate resistance at both sites and years.

Table 4.8: Rust severity of vegetable runner bean lines at two sites for two years

Mean severity scores of Rust					
	2013			2014	
Genotypes	**Kabete**	**Ol Joro-Orok**	**Genotypes**	**Kabete**	**Ol Joro-Orok**
KAB13-1-105	3.5	2.5	KAB-RB13-1-105/3	4.0	3.0
KAB13-305-130	2.5	6.5	KAB-RB13-305-130/1	3.7	2.0
KAB13-308-57	2.5	4.5	KAB-RB13-308-57/4	4.7	3.3
KAB13-309-60	1.5	5.0	KAB-RB13-309-60/3	2.0	3.0
KAB13-309-64	2.5	4.0	KAB-RB13-309-64/4	2.3	4.3
KAB13-311-102	2.5	2.5	KAB-RB13-311-102/2	2.7	3.3
KAB13-311-103	1.5	1.0	KAB-RB13-311-103/5	4.7	3.7
KAB13-312-135	2.5	2.5	KAB-RB13-312-135/4	5.3	2.7
KAB13-312-35	1.5	3.0	KAB-RB13-312-35/1A	5.7	3.0
KAB13-312-36	1.5	3.0	KAB-RB13-312-36/1	7.3	2.0
KAB13-318-34	1.0	1.0	KAB-RB13-318-34/1	5.3	2.7
KAB13-326-59	4.5	1.5	KAB-RB13-326-59/4	3.7	2.7
KAB13-331-66	2.0	2.0	KAB-RB13-331-66/2	2.7	4.7
KAB13-336-28	2.0	2.0	KAB-RB13-336-28/4B	2.7	3.0
KAB13-339-89	2.0	1.5	KAB-RB13-339-89/6	2.3	3.0
KAB13-363-131	1.5	2.5	KAB-RB13-363-131/2A	2.7	4.0

Table 4.8(continued)

Mean severity scores of Rust					
	2013			2014	
Genotypes	**Kabete**	**Ol Joro-Orok**	**Genotypes**	**Kabete**	**Ol Joro-Orok**
KAB13-380-55	5.5	2.5	KAB-RB13-380-55/1	2.7	5.7
KAB13-446-5	2.0	3.0	KAB-RB13-446-5/2	2.7	1.3
KAB13-46-22	3.5	4.5	KAB-RB13-46-22/2	2.3	1.0
KAB13-46-23	3.0	4.0	KAB-RB13-46-23/1	3.0	1.0
KAB13-470-72	2.0	4.0	KAB-RB13-470-72/3	2.7	2.7
KAB13-470-8	1.5	2.5	KAB-RB13-470-8/4	2.3	2.3
KAB13-649-70	2.5	2.5	KAB-RB13-649-70/2	3.0	3.7
OL13-21-1	2.5	4.0	OL-RB13-21-1/4	4.0	2.0
SUB13-114-77	2.5	2.5	SUB-RB13-114-77/2	6.0	2.7
SUB13-117-68	2.5	4.5	SUB-RB13-117-68/1	2.3	3.0
SUB13-133-10	2.0	3.0	SUB-RB13-133-10/4	2.7	2.0
SUB13-178-123	1.0	3.0	SUB-RB13-178-123/3	3.7	2.7
SUB13-240-125	2.0	2.0	SUB-RB13-240-125/5	4.0	3.0
SUB13-240-126	2.0	2.5	SUB-RB13-240-126/2	1.7	2.0
SUB13-271-78	4.0	2.5	SUB-RB13-271-78/3B	2.3	2.0
SUB13-271-79	3.0	1.5	SUB-RB13-271-79/5	3.3	2.7
SUB13-305-76	2.5	2.0	SUB-RB13-305-76/3	2.3	2.3
SUB13-82-69	1.5	2.0	SUB-RB13-82-69/3	2.7	2.7
KAB13-30-87	1.5	5.0	KAB13-30-87	_	_
KAB13-310-86	1.0	4.0	KAB13-310-86	_	_
KAB13-302-90	6.0	5.5	KAB13-302-90	_	_
Check			**Check**		
White Emergo	4.5	4.5	White Emergo	7.3	4.7
Mean	2.9	3.0	Mean	3.5	2.8
$LSD_{0.05}$	3.1	2.6	$LSD_{0.05}$	3.2	1.9
CV (%)	52.9	44.2	CV (%)	56.5	43.1

- = represents genotypes that were not selected for evaluation in the second year

4.3.7 Reaction of genotypes to common bacterial blight

Significant differences in reaction to common bacterial blight among genotypes were recorded at both sites and years (Appendix 15 and 16). About 40% of genotypes had moderate resistance (scores of 4 to 6) to common bacterial blight at both sites and years. Among the test lines, 25 genotypes at Kabete and 18 genotypes at Ol Joro-Orok were resistant in 2013 while in the year 2014, 24 genotypes showed resistance at both sites (Table 4.9). These resistant lines showed mean disease scores of 1 to 3. White Emergo was susceptible at Ol Joro-orok in 2013 and Kabete in 2014 (Table 4.9).

Table 4.9: Reaction of vegetable runner bean lines to common bacterial blight at two sites for two years

Mean severity scores of Common Bacterial Blight					
	2013			2014	
Genotypes	**Kabete**	**Ol Joro-Orok**	**Genotypes**	**Kabete**	**Ol Joro-Orok**
KAB13-1-105	4.0	5.0	KAB-RB13-1-105/3	2.7	3.0
KAB13-305-130	1.5	5.0	KAB-RB13-305-130/1	2.7	3.0
KAB13-308-57	1.0	5.5	KAB-RB13-308-57/4	5.0	3.7
KAB13-309-60	2.0	5.5	KAB-RB13-309-60/3	2.0	7.3
KAB13-309-64	1.5	2.0	KAB-RB13-309-64/4	4.3	6.7
KAB13-311-102	1.5	4.0	KAB-RB13-311-102/2	1.7	2.0
KAB13-311-103	2.5	2.0	KAB-RB13-311-103/5	4.7	6.0
KAB13-312-135	3.0	3.5	KAB-RB13-312-135/4	2.3	4.0
KAB13-312-35	3.0	2.0	KAB-RB13-312-35/1A	3.3	4.3
KAB13-312-36	3.0	4.5	KAB-RB13-312-36/1	2.7	4.0
KAB13-318-34	2.5	2.5	KAB-RB13-318-34/1	3.7	5.0
KAB13-326-59	5.0	2.0	KAB-RB13-326-59/4	3.0	3.0
KAB13-331-66	1.5	1.0	KAB-RB13-331-66/2	6.0	3.0
KAB13-336-28	4.0	2.5	KAB-RB13-336-28/4B	5.3	2.3
KAB13-339-89	5.5	2.5	KAB-RB13-339-89/6	4.3	3.3
KAB13-363-131	4.0	2.0	KAB-RB13-363-131/2A	3.0	3.3
KAB13-380-55	4.0	1.5	KAB-RB13-380-55/1	2.7	3.7
KAB13-446-5	1.5	2.0	KAB-RB13-446-5/2	3.7	4.7
KAB13-46-22	2.0	4.0	KAB-RB13-46-22/2	2.0	3.0
KAB13-46-23	3.0	2.0	KAB-RB13-46-23/1	2.7	3.7
KAB13-470-72	1.0	3.0	KAB-RB13-470-72/3	3.0	2.7
KAB13-470-8	1.5	4.0	KAB-RB13-470-8/4	1.7	3.0
KAB13-649-70	3.5	2.5	KAB-RB13-649-70/2	3.0	2.3
OL13-21-1	2.5	4.5	OL-RB13-21-1/4	5.3	5.7
SUB13-114-77	4.0	4.0	SUB-RB13-114-77/2	1.7	2.3
SUB13-117-68	2.5	1.5	SUB-RB13-117-68/1	3.3	3.0
SUB13-133-10	2.5	4.5	SUB-RB13-133-10/4	2.0	3.0
SUB13-178-123	4.0	1.5	SUB-RB13-178-123/3	1.7	1.7
SUB13-240-125	3.5	5.5	SUB-RB13-240-125/5	2.7	1.7
SUB13-240-126	2.5	4.5	SUB-RB13-240-126/2	2.3	4.7
SUB13-271-78	2.0	2.5	SUB-RB13-271-78/3B	2.3	1.3
SUB13-271-79	2.5	2.5	SUB-RB13-271-79/5	2.0	2.7
SUB13-305-76	2.5	2.5	SUB-RB13-305-76/3	2.7	3.3
SUB13-82-69	3.5	3.5	SUB-RB13-82-69/3	2.7	1.3
KAB13-30-87	1.5	7.5	KAB13-30-87	_	_
KAB13-310-86	2.0	4.0	KAB13-310-86	_	_
KAB13-302-90	4.0	7.0	KAB13-302-90	_	_
Check			**Check**		
White Emergo	4.0	8.0	White Emergo	7.0	4.7
Mean	2.8	3.3	Mean	3.2	3.5
$LSD_{0.05}$	2.3	2.6	$LSD_{0.05}$	2.5	3.2
CV (%)	41.3	40.0	CV (%)	48.4	55.8

- = represents genotypes that were not selected for evaluation in the second year

4.3.8 Reaction of genotypes to bean common mosaic virus disease (BCMV)

Bean common mosaic virus (BCMV) disease was observed at Ol Joro-Orok and not at Kabete hence disease evaluation was done only at Ol Joro-Orok. The test lines showed significant differences in their reaction to infection by bean common mosaic virus at Ol Joro-Orok in both years (Appendix 15 and 16). About 86% of the genotypes showed scores of 1 to 3 to BCMV in both yearsTable 4.10). On the other hand, White Emergo had intermediate resistance (scores of 4 to 6) to BCMV in both years. About 34% of genotypes in 2013 and 14% of genotypes in 2014 showed intermediate resistance with scores ranging from 4 to 6. Among the test lines, KAB13-331-66 was susceptible to BCMV with a score of 7 in the first year (Table 4.10).

Table 4.10: Reaction of vegetable runner bean lines to BCMV disease at Ol Joro-orok in two years

Mean severity scores of Bean Common Mosaic disease			
	2013		2014
Genotypes	Ol Joro-Orok	Genotypes	Ol Joro-Orok
KAB13-1-105	4.0	KAB-RB13-1-105/3	3.3
KAB13-305-130	4.5	KAB-RB13-305-130/1	3.0
KAB13-308-57	4.0	KAB-RB13-308-57/4	3.7
KAB13-309-60	6.5	KAB-RB13-309-60/3	6.0
KAB13-309-64	6.5	KAB-RB13-309-64/4	4.3
KAB13-311-102	2.5	KAB-RB13-311-102/2	4.3
KAB13-311-103	2.0	KAB-RB13-311-103/5	2.3
KAB13-312-135	2.5	KAB-RB13-312-135/4	2.0
KAB13-312-35	2.0	KAB-RB13-312-35/1A	2.3
KAB13-312-36	2.0	KAB-RB13-312-36/1	3.3
KAB13-318-34	4.0	KAB-RB13-318-34/1	3.0
KAB13-326-59	2.0	KAB-RB13-326-59/4	3.3
KAB13-331-66	7.0	KAB-RB13-331-66/2	2.7
KAB13-336-28	4.0	KAB-RB13-336-28/4B	2.7
KAB13-339-89	2.5	KAB-RB13-339-89/6	3.3
KAB13-363-131	3.0	KAB-RB13-363-131/2A	2.0
KAB13-380-55	1.5	KAB-RB13-380-55/1	3.3
KAB13-446-5	1.5	KAB-RB13-446-5/2	2.3
KAB13-46-22	2.0	KAB-RB13-46-22/2	2.7
KAB13-46-23	4.0	KAB-RB13-46-23/1	2.7
KAB13-470-72	3.0	KAB-RB13-470-72/3	2.0
KAB13-470-8	2.5	KAB-RB13-470-8/4	1.7
KAB13-649-70	2.0	KAB-RB13-649-70/2	3.3
OL13-21-1	2.5	OL-RB13-21-1/4	2.7
SUB13-114-77	3.0	SUB-RB13-114-77/2	1.3
SUB13-117-68	3.0	SUB-RB13-117-68/1	3.7
SUB13-133-10	1.0	SUB-RB13-133-10/4	2.7
SUB13-178-123	3.0	SUB-RB13-178-123/3	2.7
SUB13-240-125	4.0	SUB-RB13-240-125/5	2.7
SUB13-240-126	2.0	SUB-RB13-240-126/2	5.3
SUB13-271-78	2.5	SUB-RB13-271-78/3B	1.7
SUB13-271-79	3.0	SUB-RB13-271-79/5	2.0
SUB13-305-76	3.5	SUB-RB13-305-76/3	2.0
SUB13-82-69	2.5	SUB-RB13-82-69/3	3.3
KAB13-30-87	5.5	KAB13-30-87	_

Table 4.10 (Continued)

Mean severity scores of Bean Common Mosaic disease			
	2013		2014
Genotypes	**Ol Joro-Orok**	**Genotypes**	**Ol Joro-Orok**
KAB13-310-86	2.5	KAB13-310-86	_
KAB13-302-90	5.0	KAB13-302-90	_
Check		**Check**	
White Emergo	5.5	White Emergo	6.0
Mean	3.1	Mean	3.1
$LSD_{0.05}$	2.6	$LSD_{0.05}$	1.9
CV (%)	41.5	CV (%)	37.8

- = represents genotypes that were not selected for evaluation in the second year

4.3.9 Reaction of genotypes to powdery mildew

Powdery mildew infection on genotypes occurred only at Kabete. There were significant differences among genotypes to infection by powdery mildew in both years (Appendix 15 and 16). Susceptibility was recorded in KAB13-310-86 in 2013 and KAB13-309-64 in 2014. About 25 genotypes in 2013 and 17 genotypes in 2014 were resistant to powdery mildew (Table 4.11). The resistant lines had mean scores ranging from 1 to 3.White Emergo was moderately resistant to powdery mildew in both years (Table 4.11). Moreover, moderate resistance to powdery mildew was observed in 12 lines in 2013 and 5 lines in 2014.

Table 4.11: Powdery mildew scores of vegetable runner bean lines at Kabete in two years

Powdery Mildew Mean severity Scores			
	2013		2014
Genotypes	**Kabete**	**Genotypes**	**Kabete**
KAB13-1-105	2.0	KAB-RB13-1-105/3	3.3
KAB13-305-130	4.5	KAB-RB13-305-130/1	4.3
KAB13-308-57	2.0	KAB-RB13-308-57/4	4.3
KAB13-309-60	6.0	KAB-RB13-309-60/3	5.0
KAB13-309-64	4.0	KAB-RB13-309-64/4	7.3
KAB13-311-102	3.5	KAB-RB13-311-102/2	5.0
KAB13-311-103	2.5	KAB-RB13-311-103/5	2.7
KAB13-312-135	2.5	KAB-RB13-312-135/4	2.3
KAB13-312-35	2.5	KAB-RB13-312-35/1A	2.0
KAB13-312-36	2.5	KAB-RB13-312-36/1	3.0
KAB13-318-34	2.0	KAB-RB13-318-34/1	2.7
KAB13-326-59	4.5	KAB-RB13-326-59/4	3.3
KAB13-331-66	1.5	KAB-RB13-331-66/2	4.3
KAB13-336-28	2.5	KAB-RB13-336-28/4B	3.7
KAB13-339-89	5.5	KAB-RB13-339-89/6	1.7
KAB13-363-131	5.5	KAB-RB13-363-131/2A	4.0
KAB13-380-55	4.5	KAB-RB13-380-55/1	4.3
KAB13-446-5	2.5	KAB-RB13-446-5/2	4.0
KAB13-46-22	1.0	KAB-RB13-46-22/2	5.0
KAB13-46-23	3.0	KAB-RB13-46-23/1	4.0
KAB13-470-72	2.5	KAB-RB13-470-72/3	2.3
KAB13-470-8	4.0	KAB-RB13-470-8/4	2.0
KAB13-649-70	1.0	KAB-RB13-649-70/2	2.3
OL13-21-1	3.0	OL-RB13-21-1/4	5.7

Table 4.12 (continued)

Powdery Mildew Mean severity Scores			
	2013		2014
Genotypes	Kabete	Genotypes	Kabete
SUB13-114-77	2.5	SUB-RB13-114-77/2	4.3
SUB13-117-68	2.0	SUB-RB13-117-68/1	3.7
SUB13-133-10	2.0	SUB-RB13-133-10/4	4.0
SUB13-178-123	2.5	SUB-RB13-178-123/3	2.3
SUB13-240-125	2.5	SUB-RB13-240-125/5	3.7
SUB13-240-126	2.5	SUB-RB13-240-126/2	3.0
SUB13-271-78	2.5	SUB-RB13-271-78/3B	3.0
SUB13-271-79	3.0	SUB-RB13-271-79/5	4.0
SUB13-305-76	2.0	SUB-RB13-305-76/3	3.3
SUB13-82-69	2.0	SUB-RB13-82-69/3	3.3
KAB13-30-87	3.0	KAB13-30-87	_
KAB13-310-86	7.0	KAB13-310-86	_
KAB13-302-90	1.5	KAB13-302-90	_
White Emergo	4.0	White Emergo	7.3
Mean	2.8	Mean	3.8
$LSD_{0.05}$	3.1	$LSD_{0.05}$	2.7
CV (%)	55.9	CV (%)	43.5

- = genotypes that were not selected for evaluation in the second year

4.3.10 Marketable pod yield

In this study, only genotypes that had the marketable vegetable pods of length more than 18cm and diameter of 2 cm or below were sampled to determine the marketable pod yield. Four harvests were done in the year 2013 and eight harvests done in 2014. Harvesting was only done for a period of 1 month compared to three months harvesting done in the commercial farms. Therefore, the pod yield presented is for harvests of one month. The test lines were therefore evaluated for marketable pod yield per harvest and cumulative yield of the harvests. Genotypes which had no marketable yield were rated as zero.Selection of lines to be evaluated in the second season was based on number of racemes, marketable pod yield, length and dameter. Although 10 genotypes did not have marketebale pods, they were selected for evaluation in second season because they showed potential of having abundant racemes and were resistant to diseases. Therefore, these lines were incorporated in the second season for further screening of their potential to vegetable pod formation. Pod sampling started after the first flowers formed pods and continued for the second set of pods after the second flowering.

Genotypes that showed promising yield in 2013 were selected for 2014. Due to poor flowering at Kabete in the first year, pod sampling was done at Ol Joro-Orok in 2013 and at Kabete in 2014.There were significant genotypic differences in cumulative yield and pod yield per harvest in both years. The mean yield of four harvests was 2,820 kg ha^{-1} in 2013 and 3,283 kg ha^{-1} for eight

harvests in 2014. Pod yield per harvest was higher in 2013 (705 kg ha-^{1}) than 2014 (411 kg ha-^{1}). In 2013, the highest total yield was found in eight lines and the yield ranged between 4000 to 7,735 kg ha^{-1}.

In 2014, six lines yielded more than 4,000 to 15,314 kg ha^{-1} (Table 4.13). The best harvests in the first year ranged from 1000 to 1142 kg ha-^{1} and 1000 to 1914 kg ha-^{1} in the second year. It was noted that genotypes yielded better at one site than the other. As indicated earlier, yield evaluation in the first year was done at Ol Joro-Orok which is predominantly cool compared to Kabete with warmer conditions. Based on site performance, KAB13-312-135, KAB13-326-59, KAB13-380-55, KAB13-46-23, OL13-21-1,SUB13-240-125 were selected because they performed well at Ol Joro-Orok, while KAB-RB13-213-36/1, KAB-RB13-363-13-2A, KAB-RB13-470-72/3 and SUB-RB13-133-10/4 were better adapted to warmer conditions at Kabete. The lowest harvest was 164.5 kg ha^{-1} in 2013, and 31.6 kg ha^{-1} in 2014 (Table 4.12).White Emergo had no yield in the first year, and recorded the lowest yield of 25 kg ha^{-1} in the second year.

In the first year, 88% of genotypes yielded pods of Grade I, 9% had pods of Grade II and 3% of Grade III pods. In 2014, 46%, of the total yield was Grade I, 39% Grade II, and 14%, Grade III (Table 4.12). In general 80% of the yield of genotypes was marketable (Grades I and II). White Emergo formed 100% pods of Grade III and had no pods with premium grades (Grade I and II). It was notable that 100% of the pods from KAB13-311-102, KAB13-312-135 and KAB13-446-5 were either grade I or II for the two years suggesting high pod quality in these lines.

Table 4.12: Marketable pod yield per harvest of vegetable runner bean lines and proportions of yield per grade for two years

Marketable pod yield harvest^{-1} (kg)									
	2013					2014			
Genotypes	Pod yield/harvest	%Grade I	%Grade II	%Grade III	Genotypes	pod yield/harvest	%Grade I	%Grade II	%Grade III
KAB13-1-105	0	0	0	0	KAB-RB13-1-105/3	342.6	56.9	18.1	25.1
KAB13-305-130	695.3	75.5	20.5	3.5	KAB-RB13-305-130/1	358.5	80	10	10
KAB13-308-57	310.5	62.8	32.2	5	KAB-RB13-308-57/4	116.8	68.6	22.5	9.3
KAB13-309-60	849.4	68.9	20.8	10	KAB-RB13-309-60/3	94.6	43.2	23.6	33.3
KAB13-309-64	0	0	0	0	KAB-RB13-309-64/4	148.1	100	0	0
KAB13-311-102	164.5	70	30	0	KAB-RB13-311-102/2	85.5	100	0	0
KAB13-311-103	520.6	100	0	0	KAB-RB13-311-103/5	346.7	0	100	0
KAB13-312-135	1036.9	100	0	0	KAB-RB13-312-135/4	209.1	100	0	0
KAB13-312-35	428	72.3	10	17.7	KAB-RB13-312-35/1A	443.7	52.1	45.1	3.2
KAB13-312-36	332.4	59.6	30.2	10.2	KAB-RB13-312-36/1	1258.5	84.1	12.7	3.2
KAB13-318-34	0	0	0	0	KAB-RB13-318-34/1	111.5	61.3	38.9	0
KAB13-326-59	1422	90	10	0	KAB-RB13-326-59/1	261.2	100	0	0
KAB13-331-66	0	0	0	0	KAB-RB13-331-66/2	414.7	0	100	0
KAB13-336-28	733.9	79	10	11	KAB-RB13-336-28/4B	174.8	44.6	17.3	38.1
KAB13-339-89	0	0	0	0	KAB-RB13-339-89/6	52.7	0	34	66
KAB13-363-131	456.3	89	11	0	KAB-RB13-363-131/2A	1133.9	56.5	19.5	24
KAB13-380-55	1193.9	76	14	10	KAB-RB13-380-55/1	523	100	0	0
KAB13-446-5	1045	95	5	0	KAB-RB13-446-5/2	31.6	100	0	0
KAB13-46-22	0	0	0	0	KAB-RB13-46-22/2	331.6	83.7	0	16.7
KAB13-46-23	1140.4	94	2.3	3.7	KAB-RB13-46-23/1	395	52.1	39.6	8.3
KAB13-470-72	534.7	86	14	0	KAB-RB13-470-72/3	1914.3	74.3	10.4	15.4
KAB13-470-8	0	0	0	0	KAB-RB13-470-8/4	71.8	83.6	16.7	0
KAB13-649-70	0	0	0	0	KAB-RB13-649-70/2	369.2	13.5	45.2	41.4
OL13-21-1	1142.4	86	10.2	3.8	OL-RB13-21-1/4	319.1	60.3	25.4	14.3
SUB13-114-77	418.1	87	13	0	SUB-RB13-114-77/2	565.7	30.6	56.9	12.5

Table 4.12
(continued)

	Marketable pod yield harvest^{-1} (kg)								
	2013					2014			
Genotypes	**Pod yield/harvest**	**%Grade I**	**%Grade II**	**%Grade III**	**Genotypes**	**pod yield/harvest**	**%Grade I**	**%Grade II**	**%Grade III**
SUB13-117-68	0	0	0	0	SUB-RB13-117-68/1	491.3	25	37.4	37.6
SUB13-133-10	554.8	79	3	18	SUB-RB13-133-10/4	1110.7	65.9	20.9	13.1
SUB13-178-123	0	0	0	0	SUB-RB13-178-123/3	40.8	100	0	0
SUB13-240-125	1050.6	79	21	0	SUB-RB13-240-125/5	91.8	100	0	0
SUB13-240-126	0	0	0	0	SUB-RB13-240-126/2	321.3	48.7	51.3	0
SUB13-271-78	740.2	76	24	0	SUB-RB13-271-78/3B	170	100	0	0
SUB13-305-76	0	0	0	0	SUB-RB13-305-76/3	308.7	77.8	22.2	0
Check					**Check**		0	0	0
White Emergo	0	0	0	0	White Emergo	25	0	0	100
Mean	705	623.7	61.3	20	Mean	411	190.2	164.3	56.5
CV (%)	56.8				CV (%)	11.83			
$LSD_{0.05}$	81.3				$LSD_{0.05}$	78.27			

Table 4.13: Cumulative marketable pod yield of vegetable runner bean lines in 2013 and 2014 at Kabete and Ol Joro-Orok

Cumulative pod yield (kg ha^{-1})			
Ol Joro-Orok		**Kabete**	
Genotypes	**2013**	**Genotypes**	**2014**
KAB13-1-105	0	KAB-RB13-1-105/3	2741
KAB13-305-130	2781	KAB-RB13-305-130/1	2868
KAB13-308-57	1242	KAB-RB13-308-57/4	935
KAB13-309-60	3398	KAB-RB13-309-60/3	757
KAB13-309-64	0	KAB-RB13-309-64/4	1185
KAB13-311-102	658	KAB-RB13-311-102/2	684
KAB13-311-103	2083	KAB-RB13-311-103/5	2774
KAB13-312-135	4148	KAB-RB13-312-135/4	1673
KAB13-312-36	1330	KAB-RB13-312-36/1	10068
KAB13-318-34	0	KAB-RB13-318-34/1	892
KAB13-326-59	5688	KAB-RB13-326-59/1	2090
KAB13-331-65	7735	KAB-RB13-331-65/3	2271
KAB13-336-28	2936	KAB-RB13-336-28/4B	1399
KAB13-339-89	0	KAB-RB13-339-89/6	421
KAB13-363-131	1825	KAB-RB13-363-131/2A	9071
KAB13-380-55	4775	KAB-RB13-380-55/1	4184
KAB13-446-5	4180	KAB-RB13-446-5/2	252
KAB13-46-22	0	KAB-RB13-46-22/2	2652
KAB13-46-23	4562	KAB-RB13-46-23/1	3160
KAB13-470-72	2139	KAB-RB13-470-72/3	15314
KAB13-470-8	0	KAB-RB13-470-8/4	574
KAB13-649-70	0	KAB-RB13-649-70/2	2954
OL13-21-1	4570	KAB-RB13-85-19B/1A	822
SUB13-114-77	1672	SUB-RB13-114-77/2	4525
SUB13-117-68	0	SUB-RB13-117-68/1	3930
SUB13-133-10	2219	SUB-RB13-133-10/4	8885
SUB13-240-125	4202	SUB-RB13-240-125/5	734
SUB13-240-126	0	SUB-RB13-240-126/2	2570
SUB13-271-78	2961	SUB-RB13-271-78/3B	1360
SUB13-305-76	0	SUB-RB13-305-76/3	2469
White Emergo	0	White Emergo	195
Mean	2820	Mean	3283
CV (%)	56.8	CV (%)	68.3
$LSD_{0.05}$	352.2	$LSD_{0.05}$	626.12

4.3.11 Pod diameter

Genotypes were evaluated for the preferred pod diameter in the market which is 2cm or less. Pod diameter was assessed on marketable pods hence the diameter of genotypes that had no marketable yield was indicated as zero. The genotypes showed significant differences in pod diameter in the both years (Appendix 15 and 16). The mean pod diameter of genotypes ranged from 1.7cm to 2.3 cm in the year 2013 and from 1.7cm to 2.5 cm in 2014 (Table 4.14). In both years, the pod diameter for Grade I and Grade II was 1.9cm, while Grade III was 2.0cm. White Emergo did not yield marketable pods in 2013 hence the diameter was not recorded. However, in 2014 White Emergo formed Grade III pods of 1.9cm in diameter (Table 4.14).

Table 4.14: Marketable pod diameter (cm) of vegetable runner bean lines in two seasons

	Pod diameter (cm)					
	2013			2014		
Genotypes	**Grade I**	**Grade II**	**Grade III**	**Grade I**	**Grade II**	**Grade III**
KAB-RB13-1-105/3	0.0	0.0	0.0	1.8	1.9	2.0
KAB-RB13-305-130/1	2.0	1.9	2.2	1.8	1.6	2.4
KAB-RB13-308-57/4	2.0	1.8	1.9	1.9	2.1	2.3
KAB-RB13-309-60/4	1.8	1.8	2.0	1.7	1.9	2.3
KAB-RB13-309-64/4	0.0	0.0	0.0	1.9	0.0	0.0
KAB-RB13-311-102/2	1.9	1.8	0.0	2.0	0.0	0.0
KAB-RB13-311-103/5	1.9	0.0	0.0	0.0	2.2	0.0
KAB-RB13-312-135/4	2.0	0.0	0.0	1.9	0.0	0.0
KAB-RB13-312-35/1A	1.9	1.9	2.1	1.9	1.9	2.5
KAB-RB13-312-36/1	1.9	1.7	2.2	1.9	1.3	2.2
KAB-RB13-318-34/1	0.0	0.0	0.0	1.8	2.1	0.0
KAB-RB13-326-59/1	1.9	1.9	0.0	2.0	0.0	0.0
KAB-RB13-331-66/2	0.0	0.0	0.0	0.0	1.9	0.0
KAB-RB13-336-28/4B	1.7	1.8	2.0	1.9	2.2	2.2
KAB-RB13-339-89/6	0.0	0.0	0.0	0.0	1.9	1.8
KAB-RB13-363-131/2A	1.9	1.9	0.0	1.8	1.9	1.9
KAB-RB13-380-55/1	1.8	1.8	1.9	2.0	0.0	0.0
KAB-RB13-446-5/2	1.8	1.9	0.0	2.1	0.0	0.0
KAB-RB13-46-22/2	0.0	0.0	0.0	1.9	0.0	1.8
KAB-RB13-46-23/1	1.9	1.7	2.3	2.2	1.8	2.3
KAB-RB13-470-72/3	2.1	2.0	2.3	2.2	2.0	2.2
KAB-RB13-470-8/4	0.0	0.0	0.0	1.8	1.9	0.0
KAB-RB13-649-70/2	0.0	0.0	0.0	1.9	1.8	2.0
OL-RB13-21-1/4	2.0	1.7	2.1	1.9	1.9	1.6
SUB-RB13-114-77/2	1.8	1.8	0.0	2.0	2.0	1.7
SUB-RB13-117-68/1	0.0	0.0	0.0	2.0	2.2	1.9
SUB-RB13-133-10/4	2.1	1.8	2.3	1.7	1.8	2.2
SUB-RB13-178-123/3	0.0	0.0	0.0	1.9	0.0	0.0
SUB-RB13-240-126/2	0.0	0.0	0.0	2.1	0.0	0.0
SUB-RB13-271-78/5	1.9	2.0	0.0	2.1	1.8	0.0
SUB13-305-76	0.0	0.0	0.0	1.9	0.0	0.0
White Emergo	0.0	0.0	0.0	0	0	1.9
Average diameter grade	1.9	1.9	2.0	1.9	1.9	2.1
$LSD_{0.05}$	0.35			0.23		
CV (%)	16			7.4		

4.3.12 Pod length

In this study only genotypes which had marketable pod length of 18cm and above were sampled. Therefore, genotypes that did not form marketable pods were not evaluated for pod length hence their lengths considered as zero. However, few genotypes with no marketable pods but had good pod diameter were incorporated in the second season. Significant differences in length among genotypes were indicated in both years (Appendix 15 and 16).

The pod length of genotypes varied from 18 to 20cm in 2013 and from 16 to 25 cm in 2014 (Table 4.15). Mean pod length of Grade I, Grade II and Grade III was 19cm in both years. White Emergo formed the shortest pods of 15cm in length. All sampled genotypes formed pods of 18cm and above in length except KAB-RB13-649-70/2 and SUB-RB13-106-12/4 which were 16.3cm and 17cm in length (Table 4.15 and Fig 4.3).

Table 4.15: Pod lengths of vegetable runner bean lines grown at two locations for two years

	Pod length (cm)					
	2013			2014		
Genotypes	**Grade I**	**Grade II**	**Grade III**	**Grade I**	**Grade II**	**Grade III**
KAB-RB13-1-105/3	0.0	0.0	0.0	19.6	20.3	19.4
KAB-RB13-305-130/1	18.3	20.6	18.5	19.3	21.0	20.2
KAB-RB13-308-57/4	18.2	20.5	18.6	20.4	20.0	18.3
KAB-RB13-309-60/4	18.1	18.0	18.6	19.4	18.6	20.0
KAB-RB13-309-64/4	0.0	0.0	0.0	20.1	0.0	0.0
KAB-RB13-311-102/2	18.2	18.3	0.0	19.8	0.0	0.0
KAB-RB13-311-103/5	19.0	0.0	0.0	0.0	19.0	0.0
KAB-RB13-312-135/4	19.6	0.0	0.0	18.5	0.0	0.0
KAB-RB13-312-35/1A	19.0	18.2	18.8	19.6	18.9	22.2
KAB-RB13-312-36/1	18.1	19.7	19.0	20.6	19.1	20.1
KAB-RB13-318-34/1	0.0	0.0	0.0	20.2	18.6	0.0
KAB-RB13-326-59/1	18.5	20.5	0.0	20.3	0.0	0.0
KAB-RB13-331-66/2	0.0	0.0	0.0	0.0	20.8	0.0
KAB-RB13-336-28/4B	18.7	18.4	18.0	19.5	24.5	19.0
KAB-RB13-339-89/6	0.0	0.0	0.0	0.0	20.0	19.4
KAB-RB13-363-131/2A	18.7	18.3	0.0	20.9	19.0	19.3
KAB-RB13-380-55/1	18.2	18.6	18.0	18.0	18.3	17.9
KAB-RB13-446-5/2	19.2	18.8	0.0	20.8	0.0	0.0
KAB-RB13-46-22/2	0.0	0.0	0.0	21.0	0.0	20.2
KAB-RB13-46-23/1	18.0	18.7	19.5	20.2	19.9	20.8
KAB-RB13-470-72/3	18.0	18.7	18.8	21.0	18.4	19.1
KAB-RB13-470-8/4	0.0	0.0	0.0	19.8	18.3	0.0
KAB-RB13-649-70/2	0.0	0.0	0.0	18.7	18.5	16.3
OL-RB13-21-1/4	18.0	18.7	18.0	18.6	18.3	17.5
SUB-RB13-114-77/2	18.3	18.6	0.0	20.9	19.2	18.8
SUB-RB13-117-68/1	0.0	0.0	0.0	19.9	19.4	19.1
SUB-RB13-133-10/4	18.6	18.3	18.6	18.5	22.9	20.2
SUB-RB13-178-123/3	0.0	0.0	0.0	20.9	0.0	0.0
SUB-RB13-240-126/2	0.0	0.0	0.0	18.9	19.5	18.2
SUB-RB13-271-79/5	18.6	18.0	0.0	20.9	20.5	17.8
SUB-RB13-106-12/4	0.0	0.0	0.0	0.0	20.3	17.3

Table 4.15 (continued)

White Emergo	0	0.0	0.0	0	0	14.9
Average length grade-1	18.6	18.9	18.5	19.9	19.4	18.2
$LSD_{0.05}$	1.7			2.0		
CV (%)	8.0			11.4		

A. Grade I Pods of lines KAB13-312-36/1 and B. SUB13-133-10/4

Figure 4.3 Pod characteristics of vegetable runner bean lines

A. Vegetable runner bean lines with abundant racemes at Ol Joro-orok and B. at Kabete and C. high yielding line KAB-RB13-470-72/3

Figure 4.4 Racemes and pods were formed by vegetable runner bean lines

4.4 Discussion

4.4.1 Growth vigor

The growth vigor of genotypes varied significantly in the two sites and years. This could be attributed to the differences in temperature and rainfall conditions across sites and years. The crop at Kabete in the first year showed intermediate vigor due to low rainfall that resulted in water stress during the crop growth (Fig 4.2 and Table 4.1). In the first year, the genotypes were planted in April but a dry spell prevailed from the month of May to 0ctober (Fig 4.2). Emam et al. (2010) reported that exposing plants to drought stress affects growth by reducing plant height and leaf area. The lines were vigorous at both sites in the second year due to the cooler and moist conditions due to lower temperatures and uniform distribution of rainfall (Fig 4.2). The fact that most genotypes showed good vigor during moist and cool conditions in the second season at both locations is an indication that indeed *P. coccineus* species thrive well under cooler conditions. Similarly, Santalla et al. (2004) reported runner bean that runner bean is a vigorous crop when grown in good climatic conditions.

4.4.2 Days to flowering

The significant differences in days to flowering under natural day length (12 hours) among genotypes can be attributed to environmental and genetic differences. The effect of temperature difference influenced genotypes time to flowering as observed by the results at the two sites. Kabete has warmer conditions with a mean temperature of 23^{o}C and thus genotypes flowered earlier than Ol Joro-Orok which is generally cool (mean temp of 15^{o}C). Wallace et al. (1991) also reported that differential effect in temperature affects the time of flowering in common beans. They further documented that, a smaller increase or decrease in mean temperatures results in a qualitatively decrease or increase respectively in days to flowering among photoperiod sensitive common bean genotypes. They further revealed that increased temperatures above the optimal reduces the days to flowering by 1) enhancing vegetative development, 2) increasing photoperiod gene activity and thus promote flower node development and vice versa.

Studies by Rodino et al.(2007); Spataro et al. (2011) has also shown *P. coccineus* to be adapted to temperate cool conditions which delay flowering and that in Africa this species thrives well in the highland cooler areas with low temperatures. The delay in flowering of White Emergo at both sites and seasons primarily categorizes this variety to be moderately photoperiod sensitive. This late flowering in White Emergo at both sites also reveal that the variety could be long-day and therefore flowering is delayed due to a non-inductive day length. Cultivars that are photoperiod sensitive delay to flower due to response to a non-promotive day length which inhibits flower

development (Wallace et al., 1985). From this study, it's clear that though the tested lines were under the same influence of short-day photoperiod there was temperature influence in time taken to flower at the two sites. At Kabete (warmer conditions) the lines flowered in 40 to 50 days from planting and took 50 to 60 days to flower at Ol Joro-Orok (cooler conditions). Likewise, these lines will flower early in conditions similar to Kabete and flower late in cooler conditions as Ol Joro-Orok. This then indicates that even under the same photoperiods, the time to flowering may differ in the tested lines depending with the area where they are grown. However, the duration to 50% flowering taken by these lines in this study is within the normal range of 40 to 60 days for runner bean to flower as reported by Brink (2006).

4.4.3 Raceme formation

The number of racemes varied significantly among genotypes, sites and years due to the interplay between genetic and environmental effects. Genotypes at Ol Joro-Orok had more racemes than Kabete in the first season due to the cooler conditions that favour ideal growth of runner bean (Fig 4.1). Results suggest that ambient temperature influenced flower formation and development. This may have contributed to the differences in number of racemes per plant that varied with season and location.

Results showed that the study genotypes flowered during the months of May to June in both years and sites. Therefore, racemes formation occurred within 40 to 60 days after planting. Within these months of flowering, temperature variations in the years greatly influenced flower formation as revealed by tremendous number of racemes during the second year as opposed to the first year at both sites. Fig 4.3 shows that the mean temperature during time of flowering at Kabete was 22.27^{o}C in the first year, and 16.98^{o}C in the second year. In the second season both sites had a mean temperature of 14^{o}C. These cool temperatures enhanced the vegetative growth and stimulated initiation of flower nodes and number of flowers in the second season at both sites. Another factor that could have contributed to observed differences in raceme formation is the genotype.

Results showed considerable differences in genotypes number of racemes per plant at both locations and year. For instance, most genotypes at Kabete in the first year hardly formed racemes due to the prevalent water stress and high temperatures. However, under the same pressure the lines KAB 13-1-105/3, KAB13-308-57/4, KAB13-312/35/1A, KAB13-312-36/1, KAB13-318-34/1, KAB13-380-55/1, KAB13-446-5/2, KAB13-46-23/1, KAB13-470-72/3,KAB13-470-8/4,KAB13-649-70/2,SUB13-178-123/3 and SUB13-106-12/4 formed adequate racemes between 6 to 13 and performed well in the second season at both sites. These lines show a unique inherent potential of forming many flowers even under such drought stress and therefore could be selected

to grow in cooler or warmer conditions. The results of this study provide evidence that flower formation is quantitatively inherited and hence has a genotypic and possibly genotypic and environmental interaction effect.

White Emergo had few or formed no racemes at all in both years indicating the genetic variability which constrains performance of this variety in shorter photoperiods. Freytag and Debouck (2002) showed that runner bean varieties selected from temperate regions are mainly adapted to cooler conditions (long-day photoperiods) hence their performance in warmer conditions (shorter photoperiods) is constrained. Hadjichristodoulou (1990) found out that most runner bean varieties are adapted to cooler climates and hence their growth in tropical areas with high temperatures yields low seed due to poor flowering. He also, documented that runner bean gave satisfactory yields when planted at cooler areas with low temperatures. However, when the same materials were grown at Central Plain (Nicosia) a place of warmer conditions (over 25 ^{o}C) they produced very few flowers and few pods. It follows from the present research that flowering in runner bean is influenced by genotype, environment and the interaction of genotype and environment. The evaluated lines exhibit inherent ability to flower in short photoperiods however the intensity of flower set may be influenced by environmental conditions. Poor flowering of White Emergo proves that the variety is not adapted to shorter photoperiods. Therefore, production of this variety is well suited for high input systems where the required extended artificial light is provided.

4.4.4 Reaction of genotypes to the prevalent diseases under the field conditions

In the tropics runner bean is affected by anthracnose (*Colletotrichum lindemuthianum*), fusarium wilt (Fusarium wilt *f.sp. phaseoli*), rust (*Uromyces phaseoli*), and halo blight (*Pseudomonas savastanoi* pv.*phaseolicola*) (Brink, 2006; Kay, 1979). The prevalent diseases at the study sites were rust, powdery mildew, bean common mosaic virus and common bacterial blight.

The genotypes were evaluated based on their resistance to diseases that were predominantly present in the field.

The diseases scores of the lines were significantly lower suggesting high resistance of the genotypes or low inoculum levels of the pathogens. In some cases disease incidence was recorded at one location and not the other like the case of bean common mosaic virus at Ol Joro-Orok and powdery mildew at Kabete only because of the high inoculum levels and presence of favorable conditions for the development of the pathogen.High humidity experienced at Kabete in June-August 2013 and 2014 resulted in infection by powdery mildew. Hagedorn (1986) reported that high humidity provides favourable environment for infection and development of powdery mildew. Conversely, rust was present at both sites but at very low levels demonstrating the diverse adaptation of the causal agent (*Uromyces appendiculatus*) to different environments. According to

Pastor Corrales (2002) bean rust has been known to occur worldwide due to the abundant diversity for virulence of *Uromyces appendiculatus*). Most genotypes had a mean disease score of 1-3 for the four diseases indicating that nearly all the genotypes have a higher degree of resistance to the four major diseases that occurred in the two sites. Therefore, selection for multiple disease resistance to the four diseases is possible.

Even though low diseases scores could be associated with unfavouarble conditions for pathogen development, this study confirms that runner bean are resistant to most diseases of *Phaseolus* genus (Beaver and Osorno, 2009; Kay, 1979). The runner bean is of special interest to breeders because it is resistant to most of the root organisms that affect *P. vulgaris* (Kay, 1979). Runner bean is widely considered a potential source of resistance to other diseases of common bean such as aschochyta blight (*Phoma exigua*), powdery mildew (*Erysiphe polygoni*), angular leafspot (*Phaeoisariopis griseola*) (Brink, 2006) and forms fertile hybrids in crosses. Moderate levels of resistance to common bacterial blight, fusarium root rot, and white mould have been transferred from runner bean to common bean. In contrast, resistance to halo blight has been transferred from common bean to runner bean (Brink, 2006).

4.4.5 Marketable pod yield

Study genotypes showed considerable variation for pod yield and pod quality. Both traits were influenced by environmental factors at the study sites. This is demonstrated by the genotypes; KAB13-312-135, KAB13-326-59, KAB13-380-55, KAB13-46-23, OL13-21-1, SUB13-240-125 having higher pod yield at Ol Joro-Orok, while KAB-RB13-213-36/1, KAB-RB13-363-13-2A, KAB-RB13-470-72/3 and SUB-RB13-133-10/4 yielding well at Kabete. These higher yields among these genotypes were observed at one location only. White Emergo had no marketable yield in the first year and the least yield per harvest (25 kg ha^{-1}) compared to the advanced runner bean lines. These enormous yield differences could have attributed to the fact that the variety has been selected from temperate regions and therefore its productivity in short-day lengths is constrained.

Caiger (1995) further indicated that the main climate criteria of runner bean selected from temperate areas when grown in African countries is to ensure the crop has 16hours of day length and in absence of such natural day length then artificial additional lighting is used. By definition a long-day plant is one that flowers when the days are longer than a certain minimum day length (Salisbury and Ross, 1992).Therefore, the critical photoperiod of White Emergo could not be achieved under the natural day length of 12 hours, and thus induction of flowering was first delayed and then flower development reduced resulting in fewer racemes. As expected number of racemes is a function of pod yield and therefore poor flowering resulted in low yields .Genotypes

that yielded more than 1,000 kg ha^{-1}show great potential of being high yielders since such yields are the ones met in high input systems. In fresh produce companies, yield per harvest is estimated at 1.3tonnes per hectare (Longonot Horticulture, personal communication). Therefore, the selected lines can be used to develop varieties for smallholder farmers who mainly rely on low input system. Most genotypes apportioned much of the marketable pod yield to Grade I and Grade II indicating the ability of genotypes to yield preferred pods that meet market demands. From the results four lines KAB13-312-135, KAB13-380-55, KAB13-46-23,OL13-21-1 and SUB13-240-125 were identified to be high yielders at Ol Joro-orok and four lines; KAB-RB13-312-36/1,KAB-RB13-363-131/2A,KAB-RB13-470-72/3 and SUB-RB13-133-10/4 at Kabete.

4.4.6 Marketable pod diameter and pod length

The pod diameter and pod length varied among genotypes and market classes because of the different attributes regarded for each market class. As seen earlier Grade I and II pods are quite long and should have a length of 18-28 cm. This also reveals that the genotypes can be selected for production of all the 3 marketable grades. All the sampled genotypes had a pod length of more than 18cm and diameter of 1.8-2.1cm which shows that the genotypes meet the market preferred characteristics of vegetable types as indicated by the specifications of fresh producers companies (Sunripe Company, personal communication 2013). White Emergo had the shortest pod length of 15.9cm compared to the maximum length of 28cm realized in large scale farms when additional light is used .This therefore indicates that conditions in the field such as soil fertility and climatic conditions were unfavorable and may have influenced the expression of this trait.

4.5 Conclusion

The new developed runner bean lines were found to be highly vigorous when grown in cooler climatic conditons.The cooler climatic condition was also found to favour number of racemes formed. Adequate raceme formation was obtained in tempertaures between 14^0C to 20^0C. However, some lines showed potential of having adequate racemes under warmer conditions like Kabete.

The new runner bean lines can flower easily under the short- day photoperiods. Days to flowering among these lines were lesser by about 7 days compared to the imported variety (White Emergo). Nonetheless, even in same short photoperiods, cooler temperatures were found to prolong the number for days to 50% flowering in most lines than warmer temperatures.

Most runner bean lines showed potential of being resistant to field disease during the study.However, further evaluations in bean disease prone areas is recommended to ascertain the

recorded resistance. The pod yield of these lines was also promising for meeting market required grades.

In most breeding systems its not easy to combine high yield with markwt preffereed characteristics in one variety. However in this study, about 15 lines showed promising ability to be developed as short-day vegetable runner bean since they flower easily and adequately under natural day length and possess market preferred characteristics. Therefore, these lines can be selected for low input systems. Among the lines,seven lines KAB13-309-60, KAB13-312-135, KAB13-326-59, KAB13-331-65, KAB13-380-55, KAB13-446-5,KAB13-46-23, OL13-21-1 and SUB13-240-125 were selected at Ol Joro-orok and nine lines KAB13-312-135, KAB13-363-131, KAB13-380-55, KAB13-470-72, SUB13-114-77, SUB13-117-68 and SUB13-133-10 at Kabete respectively. The selected lines not only have high yields but are also disease resistant and produce much of Grade I and Grade II lines which are the premium grades in the market.

This study also shows evidence that White Emergo grown in short photoperiods especially under low input conditions has poor flowering, low pod yield, pod quality and is susceptible to diseases. This therefore, supports the view that this variety is not widely adapted and suitable only for high input systems where extended artificial light is used.

CHAPTER FIVE

SELECTION FOR IMPROVED SHORT-DAY GRAIN TYPE RUNNER BEAN

Abstract

Runner bean (*Phaseolus coccineus* L.) also known as butter bean, is grown in high altitudes of eastern Africa where common bean (*Phaseolus vulgaris* L.) is poorly adapted. Its productivity is poor because no improved short-day varieties are available. Farmers rely on low yielding landraces, which are susceptible to diseases. The objective of this study was to select improved short-day runner bean lines combining high grain yield potential with resistance to diseases suitable for cultivation under tropical conditions. One hundred thirty-nine $F_{6.8}$ lines were evaluated in a randomized complete block design with three replicates at Kabete (1860 m.a.s.l) and Ol Joro-Orok (2300 m.a.s.l) in 2013 and 2014. Five local landraces were used as checks. Data was collected on plant vigor, duration to 50% flowering, number of racemes, reaction to diseases, and grain yield. Scoring for plant vigour and diseases was based on 1 to 9, where 1-3 is resistant/vigorous, 4-6 intermediate and 7-9 susceptible/ poor vigour. Analysis of variance showed that there were significant differences for number of racemes per plant, reaction to diseases and grain yield. About 80% of the new locally developed lines flowered easily and had at least eight racemes per plant compared with the local landraces. Each raceme had 15 to 20 flowers. Major diseases observed were rust, common bacterial blight (CBB), bean common mosaic virus (BCMV) at Ol Joro-Orok, and powdery mildew at Kabete. CBB and BCMV were the most severe diseases at both sites. The new lines showed higher degree of resistance (scores of 1 to 3) to the three diseases. The mean grain yield at Kabete was 4426 kg ha^{-1} compared to 6523 kg ha^{-1} at Ol Joro-Orok. The new lines had an average yield advantage of up to 67% compared with local short-day landraces. The results indicated that new high yielding short-day runner bean varieties with resistance to major diseases and tropical adaptation can be developed from these lines.

Key words: butter bean, tropical adaptation, yield, diseases

5.1 Introduction

Grain legumes are rich in dietary proteins which compliment nutritional value of cereals (CGIAR, 2012). In Kenya, there has been a need to intensify productivity of underutilized legumes to enhance food security (Wanjekeche et al., 2007). Runner bean (*Phaseolus coccineus*), is one of the cultivated Phaseolus species offers a great opportunity as a grain legume in Africa. The crop is grown both for its dry grain and immature green pods as vegetable. Runner beancan be either bush type or climbing. Flowering occurs 30-60 days after planting and the crop can be harvested for green pods 80 to 90 days from planting, and 100-120 days for dry grain (Purseglove, 1987).

In Kenya, the grain runner bean is traditionally grown at elevations between 2000 and 2500 m.a.s.l in Nakuru and Nyandarua Counties with the white seeded variety commonly referred to as 'butter bean' dominating (Kahuro, 1990; Suttie, 1969).The white seeded variety is also grown in South Africa (Brink, 2006). Grain yield in Kenya has been estimated at 900 to1100 kg ha^{-1} (Kahuro, 1990). Seeds of runner beancan be broad-oblong, black, white, cream, brown or pink to purple speckled.

Runner bean is thought to have originated from uplands of Chiapas and Guatemala in Central America (Purse Glove, 1987; Westphal, 1974). However, the dates of introduction, distribution and early cultivation in Kenya are unknown, but farmers have cultivated it for subsistence in small plots for many years. The white seeded Kenyan variety flowers and sets pods easily but has poor yields (Kahuro, 1990; Kay, 1979). Most breeding work in Kenya for the last three decades has focused on common bean and other legumes (Kimani, 2009). Until recently, runner bean has received little research attention, not only in Kenya but also in eastern Africa, and probably, worldwide. As result, runner bean is among the underutilized grain legumes, with low per capita consumption in the Kenya and Africa at large.

Runner bean is of great potential as a grain legume, vegetable, fodder crop and as useful source of diversity for improvement of common bean (Singh, 2001). Consequently, this demands a revitalization of this crop and exploitation of its potential. Climbing runner bean have yield advantage over the bush types and occupy very little of the contemporary commercial acreage (CIAT, 2004). Owing to the fact that evaluations on runner bean have revealed the crop to have potentially valuable traits which are rare and nonexistent in common bean, there is need to improve the available germplasm (Santalla et al., 2004). These shortcomings led to the development of populations of short-day runner beanin 2004 by the University of Nairobi Bean program.These populations were advanced through a series of bulk selections up to $F_{6.8}$ generations. However, selection of runner bean lines combining high grain yield and are disease resistant is yet to be done (Kimani, 2009). The objective of this study therefore was to evaluate

and select locally adapted short-day runner bean lines that combine high grain yield and are resistant to diseases for smallholder farmers.

5.2 Materials and Methods

5.2.1 Plant Materials

The study materials were 142 $F_{6.8}$ lines which were initially developed in 2004 from crosses between five short-day local landraces (Kin 1, Kin 2, Kin 4, Kenya local and Nyeri) as male parents, and one female imported variety (White Emergo) .These landraces were selections from farmer' fields in Kinangop and Nyeri and hence the designation of names. Progenies from the crosses were advanced through bulk population method up to F_5 generation where selections began.

About 1154 short-day single plant selections were made from F_5 bulk populations and evaluated at Ol Joro-Orok, Subukia and Kabete Field Station during the 2009 long rain season. These single plant selections were used to establish progeny rows during the 2009 short rain season and families during 2010 long rain season. Selection within and among families continued up to $F_{6.8}$ generation which was constituted into a working collection used in this study. A total of 139 $F_{6.8}$ lines were used to establish pod-to- progeny rows for preliminary yield trials (PYT) during the 2013 long rain season at Kabete Field Station and Ol Joro-Orok. About 50 lines which had more than 30pods per plant were selected and evaluated in advanced yield trials (AYT) at Kabete and Ol Joro-Orok in 2014.However, the results show tables of means of 42 runner bean lines while the performance of 139 lines is presented in Appendix 6 and 7.

5.2.2 Trial sites

The field experiments were conducted at Kabete Field station and KALRO- Ol Joro-Orok for two seasons.

Kabete Field Station is located in Nairobi County at an altitude of 1840m above sea level. The area is in agro-ecological zone III (900-1860m.a.s.l) and has a bimodal rainfall pattern with peaks in April and November. The annual rainfall is about 1000mm which is received during long rains (March to May) and short rains (October to December).The site has a maximum and a minimum mean temperature of 24.3^{o}C and 13.7^{o}C, respectively. The dominant soil are humic nitisols soils which are very deep, well drained, dark reddish, deep friable clay type resistant to erosion (Jaetzold et al., 2006).

Ol Joro-Orok- KALRO station is located in Nyandarua County at an altitude of 2300m a.s.l. This site is in agro-ecological zone II (highland areas with 1980-2700m.a.s.l).The mean annual rainfall is 1000mm. However, reliability of rains is high from April until November. The mean maximum

temperatures are 22^{o}C and mean minimum temperatures are 10-16^{o}C .The dominant soils are planosols. These soils are deep, imperfectly drained, firm and very dark greyish brown in colour (Jaetzold et al., 2006).

5.2.3 Experimental design and crop husbandry

The experiments were conducted between 2013 and 2014 during long and short rain seasons. The first season was from April 2013 to Dec 2013 and second season from March to December 2014. In each season, experiments were laid out in a completely randomized block design with three replications. A plot comprised of a single row of 3m length. Within row spacing was 30cm. The spacing between rows was 50cm.Therefore a plot had10 plants. The test lines were planted using pod to progeny row method.

The crop was weeded when necessary. A string or stakes were used to support the plant whereby each individual plant was staked at Ol Joro-Orok or tied with a string at Kabete (at the base of the plant) to a top placed heavy weight wire suspended horizontally across the row. The wire was supported by sturdy wooden Eucalyptus poles on each side of the row. Insect pests were controlled by alternate application of Cyclone® (10% cypermethrin + 35% chlorpryphos) and Confidor® (imidacloprid) at the rate of 1.5ml L^{-1} after every two months. A total of 50 single plants selections that were highly vigorous (vigor score of 1-3), had more than thirty pods per plant and showed high resistance to predominant diseases were selected and planted in the second season. The pods from selected plants were left to dry in the field. Pods from each plant were harvested separately, counted, threshed, weighed and treated with insecticides. Seeds from selected were advanced to the next season.

5.2.4 Data collection

Data was collected on plant vigor, duration to 50% flowering, number of racemes, disease resistance and grain yield. Plant vigor was determined by sampling ten plants per plot and rating on basis of plant height, stability of stem and vegetative growth on a scale of 1 to 9, where 1=excellent vigor, 3=good vigor, 5= intermediate vigor, 7=very poor vigor. Duration to 50% flowering was recorded as the number of days from sowing to the date when 50% of plants had one or more open flowers.

The numbers of racemes were counted on a single plant basis at 1st and 2nd flowering stages. Counting of racemes for the second flowering was done only after the first flowers had formed pods. CIAT disease scale was used to score the reaction of genotypes to infection by common bacterial blight, powdery mildew, rust and bean common mosaic virus diseases. On this scale, a mean score of 1-3= resistant, 4-6= intermediate, and 7-9 susceptible (Table 5.1). Pods were

harvested at maturity stage and counted. The pods were also threshed and seeds dried then weighed to determine grain yield per plant and finally total yield per hectare.

Table 5.1: Scale used to evaluate the reaction of bean germplasm to fungal diseases.

Rating	Category	Description	Comments
1-3	Resistant	No visible symptom or light symptoms (2% of the leaf)	Germplasm useful as a parent or commercial variety.
4-6	Intermediate	Visibleand conspicuous symptoms (2-5% of the leaf) resulting only in limited economic damage.	Germplasm can be used as commercial variety or source of resistance to disease.
7-9	Susceptible	Severe to very severe symptoms (10-25% of the leaf) causing yield losses or plant death.	Germplasm in most cases not useful as parent or commercial variety

Source: van Schoonhoven and Pastor-Corrales, 1987

5.2.5 Data analysis

Quantitative data was subjected to analysis of variance (ANOVA) using Genstat statistical package, 13th edition (VSN international, 2011).The analysis was done separately for each site and year. The means were separated by Fisher's Protected Least Significant Difference method at 5 and 1% probability levels. Results of table of means are based on 44 lines however the performance of all the 114 $F_{6.8}$ lines is presented in Appendix 6 and 7.

5.3 Results

5.3.1 Weather conditions at experimental sites

The weather data was obtained from Kabete and Ol Joro-Orok meterological Stations. The mean temperatures were lower at Ol Joro-Orok than Kabete in both years (2013 and 2014). In 2013, mean monthly temperatures ranged from 13-16^{o}C at Ol Joro-Orok, and 16-28^{o}C at Kabete from planting to pod maturity as shown in Fig 5.1. Temperatures in 2014 were low at both locations and hence mean monthly temperatures ranged from 12-16^{o}C at Ol Joro-Orok and 16-19^{o}C at Kabete (Fig 5.1). The first and second flowering occurred between April and June in both years. Within these three months, mean temperatures were 16^{o}C at both sites in 2014, while in 2013 the mean temperature at Kabete was 24^{o}C compared to 15^{o}C at Ol Joro-orok.

In the first year (2013), Kabete received a total rainfall of 1139.9mm, while Ol Joro-orok had 1516mm in the same year from planting to pod maturity (Fig 5.2). The highest rainfall in 2013 was recorded in the month of April (508mm) at Kabete, and 295mm at Ol Joro-Orok. During the second year (2014), the total rainfall decreased at both sites but was well distributed throughout

the year. Kabete recorded 793mm compared with 823.4mm at Ol Joro-Orok in the second year. The highest rainfall in 2014 was experienced in the month of March at Kabete and in July and August at Ol Joro-Orok (Figure 5.2). At Kabete, a dry spell was experienced from the May to October with low rainfall not amounting to 40mm per month while such rainfall was observed in July to September in2014.

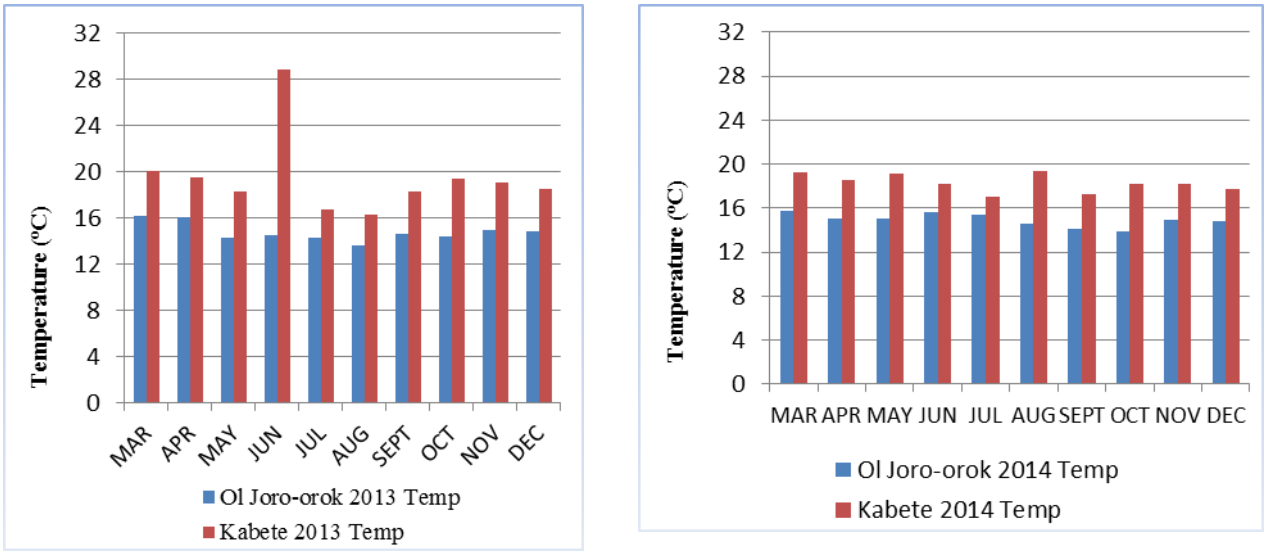


Figure 5.1: Mean monthly temperature for Kabete and Ol Joro-orok in 2013 and 2014

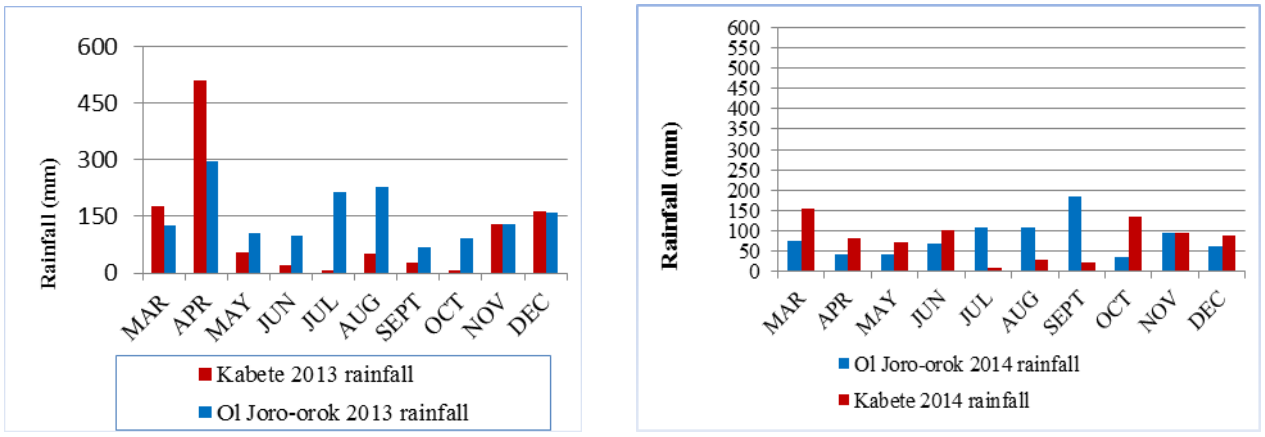


Figure 5. 2: Mean monthly rainfall for Kabete and Ol Joro-orok in 2013 and 2014

5.3.2 Plant Vigor

Significant genotypic differences in plant vigor were detected at Kabete during the first year and at Ol Joro-Orok in the second year (Appendix 13 and 14). The vigor of these genotypes ranged from 1 to 4 in both years and sites. About 80% of the genotypes were very vigorous with mean vigor scores of 1 to 3 at both sites and years (Table 5.2). Of the 42 genotypes evaluated, 19 and 28 genotypes were found to be the most vigorous at both sites in 2013 and 2014 respectively (Table 5.2). Genotypes were more vigorous (vigor score of 1 to 2) in the second year than in the first year

at both locations. In 2013, only five and two genotypes showed intermediate vigor score of 4 at Kabete and Ol Joro-Orok whereas in 2014 such intermediate vigor was recorded by two genotypes at both sites. Among the check varieties, Dwarf 1 and Dwarf 3 showed intermediate vigor score of 4 at Kabete in the first season, while Nyeri had vigor scores ranging from 1 to 3 in both years and at all sites (Table 5.2).

Table 5.2: Plant vigor scores of grain runner bean lines at Kabete and ol Joro-orok for two years

Plant vigor scores					
2013			**2014**		
Genotypes	**Kabete**	**Ol Joro-orok**	**Genotypes**	**Kabete**	**Ol Joro-orok**
KAB-OL-RB13-440-232	2.3	2.3	KAB-OL-RB-440-232/5	3.0	3.0
KAB-RB13-155-122	2.3	2.3	KAB-RB13-155-122/4	1.7	1.7
KAB-RB13-308-222	1.7	3.0	KAB-RB13-308-222/1	1.0	2.3
KAB-RB13-310-161	1.3	2.3	KAB-RB13-310-161/5	2.3	1.0
KAB-RB13-310-162	3.3	2.3	KAB-RB13-310-162/4	1.0	2.3
KAB-RB13-312-160	2.3	1.7	KAB-RB13-312-160/3	2.3	1.7
KAB-RB13-314-191	1.0	2.3	KAB-RB13-314-191/3	1.7	1.7
KAB-RB13-315-197	4.3	1.7	KAB-RB13-315-197/4	1.7	1.7
KAB-RB13-319-182	3.7	2.3	KAB-RB13-319-182/6	3.0	1.7
KAB-RB13-319-193	3.0	2.3	KAB-RB13-319-193/4	1.7	1.7
KAB-RB13-319-194	1.0	3.0	KAB-RB13-319-194/1	2.3	1.0
KAB-RB13-321-185	1.0	3.0	KAB-RB13-321-185/1	3.0	2.3
KAB-RB13-325-200	3.7	2.3	KAB-RB13-325-200/4	1.7	1.0
KAB-RB13-326-207	3.7	1.7	KAB-RB13-326-207/1	2.3	2.3
KAB-RB13-327-48	2.3	1.7	KAB-RB13-327-48/1	2.3	3.0
KAB-RB13-327-92	1.7	1.7	KAB-RB13-327-92/1	1.7	2.3
KAB-RB13-329-165	2.3	1.7	KAB-RB13-329-165/1	1.7	1.7
KAB-RB13-331-113	1.0	3.0	KAB-RB13-331-113/3	3.0	1.7
KAB-RB13-334-29	2.3	3.7	KAB-RB13-334-29/1	1.7	1.0
KAB-RB13-336-63	3.3	1.7	KAB-RB13-336-63/1	1.0	1.7
KAB-RB13-338-41	1.7	1.7	KAB-RB13-338-41/1	2.3	1.7
KAB-RB13-341-143	3.0	2.3	KAB-RB13-341-143/4	1.7	1.7
KAB-RB13-343-184	3.0	2.3	KAB-RB13-343-184/3	3.7	3.0
KAB-RB13-343-189	3.0	1.7	KAB-RB13-343-189/5A	1.7	2.3
KAB-RB13-364-212	1.7	3.7	KAB-RB13-364-212/2	1.0	1.0
KAB-RB13-37-16	1.7	1.7	KAB-RB13-37-16/1	1.0	1.7
KAB-RB13-379-148	1.7	1.7	KAB-RB13-379-148/1	1.0	2.3
KAB-RB13-396-210	3.0	1.7	KAB-RB13-396-210/1	2.3	1.7
KAB-RB13-399-219	2.3	2.3	KAB-RB13-399-219/5	3.0	1.0
KAB-RB13-426-84	1.7	3.0	KAB-RB13-426-84A/1	2.3	2.3
KAB-RB13-46-124	1.7	1.7	KAB-RB13-46-124/1	1.0	1.7
KAB-RB13-471-117	3.0	3.0	KAB-RB13-471-117/1	2.3	2.3

Table 5.2 (continued)

Plant vigor

	2013			2014	
Genotypes	**Kabete**	**Ol Joro-orok**	**Genotypes**	**Kabete**	**Ol Joro-orok**
KAB-RB13-62-9	2.3	2.3	KAB-RB13-62-9/2	1.0	3.0
KAB-RB13-85-18	3.7	1.7	KAB-RB13-85-18A/4	2.3	2.3
SUB-OL-RB13-177-3	1.7	1.7	SUB-OL-RB13-177-3/3	3.0	1.0
SUB-OL-RB13-226-251	3.0	2.3	SUB-OL-RB13-226-251/4	1.7	2.3
SUB-OL-RB13-275-248	1.0	3.0	SUB-OL-RB13-275-248/3	1.7	1.7
SUB-OL-RB13-275-249	1.7	1.7	SUB-OL-RB13-275-249/5	1.0	1.0
SUB-RB13-221-128	1.7	1.7	SUB-RB13-221-128/3	3.0	3.0
SUB-RB13-269-129	1.7	2.3	SUB-RB13-269-129/3	1.0	1.7
SUB-RB13-30A8-75	3.0	2.3	SUB-RB13-308-75/2	1.7	3.7
SUB-RB13-325-134	2.3	2.3	SUB-RB13-325-134/5	3.7	2.3
Checks			**Checks**		
Dwarf 1	4.3	3.7	Dwarf 1	3.7	2.3
Dwarf 3	3.7	2.7	Dwarf 3	1.7	2.3
Nyeri	2.3	3.0	Nyeri	2.3	1.7
Mean	2.9	2.2	Mean	2.13	1.98
CV (%)	57.2	55.4	CV (%)	75.2	71.4
$LSD_{0.05}$	2.2	1.9	$LSD_{0.05}$	2.6	2.3

5.3.3 Days to 50% flowering

There were significant differences ($P \leq 0.05$) among the genotypes for duration to flowering at both sites in the second year only (Appendix 13 and 14). In the first year, genotypes took 47-52 days to flower at Kabete, and 49-52 days to flower at Ol Joro-Orok in both years(Table 5.3). However in the second year, genotypes flowered earlier at Kabete (on average 43 days) and took longer to flower at Ol Joro-Orok (average of 55 days).

There was a considerable distinction in time to flowering among genotypes in the second season and time of flowering differed with more than seven days between the two sites (Table 5.3). Therefore, during the second year, the genotypes took 30-49 days to flower at Kabete and 51-58 days at Ol Joro-Orok. Among the checks, the dwarf genotypes flowered earlier with 30 days, while the climbing types such as Nyeri flowered in 38 days. Genotypes were grouped as early or late flowering based on the large variation of days to flowering in the year 2014. At Kabete, 10 genotypes were found to flower early within 33-40 days while 32 genotypes flowered late within 40-49 days. At Ol Joro-Orok, 15 genotypes were found to flower early in 50-55 days and 27 flowered late in 56-59 days. KAB-RB13-326-207/1, KAB-RB13-341-143/4, KAB-RB13-364-212/2, KAB-RB13-37-16/1, KAB-RB13-379-148/1, SUB-OL-RB13-248/3 and SUB-OL-RB13-275-248/5 were early flowering while 24 genotypes were late flowering at both sites.

Table 5.3: Days to 50% flowering of grain runner bean lines grown at two locations for two years

Days to 50% flowering					
2013			2014		
Genotypes	Kabete	Ol Joro-orok	Genotypes	Kabete	Ol Joro-orok
KAB-OL-RB13-440-232	49.0	50.0	KAB-OL-RB-440-232/5	47	56
KAB-RB13-155-122	49.0	50.7	KAB-RB13-155-122/4	43	53
KAB-RB13-308-222	51.7	50.0	KAB-RB13-308-222/1	45	58
KAB-RB13-310-161	50.7	50.7	KAB-RB13-310-161/5	46	56
KAB-RB13-310-162	49.0	50.7	KAB-RB13-310-162/4	44	57
KAB-RB13-312-160	47.0	50.0	KAB-RB13-312-160/3	46	58
KAB-RB13-314-191	51.3	51.0	KAB-RB13-314-191/3	44	56
KAB-RB13-315-197	49.7	50.7	KAB-RB13-315-197/4	45	52
KAB-RB13-319-182	50.3	50.7	KAB-RB13-319-182/6	48	58
KAB-RB13-319-193	51.3	50.0	KAB-RB13-319-193/4	48	56
KAB-RB13-319-194	50.0	51.0	KAB-RB13-319-194/1	47	58
KAB-RB13-321-185	52.0	50.7	KAB-RB13-321-185/1	41	55
KAB-RB13-325-200	49.7	50.0	KAB-RB13-325-200/4	48	57
KAB-RB13-326-207	50.7	51.0	KAB-RB13-326-207/1	35	52
KAB-RB13-327-48	51.7	49.0	KAB-RB13-327-48/1	46	58
KAB-RB13-327-92	49.7	48.7	KAB-RB13-327-92/1	49	57
KAB-RB13-329-165	49.7	50.0	KAB-RB13-329-165/1	44	55
KAB-RB13-331-113	50.7	48.3	KAB-RB13-331-113/3	47	54
KAB-RB13-334-29	50.3	50.0	KAB-RB13-334-29/1	49	59
KAB-RB13-336-63	49.3	49.3	KAB-RB13-336-63/1	44	55
KAB-RB13-338-41	50.0	50.3	KAB-RB13-338-41/1	34	56
KAB-RB13-341-143	50.0	50.7	KAB-RB13-341-143/4	38	54
KAB-RB13-343-184	49.3	50.3	KAB-RB13-343-184/3	47	57
KAB-RB13-343-189	49.3	50.0	KAB-RB13-343-189/5A	45	57
KAB-RB13-364-212	50.3	50.7	KAB-RB13-364-212/2	37	54
KAB-RB13-37-16	49.0	49.0	KAB-RB13-37-16/1	35	52
KAB-RB13-379-148	49.7	51.7	KAB-RB13-379-148/1	34	51
KAB-RB13-396-210	50.0	50.7	KAB-RB13-396-210/1	48	58
KAB-RB13-399-219	50.7	50.3	KAB-RB13-399-219/5	41	57
KAB-RB13-426-84	50.0	48.0	KAB-RB13-426-84A/1	45	58
KAB-RB13-46-124	49.7	51.0	KAB-RB13-46-124/1	42	56
KAB-RB13-471-117	49.0	49.3	KAB-RB13-471-117/1	47	57
KAB-RB13-522-73	50.7	49.7	KAB-RB13-522-73/1	44	56
KAB-RB13-62-9	52.0	50.0	KAB-RB13-62-9/2	48	56
KAB-RB13-85-18	50.0	50.0	KAB-RB13-85-18/4	42	56
SUB-OL-RB13-177-3	49.0	50.0	SUB-OL-RB13-177-3/3	42	59
SUB-OL-RB13-226-251	50.0	50.7	SUB-OL-RB13-226-251/4	39	56
SUB-OL-RB13-275-248	50.3	51.3	SUB-OL-RB13-275-248/3	34	55
SUB-OL-RB13-275-249	50.0	51.0	SUB-OL-RB13-275-249/5	33	55

Table 5.3(Continued)

Days to 50% flowering					
2013			**2014**		
Genotypes	**Kabete**	**Ol Joro-orok**	**Genotypes**	**Kabete**	**Ol Joro-orok**
SUB-RB13-221-128	49.0	49.3	SUB-RB13-221-128/3	48	55
SUB-RB13-269-129	49.0	49.7	SUB-RB13-269-129/3	39	52
SUB-RB13-308-75	49.7	49.0	SUB-RB13-308-75/2	48	58
SUB-RB13-325-134	50.7	48.7	SUB-RB13-325-134/5	45	54
Checks			**Checks**		
Dwarf 1	50.3	50.7	Dwarf 1	30	52
Dwarf 3	51.3	51.0	Dwarf 3	31	54
Nyeri	50.7	52.0	Nyeri	38	52
Kin 2	49.7	51.0	Kin 2	_	_
Kin 3	48.7	52.3	Kin 3	_	_
Mean	50.9	50.2	Mean	43	55
CV (%)	41.9	6.5	CV (%)	13	5
$LSD_{0.05}$	34.3	5.2	$LSD_{0.05}$	9	4

5.3.4 Raceme formation in 2013

There were significant differences among genotypes in formation of racemes at first and second flush of flowering at both sites except at Kabete in the second flowering (Appendix 13). The numbers of racemes were fewer at Kabete (1-3 racemes per plant) than Ol Joro-Orok at both flowering stages. There was poor flowering at Kabete in the second season and about 43% of genotypes did not form any raceme (Table 5.4). On the other hand, genotypes had more racemes at Ol Joro-Orok (5-7 racemes/plant on average) at first and second flowering. Apart from having at least 5 racemes per plant at Ol Joro-Orok in the first flush of flowering, the check local landraces generally formed fewer racemes (less than 3 racemes /plant) at Kabete and at both sites in the second flowering in the year 2013 (Table 5.4). It was also noted that the dwarf landraces did not flower at all during the second flushes of flowering at both sites.

Table 5.4: Number of racemes plant-^{1} during the first and second flush of flowering of grain runner bean lines grown at two locations in the year 2013.

2013					
Genotypes	**Numberof racemes plant^{-1} during first flowering**		**Genotypes**	**Number of racemes plant^{-1} during second flowering**	
	Kabete	**Ol Joro-orok**		**Kabete**	**Ol Joro-orok**
KAB-OL-RB-440-232	2	6	KAB-OL-RB-440-232	0	1
KAB-RB13-155-122	2	6	KAB-RB13-155-122	0	6
KAB-RB13-308-222	3	5	KAB-RB13-308-222	0	9
KAB-RB13-310-161	2	7	KAB-RB13-310-161	0	5
KAB-RB13-310-162	3	9	KAB-RB13-310-162	3	3
KAB-RB13-312-160	5	10	KAB-RB13-312-160	2	5
KAB-RB13-314-191	3	10	KAB-RB13-314-191	0	7
KAB-RB13-315-197	3	4	KAB-RB13-315-197	0	5
KAB-RB13-319-182	2	9	KAB-RB13-319-182	0	5
KAB-RB13-319-193	1	5	KAB-RB13-319-193	2	5
KAB-RB13-319-194	1	7	KAB-RB13-319-194	0	6
KAB-RB13-321-185	1	12	KAB-RB13-321-185	1	5
KAB-RB13-325-200	2	6	KAB-RB13-325-200	0	4
KAB-RB13-326-207	4	11	KAB-RB13-326-207	1	11
KAB-RB13-327-48	10	5	KAB-RB13-327-48	1	4
KAB-RB13-327-92	7	7	KAB-RB13-327-92	1	7
KAB-RB13-329-165	2	3	KAB-RB13-329-165	0	2
KAB-RB13-331-113	6	6	KAB-RB13-331-113	2	6
KAB-RB13-334-29	10	4	KAB-RB13-334-29	2	4
KAB-RB13-336-63	6	7	KAB-RB13-336-63	3	4
KAB-RB13-338-41	4	6	KAB-RB13-338-41	3	5
KAB-RB13-341-143	3	9	KAB-RB13-341-143	0	7
KAB-RB13-343-184	3	9	KAB-RB13-343-184	0	10
KAB-RB13-343-189	2	9	KAB-RB13-343-189	0	7
KAB-RB13-364-212	3	8	KAB-RB13-364-212	0	6
KAB-RB13-37-16	5	10	KAB-RB13-37-16	2	6
KAB-RB13-379-148	2	10	KAB-RB13-379-148	2	6
KAB-RB13-396-210	3	6	KAB-RB13-396-210	0	5
KAB-RB13-399-219	2	6	KAB-RB13-399-219	2	7
KAB-RB13-426-84	7	6	KAB-RB13-426-84	2	6
KAB-RB13-46-124	3	8	KAB-RB13-46-124	0	5
KAB-RB13-471-117	8	6	KAB-RB13-471-117	2	4
KAB-RB13-522-73	5	4	KAB-RB13-522-73	2	6
KAB-RB13-62-9	4	9	KAB-RB13-62-9	0	2
KAB-RB13-85-18	1	6	KAB-RB13-85-18	1	2
SUB-OL-RB13-177-3	2	5	SUB-OL-RB13-177-3	1	7
SUB-OL-RB13-226-251	2	6	SUB-OL-RB13-226-251	0	4
SUB-OL-RB13-275-248	4	8	SUB-OL-RB13-275-248	1	5
SUB-RB13-221-128	7	4	SUB-RB13-221-128	2	6

Table 5.4 (continued)

	2013				
Genotypes	**Numberof racemes plant^{-1} during first flowering**		**Genotypes**	**Number of racemes plant^{-1} during second flowering**	
	Kabete	**Ol Joro-orok**		**Kabete**	**Ol Joro-orok**
SUB-RB13-269-129	7	7	SUB-RB13-269-129	1	8
SUB-RB13-308-75	5	8	SUB-RB13-308-75	1	4
SUB-RB13-325-134	8	7	SUB-RB13-325-134	2	8
Checks			**Checks**		
Dwarf 1	3	7	Dwarf 1	0	0
Dwarf 3	1	4	Dwarf 3	0	0
Kin 2	1	5	Kin 2	0	3
Kin 3	1	5	Kin 3	1	2
Nyeri	1	9	Nyeri	0	1
Mean	2.5	7	Mean	1	5
CV (%)	87.9	47	CV (%)	62	65
$LSD_{0.05}$	3.6	5.3	$LSD_{0.05}$	2.0	6

5.3.5 Raceme formation in 2014

There were significant differences in formation of racemes during the first and second flush of flowering at both sites (Appendix 14). Over 60% of genotypes formed significantly more racemes (more than 10 racemes /plant) than the local landraces at both sites in the second flowering stage (Table 5.5). The numbers of racemes formed during the first flush were higher at Kabete (on average 6 racemes plant^{-1}) than at Ol Joro-0rok (4 racemes plant^{-1}). Interestingly, genotypes had more racemes (9 racemes plant^{-1}) at both sites in the second stage of flowering (Table 5.5).

In the first flowering, 16 genotypes formed at least 5 racemes per plant whereas 37 genotypes had more than 8 racemes per plant in the second flowering at both sites. There were variations in flowering among the local landraces. Dwarfs genotypes flowered well at Kabete in the first flush and at Ol Joro-Orok in the second flush. Likewise, Nyeri formed at least six racemes per plant in both flowering stages and at both sites. Nonetheless, these dwarfs flowered poorly at Kabete in the second flowering and at Ol Joro-Orok in the first flowering (Table 5.5). Kin 2 and Kin 3 did not germinate in the second year hence no racemes were recorded.

Table 5. 5: Number of racemes plant-[1] formed during the first and second flush of flowering of grain runner bean lines grown at two locations in 2014

2014					
Genotypes	**Numberof racemes/plant duringthe first flowering**		**Genotypes**	**Number of racemes/plant during the second flowering**	
	Kabete	**Ol Joro-orok**		**Kabete**	**Ol Joro-orok**
KAB-OL-RB-440-232/5	4	8	KAB-OL-RB-440-232/5	8	8
KAB-RB13-155-122/4	8	3	KAB-RB13-155-122/4	8	9
KAB-RB13-308-222/1	5	2	KAB-RB13-308-222/1	10	10
KAB-RB13-310-161/5	6	5	KAB-RB13-310-161/5	8	7
KAB-RB13-310-162/4	8	4	KAB-RB13-310-162/4	9	13
KAB-RB13-312-160/3	7	4	KAB-RB13-312-160/3	9	9
KAB-RB13-314-191/3	5	4	KAB-RB13-314-191/3	9	10
KAB-RB13-315-197/4	6	6	KAB-RB13-315-197/4	13	6
KAB-RB13-319-182/6	5	3	KAB-RB13-319-182/6	11	9
KAB-RB13-319-193/4	7	3	KAB-RB13-319-193/4	8	11
KAB-RB13-319-194/1	4	6	KAB-RB13-319-194/1	9	8
KAB-RB13-321-185/1	8	2	KAB-RB13-321-185/1	13	10
KAB-RB13-325-200/4	5	2	KAB-RB13-325-200/4	6	12
KAB-RB13-326-207/1	11	7	KAB-RB13-326-207/1	12	7
KAB-RB13-327-48/1	5	3	KAB-RB13-327-48/1	11	11
KAB-RB13-327-92/1	9	3	KAB-RB13-327-92/1	11	10
KAB-RB13-329-165/1	6	1	KAB-RB13-329-165/1	13	9
KAB-RB13-331-113/3	6	5	KAB-RB13-331-113/3	8	9
KAB-RB13-334-29/1	4	4	KAB-RB13-334-29/1	7	13
KAB-RB13-336-63/1	4	2	KAB-RB13-336-63/1	11	9
KAB-RB13-338-41/1	8	5	KAB-RB13-338-41/1	9	14
KAB-RB13-341-143/4	9	4	KAB-RB13-341-143/4	13	7
KAB-RB13-343-184/3	8	7	KAB-RB13-343-184/3	14	12
KAB-RB13-343-189/5A	8	4	KAB-RB13-343-189/5A	10	14
KAB-RB13-364-212/2	8	5	KAB-RB13-364-212/2	10	7
KAB-RB13-37-16/1	5	3	KAB-RB13-37-16/1	8	7
KAB-RB13-379-148/1	10	6	KAB-RB13-379-148/1	9	8
KAB-RB13-396-210/1	7	8	KAB-RB13-396-210/1	10	9
KAB-RB13-399-219/5	7	5	KAB-RB13-399-219/5	12	10
KAB-RB13-426-84A/1	7	3	KAB-RB13-426-84A/1	7	8
KAB-RB13-46-124/1	7	4	KAB-RB13-46-124/1	8	11
KAB-RB13-471-117/1	6	5	KAB-RB13-471-117/1	7	9
KAB-RB13-522-73/1	3	1	KAB-RB13-522-73/1	8	14
KAB-RB13-62-9/2	5	4	KAB-RB13-62-9/2	5	9
KAB-RB13-85-18A/4	7	2	KAB-RB13-85-18A/4	8	12
SUB-OL-RB13-177-3/3	7	2	SUB-OL-RB13-177-3/3	6	11
SUB-OL-RB13-226-251/4	4	3	SUB-OL-RB13-226-251/4	11	12
SUB-OL-RB13-275-248/3	10	4	SUB-OL-RB13-275-248/3	8	8

Table 5.5 (continued)

2014					
Genotypes	**Numberof racemes/plant duringthe first flowering**		**Genotypes**	**Number of racemes/plant during the second flowering**	
	Kabete	**Ol Joro-orok**		**Kabete**	**Ol Joro-orok**
SUB-RB13-221-128/3	3	3	SUB-RB13-221-128/3	5	9
SUB-RB13-269-129/3	7	6	SUB-RB13-269-129/3	12	9
SUB-RB13-308-75/2	4	2	SUB-RB13-308-75/2	10	13
SUB-RB13-325-134/5	5	5	SUB-RB13-325-134/5	10	8
Checks			**Checks**		
Dwarf 1	7	1	Dwarf 1	0	7
Dwarf 3	12	3	Dwarf 3	0	18
Kin 2	_	_	Kin 2	_	_
Kin 3	_	_	Kin 3	_	_
Nyeri	7	6	Nyeri	9	8
Mean	6.12	3.94	Mean	8.2	9.37
CV (%)	49.9	52.4	CV (%)	43.9	36.4
$LSD_{0.05}$	4.93	3.4	$LSD_{0.05}$	5.81	5.52

5.3.6 Reaction of genotypes to rust

The genotypes' reaction to rust infection had a significant effect at Ol Joro-orok in the first year and at Kabete in the second year (Appendix 13 and 14). The evaluated genotypes showed scores of 1 to 3 at both sites and years. Among the developed runner beanlines, moderate resistance to rust was recorded in KAB-RB13-379-148/1 at Kabete in the second year (Table 5.6). Similarly, the local landraces showed scores of 1 to 3 to rust in both years and sites as shown in Table 5.6 except in the second season where Dwarf 1 and had intermediate resistance at Kabete (Figure 5.3A).

Table 5.6: Reaction of grain runner bean lines to rust at two locations over two years

Rust scores					
2013			**2014**		
Genotypes	**Kabete**	**Ol Joro-orok**	**Genotypes**	**Kabete**	**Ol Joro-orok**
KAB-OL-RB13-440-232	1.0	1.0	KAB-OL-RB-440-232/5	1.7	3.0
KAB-RB13-155-122	1.0	1.0	KAB-RB13-155-122/4	1.3	2.3
KAB-RB13-308-222	1.0	1.0	KAB-RB13-308-222/1	1.7	2.7
KAB-RB13-310-161	1.0	1.0	KAB-RB13-310-161/5	2.3	2.3
KAB-RB13-310-162	1.0	1.0	KAB-RB13-310-162/4	1.0	2.0
KAB-RB13-312-160	2.0	1.0	KAB-RB13-312-160/3	2.0	2.3
KAB-RB13-314-191	1.3	1.0	KAB-RB13-314-191/3	1.3	2.0

Table 5.6 (continued)

Rust scores					
	2013			2014	
Genotypes	**Kabete**	**Ol Joro-orok**	**Genotypes**	**Kabete**	**OJK**
KAB-RB13-315-197	1.0	1.0	KAB-RB13-315-197/4	2.3	1.7
KAB-RB13-319-182	1.0	1.3	KAB-RB13-319-182/6	1.3	2.0
KAB-RB13-319-193	1.0	1.3	KAB-RB13-319-193/4	3.0	2.3
KAB-RB13-319-194	1.0	2.3	KAB-RB13-319-194/1	1.0	2.7
KAB-RB13-321-185	1.0	1.0	KAB-RB13-321-185/1	1.7	1.7
KAB-RB13-325-200	1.0	1.0	KAB-RB13-325-200/4	2.3	3.0
KAB-RB13-326-207	1.7	1.0	KAB-RB13-326-207/1	1.0	1.7
KAB-RB13-327-48	1.7	1.7	KAB-RB13-327-48/1	1.0	3.3
KAB-RB13-327-92	1.7	1.7	KAB-RB13-327-92/1	1.3	3.0
KAB-RB13-329-165	1.0	1.0	KAB-RB13-329-165/1	1.3	2.3
KAB-RB13-331-113	1.7	1.7	KAB-RB13-331-113/3	1.7	3.0
KAB-RB13-334-29	1.3	3.0	KAB-RB13-334-29/1	1.7	3.7
KAB-RB13-336-63	2.0	1.7	KAB-RB13-336-63/1	2.3	2.3
KAB-RB13-338-41	1.7	1.7	KAB-RB13-338-41/1	1.7	2.7
KAB-RB13-341-143	1.0	1.0	KAB-RB13-341-143/4	1.7	3.0
KAB-RB13-343-184	1.0	1.0	KAB-RB13-343-184/3	1.3	2.0
KAB-RB13-343-189	1.0	1.0	KAB-RB13-343-189/5A	1.3	1.3
KAB-RB13-364-212	1.0	1.3	KAB-RB13-364-212/2	1.3	2.7
KAB-RB13-37-16	2.7	1.7	KAB-RB13-37-16/1	2.3	1.7
KAB-RB13-379-148	1.7	1.0	KAB-RB13-379-148/1	4.7	2.3
KAB-RB13-396-210	1.7	1.0	KAB-RB13-396-210/1	1.0	2.7
KAB-RB13-399-219	1.3	1.0	KAB-RB13-399-219/5	2.0	1.7
KAB-RB13-426-84	1.7	1.7	KAB-RB13-426-84A/1	1.0	3.3
KAB-RB13-46-124	1.0	1.0	KAB-RB13-46-124/1	1.3	2.3
KAB-RB13-471-117	1.7	1.7	KAB-RB13-471-117/1	1.7	2.3
KAB-RB13-522-73	1.7	1.7	KAB-RB13-522-73/1	1.7	1.0
KAB-RB13-62-9	1.0	1.0	KAB-RB13-62-9/2	2.0	1.7
KAB-RB13-85-18	1.0	1.7	KAB-RB13-85-18A/4	1.3	2.3
SUB-OL-RB13-177-3	1.0	1.0	SUB-OL-RB13-177-3/3	1.3	3.0
SUB-OL-RB13-226-251	1.0	1.0	SUB-OL-RB13-226-251/4	1.0	2.3
SUB-OL-RB13-275-248	1.0	1.0	SUB-OL-RB13-275-248/3	2.0	2.7
SUB-OL-RB13-275-249	1.0	1.0	SUB-OL-RB13-275-249/5	1.0	2.3
SUB-RB13-221-128	1.7	2.0	SUB-RB13-221-128/3	1.3	2.7
SUB-RB13-269-129	1.7	1.7	SUB-RB13-269-129/3	1.0	3.0
SUB-RB13-308-75	1.7	2.3	SUB-RB13-308-75/2	1.0	2.3
SUB-RB13-325-134	1.3	1.7	SUB-RB13-325-134/5	2.0	2.3
Checks			**Checks**		
Dwarf 1	1.3	1.7	Dwarf 1	5.0	3.3
Dwarf 3	1.0	1.0	Dwarf 3	3.0	3.3
Nyeri	1.3	1.0	Nyeri	3.3	3.0
Kin 2	1.0	1.7	Kin 2	_	_

Kin 3	1.0	1.0	Kin 3	_	_
Mean	1.2	1.4	Mean	1.36	2.4
CV (%)	14.9	52.5	CV (%)	42.9	58.7
$LSD_{0.05}$	0.69	1.2	$LSD_{0.05}$	0.94	2.30

5.3.7 Reaction of genotypes to common bacterial blight

The genotypes varied significantly to infection by common bacterial blight infection at Kabete in both years (Appendix 13 and 14). Genotypes at Ol Joro-Orok did not show significant differences. About two thirds of the genotypes exhibited scores of 1 to 2 to common bacterial blight as indicated in Table 5.7.Intermediate resistance (score of 4 to 5) was exhibited by KAB-RB13-308-222 and KAB-RB13-426-84 in the first year at Ol Joro-Orok. The local landraces were also recorded scores of 1 to 3 at both sites and locations (Table 5.7).

Table 5.7 Reaction of grain runner bean lines to common bacterial blight infection at two sites for two years.

Common bacterial blight mean scores					
2013			**2014**		
Genotypes	**Ol Joro-Orok**	**Kabete**	**Genotypes**	**Kabete**	**Ol Joro-Orok**
KAB-OL-RB13-440-232	2.0	1.0	KAB-OL-RB-440-232/5	1.7	1.3
KAB-RB13-155-122	1.7	1.0	KAB-RB13-155-122/4	1.3	2.0
KAB-RB13-308-222	3.7	1.0	KAB-RB13-308-222/1	1.3	2.3
KAB-RB13-310-161	1.3	1.0	KAB-RB13-310-161/5	1.0	2.3
KAB-RB13-310-162	1.2	1.0	KAB-RB13-310-162/4	2.3	2.0
KAB-RB13-312-160	2.0	2.7	KAB-RB13-312-160/3	2.3	1.7
KAB-RB13-314-191	2.0	1.7	KAB-RB13-314-191/3	1.0	1.7
KAB-RB13-315-197	1.7	1.0	KAB-RB13-315-197/4	1.0	3.0
KAB-RB13-319-182	2.0	1.0	KAB-RB13-319-182/6	2.0	2.0
KAB-RB13-319-193	3.0	1.0	KAB-RB13-319-193/4	2.0	2.3
KAB-RB13-319-194	2.7	1.0	KAB-RB13-319-194/1	1.3	2.0
KAB-RB13-321-185	1.3	1.0	KAB-RB13-321-185/1	1.7	2.3
KAB-RB13-325-200	3.0	1.7	KAB-RB13-325-200/4	1.0	1.3
KAB-RB13-326-207	2.3	1.0	KAB-RB13-326-207/1	1.7	2.3
KAB-RB13-327-48	2.7	1.7	KAB-RB13-327-48/1	2.0	1.3
KAB-RB13-327-92	2.3	1.3	KAB-RB13-327-92/1	1.7	2.3
KAB-RB13-329-165	1.7	1.0	KAB-RB13-329-165/1	1.0	2.0
KAB-RB13-331-113	1.7	1.3	KAB-RB13-331-113/3	1.0	2.3
KAB-RB13-334-29	2.0	1.7	KAB-RB13-334-29/1	2.0	2.3
KAB-RB13-336-63	2.3	2.3	KAB-RB13-336-63/1	1.0	2.3
KAB-RB13-338-41	2.7	1.7	KAB-RB13-338-41/1	1.0	2.0
KAB-RB13-341-143	1.3	1.3	KAB-RB13-341-143/4	1.0	2.7
KAB-RB13-343-184	1.7	1.0	KAB-RB13-343-184/3	2.0	2.7
KAB-RB13-343-189	2.3	1.0	KAB-RB13-343-189/5A	1.3	3.0
KAB-RB13-364-212	1.7	1.7	KAB-RB13-364-212/2	1.3	1.7
KAB-RB13-37-16	2.3	1.7	KAB-RB13-37-16/1	1.0	2.3

Table 5.7 (continued)

Common bacterial blight mean scores					
	2013			2014	
Genotypes	**Ol Joro-Orok**	**Kabete**	**Genotypes**	**Kabete**	**Ol Joro-Orok**
KAB-RB13-379-148	1.3	1.0	KAB-RB13-379-148/1	1.0	2.0
KAB-RB13-396-210	2.3	1.0	KAB-RB13-396-210/1	3.0	2.7
KAB-RB13-399-219	2.0	1.0	KAB-RB13-399-219/5	1.0	1.7
KAB-RB13-426-84	4.7	2.3	KAB-RB13-426-84A/1	1.7	2.3
KAB-RB13-46-124	2.3	1.0	KAB-RB13-46-124/1	1.0	2.3
KAB-RB13-471-117	2.3	1.3	KAB-RB13-471-117/1	2.3	1.7
KAB-RB13-522-73	1.7	1.7	KAB-RB13-522-73/1	1.0	2.0
KAB-RB13-62-9	2.0	1.0	KAB-RB13-62-9/2	2.0	3.0
KAB-RB13-85-18	2.3	1.7	KAB-RB13-85-18A/4	1.3	3.0
SUB-OL-RB13-177-3	1.7	1.0	SUB-OL-RB13-177-3/3	2.3	2.0
SUB-OL-RB13-226-251	1.7	1.0	SUB-OL-RB13-226-251/4	1.7	1.0
SUB-OL-RB13-275-248	1.7	1.0	SUB-OL-RB13-275-248/3	1.3	2.0
SUB-OL-RB13-275-249	2.0	1.0	SUB-OL-RB13-275-249/5	1.3	2.0
SUB-RB13-221-128	2.3	1.7	SUB-RB13-221-128/3	3.0	2.3
SUB-RB13-269-129	3.3	1.7	SUB-RB13-269-129/3	2.0	2.3
SUB-RB13-308-75	2.3	1.3	SUB-RB13-308-75/2	1.0	3.0
SUB-RB13-325-134	3.0	2.0	SUB-RB13-325-134/5	1.3	2.7
Checks			**Checks**		
Dwarf 1	3.3	1.0	Dwarf 1	2.3	2.0
Dwarf 3	3.3	1.0	Dwarf 3	1.3	2.0
Nyeri	2.3	1.0	Nyeri	2.3	3.3
Kin 2	2.3	1.0	Kin 2	_	_
Kin 3	3.0	1.0	Kin 3	_	_
Mean	1.1	2.3	Mean	1.19	2.21
CV (%)	27.6	42.3	CV (%)	36.9	52.2
$LSD_{0.05}$	0.69	1.6	$LSD_{0.05}$	0.71	1.87

5.3.8 Reaction of genotypes to powdery mildew

Powdery mildew symptoms were prevalent at Kabete and therefore disease evaluation was done at this site only (Appendix 13 and 14). There were significant differences among genotypes in reaction to powdery mildew infection in both seasons at Kabete (Table 5.8 and figure 5.3B). More than 90 % of the genotypes were rated to have scores of 1 to 3 to powdery mildew. About 10% of genotypes showed intermediate resistance with a score of 6. The local landraces also had scores of 1 to 3 at both sites and seasons. However, among the landraces; Dwarf 1 and Nyeri were greatly infected by powdery mildews (score of 5 to 6) at Kabete in the second year (Table 5.8).

Table 5.8: Reaction of grain runner bean lines to powdery mildew infection at Kabete in two years.

Mean scores of powdery mildew			
2013		**2014**	
Genotypes	**scores**	**Genotypes**	**scores**
KAB-OL-RB13-440-232	1.7	KAB-OL-RB-440-232/5	3.0
KAB-RB13-155-122	1.0	KAB-RB13-155-122/4	1.7
KAB-RB13-308-222	2.3	KAB-RB13-308-222/1	1.7
KAB-RB13-310-161	1.0	KAB-RB13-310-161/5	3.0
KAB-RB13-310-162	1.3	KAB-RB13-310-162/4	2.0
KAB-RB13-312-160	2.7	KAB-RB13-312-160/3	3.7
KAB-RB13-314-191	2.3	KAB-RB13-314-191/3	2.0
KAB-RB13-315-197	1.0	KAB-RB13-315-197/4	2.0
KAB-RB13-319-182	1.0	KAB-RB13-319-182/6	2.7
KAB-RB13-319-193	2.3	KAB-RB13-319-193/4	2.3
KAB-RB13-319-194	1.0	KAB-RB13-319-194/1	2.0
KAB-RB13-321-185	1.0	KAB-RB13-321-185/1	2.0
KAB-RB13-325-200	1.0	KAB-RB13-325-200/4	1.3
KAB-RB13-326-207	1.0	KAB-RB13-326-207/1	3.7
KAB-RB13-327-48	1.7	KAB-RB13-327-48/1	2.0
KAB-RB13-327-92	3.7	KAB-RB13-327-92/1	2.3
KAB-RB13-329-165	1.0	KAB-RB13-329-165/1	3.0
KAB-RB13-331-113	4.7	KAB-RB13-331-113/3	3.0
KAB-RB13-334-29	3.0	KAB-RB13-334-29/1	3.3
KAB-RB13-336-63	3.0	KAB-RB13-336-63/1	3.7
KAB-RB13-338-41	1.0	KAB-RB13-338-41/1	2.3
KAB-RB13-341-143	1.0	KAB-RB13-341-143/4	3.0
KAB-RB13-343-184	1.0	KAB-RB13-343-184/3	2.7
KAB-RB13-343-189	1.0	KAB-RB13-343-189/5A	2.0
KAB-RB13-364-212	1.0	KAB-RB13-364-212/2	2.0
KAB-RB13-37-16	2.3	KAB-RB13-37-16/1	2.3
KAB-RB13-379-148	4.3	KAB-RB13-379-148/1	1.7
KAB-RB13-396-210	1.0	KAB-RB13-396-210/1	2.7
KAB-RB13-399-219	1.3	KAB-RB13-399-219/5	2.3
KAB-RB13-426-84	1.0	KAB-RB13-426-84A/1	2.3
KAB-RB13-46-124	1.0	KAB-RB13-46-124/1	2.7
KAB-RB13-471-117	1.7	KAB-RB13-471-117/1	3.3
KAB-RB13-522-73	1.7	KAB-RB13-522-73/1	2.7
KAB-RB13-62-9	1.0	KAB-RB13-62-9/2	2.0
KAB-RB13-85-18	1.0	KAB-RB13-85-18A/4	2.0
SUB-OL-RB13-177-3	4.3	SUB-OL-RB13-177-3/3	2.0
SUB-OL-RB13-226-251	1.0	SUB-OL-RB13-226-251/4	2.3
SUB-OL-RB13-275-248	1.3	SUB-OL-RB13-275-248/3	3.3
SUB-OL-RB13-275-249	1.0	SUB-OL-RB13-275-249/5	2.3

Table 5.8 (continued)

Mean scores of powdery mildew			
	2013		**2014**
SUB-RB13-221-128	1.3	SUB-RB13-221-128/3	2.0
SUB-RB13-269-129	1.3	SUB-RB13-269-129/3	2.0
SUB-RB13-308-75	1.7	SUB-RB13-308-75/2	2.3
SUB-RB13-325-134	1.7	SUB-RB13-325-134/5	3.3
Checks		**Checks**	
Dwarf 1	2.7	Dwarf 1	5.7
Dwarf 3	1.0	Dwarf 3	3.3
Nyeri	3.3	Nyeri	5.0
Kin 2	2.3	Kin 2	_
Kin 3	1.3	Kin 3	_
Mean	1.6	Mean	2.32
CV (%)	83.4	CV (%)	32.4
$LSD_{0.05}$	2.2	$LSD_{0.05}$	1.21

5.3.9 Reaction of genotypes to Bean Common Mosaic Virus

The symptoms of bean common mosaic virus (BCMV) were observed at Ol Joro-Orok and not Kabete. There were no significant effects among genotypes reaction to the disease in both years (Appendix 13 and 14). Disease scores varied from 2 to 4 in 2013 and from 2 to 5 in 2014. Seventy nine percentof genotypes recorded scores of 1 to 3 in during the first year compared to 70% in the second year (Table 5.9). About 15% of genotypes showed intermediate resistance (scores of 4-6) in the first year. This intermediate resistance increased to 30% during the second year. Among the local checks, Kin 2 and Kin 3 showed intermediate resistance (scores of 4) in the first year. However, the two dwarf checks and Nyeri 1 showed scores of 1 to 3 in both years (Table 5.9).

Table 5.9. Reaction of grain runner bean lines to Bean Common Mosaic Virus at Ol Joro-Orok for two years

Mean scores of Bean Common Mosaic virus			
2013		**2014**	
Genotypes	**Scores**	**Genotypes**	**Scores**
KAB-OL-RB13-440-232	3.0	KAB-OL-RB13-440-232/5	3.7
KAB-RB13-155-122	4.3	KAB-RB13-155-122/4	4.0
KAB-RB13-308-222	2.7	KAB-RB13-308-222/1	4.0
KAB-RB13-310-161	2.7	KAB-RB13-310-161/5	3.7
KAB-RB13-310-162	2.3	KAB-RB13-310-162/4	3.0
KAB-RB13-312-160	3.0	KAB-RB13-312-160/3	3.7
KAB-RB13-314-191	3.0	KAB-RB13-314-191/3	3.3
KAB-RB13-315-197	2.7	KAB-RB13-315-197/4	4.0
KAB-RB13-319-182	3.0	KAB-RB13-319-182/6	2.7
KAB-RB13-319-193	2.3	KAB-RB13-319-193/4	3.0

Table 5.9 (continued)

	Mean scores of Bean Common Bacterial blight		
	2013		**2014**
KAB-RB13-319-194	3.3	KAB-RB13-319-194/1	5.0
KAB-RB13-321-185	2.7	KAB-RB13-321-185/1	2.3
KAB-RB13-325-200	3.0	KAB-RB13-325-200/4	2.7
KAB-RB13-326-207	3.0	KAB-RB13-326-207/1	4.0
KAB-RB13-327-48	4.3	KAB-RB13-327-48/1	3.3
KAB-RB13-327-92	3.7	KAB-RB13-327-92/1	4.0
KAB-RB13-329-165	2.7	KAB-RB13-329-165/1	3.0
KAB-RB13-331-113	2.3	KAB-RB13-331-113/3	2.0
KAB-RB13-334-29	3.7	KAB-RB13-334-29/1	2.3
KAB-RB13-336-63	3.7	KAB-RB13-336-63/1	3.0
KAB-RB13-338-41	3.0	KAB-RB13-338-41/1	2.7
KAB-RB13-341-143	3.0	KAB-RB13-341-143/4	2.0
KAB-RB13-343-184	3.0	KAB-RB13-343-184/3	2.0
KAB-RB13-343-189	3.0	KAB-RB13-343-189/5A	2.3
KAB-RB13-364-212	3.0	KAB-RB13-364-212/2	3.0
KAB-RB13-37-16	3.0	KAB-RB13-37-16/1	2.0
KAB-RB13-379-148	3.0	KAB-RB13-379-148/1	3.0
KAB-RB13-396-210	3.0	KAB-RB13-396-210/1	4.7
KAB-RB13-399-219	3.0	KAB-RB13-399-219/5	4.3
KAB-RB13-426-84	3.3	KAB-RB13-426-84A/1	3.3
KAB-RB13-46-124	3.0	KAB-RB13-46-124/1	3.7
KAB-RB13-471-117	3.7	KAB-RB13-471-117/1	2.0
KAB-RB13-522-73	3.7	KAB-RB13-522-73/1	2.3
KAB-RB13-62-9	3.0	KAB-RB13-62-9/2	3.3
KAB-RB13-85-18	3.0	KAB-RB13-85-18A/4	2.7
SUB-OL-RB13-177-3	2.3	SUB-OL-RB13-177-3/3	2.0
SUB-OL-RB13-226-251	3.0	SUB-OL-RB13-226-251/4	2.3
SUB-OL-RB13-275-248	3.0	SUB-OL-RB13-275-248/3	3.3
SUB-OL-RB13-275-249	3.0	SUB-OL-RB13-275-249/5	3.3
SUB-RB13-221-128	3.7	SUB-RB13-221-128/3	3.3
SUB-RB13-269-129	3.0	SUB-RB13-269-129/3	2.0
SUB-RB13-308-75	2.3	SUB-RB13-308-75/2	2.3
SUB-RB13-325-134	2.3	SUB-RB13-325-134/5	2.7
Checks		**Checks**	
Dwarf 1	3.0	Dwarf 1	3.3
Dwarf 3	3.0	Dwarf 3	3.0
Nyeri	3.0	Nyeri	3.0
Kin 2	3.7	Kin 2	_
Kin 3	3.7	Kin 3	_
Mean	3.0	Mean	3.03
CV (%)	34.0	CV (%)	51.8
$LSD_{0.05}$	0.99	$LSD_{0.05}$	2.54

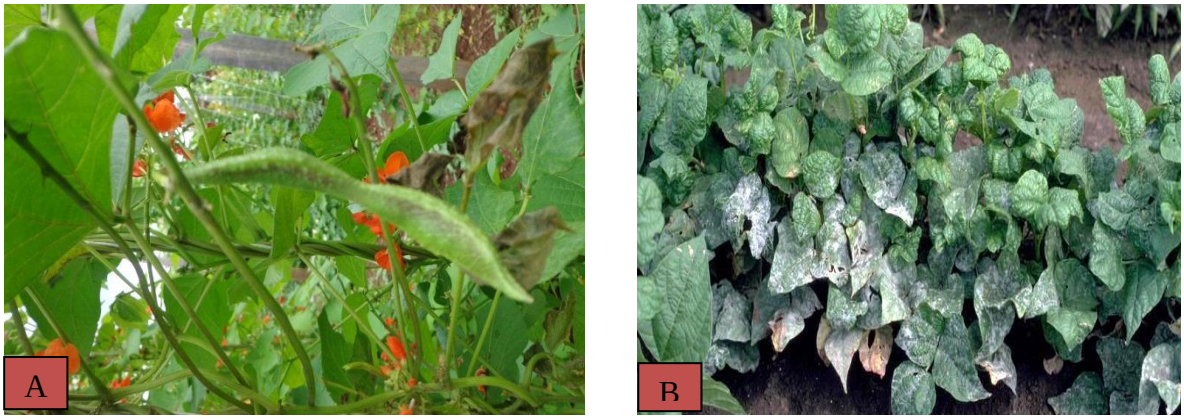


Figure 5. 3: A) Rust infection (russetting) on pods and leaves B) Dwarf 1 variety infected by powdery mildew at Kabete Field Station.

5.3.10 Grain yield

Grain yield was evaluated at Ol Joro-Orok (predominantly cool conditions) in 2013 and at Kabete (warm conditions) in 2014. The local landraces Kin 2 and Kin 3 were used as checks in 2013, while Nyeri 1, Dwarf 1 and Dwarf 2 were incorporated in 2014. Analysis of variance showed that there were significant differences in grain yield among the test genotypes at both sites and seasons (Appendix 5). Mean grain yield varied from 2,300 to 13,300 kg ha-^{1} in 2013, and from 2500 to 7100 kg ha-^{1} in 2014. The mean yield was higher (6753 kg ha-^{1}) in the first year compared to 4426 kg ha-^{1} in the second year (Table 5.10). In the first year, 15 genotypes yielded more than 9500 kg ha^{-1} in comparison to the second year in which high yields of more than 5000 kg ha^{-1} were recorded by 14 genotypes. The results clearly demonstrated that grain yield was influenced by climatic and edaphic conditions especially temperature.

Yields of test genotypes were higher under cooler conditions in the first year at Ol Joro-Orok (Table 5.10). About 20 genotypes yielded more than 8000 kg ha^{-1} at Ol Joro-Orok in 2013. The local landraces; Kin 2 and Kin 3 had the lowest yield of less than 3000 kg ha^{-1} in 2013. Nonetheless, Nyeri 1 in the second year had higher yields of up to 6000 kg ha-^{1} at Kabete. The yield of genotypes decreased by 60% in the second year. For instance, KAB-RB13-325-200, KAB-RB13-327-92, KAB-RB13-338-41 yielded more than 10,000 kg ha-^{1} in 2013, yet the same genotypes yielded less than 4000 kg ha^{-1} in 2014 (Table 5.10).

Based on the yield performance and resistance to diseases, eleven lines KAB-RB13-334-29, KAB-RB13-336-63, KAB-RB13-338-41, KAB-RB13-364-212, KAB-RB13-37-16, KAB-RB13-426-84, KAB-RB13-46-124, KAB-RB13-471-117, SUB-OL-RB13-226-251, SUB-RB13-269-129 and SUB-RB13-325-134 were selected at Ol Joro-Orok and KAB-RB13-308-222/1, KAB-RB13-314-191/3, KAB-RB13-321-185/1, KAB-RB13-326-207/1, KAB-RB13-327-48/1, KAB-RB13-329-

165/1, KAB-RB13-341-143/4, KAB-RB13-343-189/5A, KAB-RB13-62-9/2, SUB-RB13-226-251/4 and SUB-RB13-269-129/3 at Kabete. These selected lines had yield more than 10,000 kg ha^{-1} at Ol Joro-Orok and more than 5,000 kg ha^{-1} at Kabete (Figure 5.4).

Table 5.10: Grain yield of runner bean lines at Kabete and Ol Joro-Orok for two years

Grain yield of runner bean genotypes (kg ha^{-1})			
2013		2014	
Genotypes	**Ol Joro-orok**	**Genotypes**	**Kabete**
KAB-OL-RB-440-232	6404	KAB-OL-RB-440-232/5	4035
KAB-RB13-155-122	7213	KAB-RB13-155-122/4	4394
KAB-RB13-308-222	6721	KAB-RB13-308-222/1	6473
KAB-RB13-310-161	5201	KAB-RB13-310-161/5	3557
KAB-RB13-310-162	9575	KAB-RB13-310-162/4	7033
KAB-RB13-312-160	8936	KAB-RB13-312-160/3	4496
KAB-RB13-314-191	7651	KAB-RB13-314-191/3	5611
KAB-RB13-315-197	6024	KAB-RB13-315-197/4	3236
KAB-RB13-319-182	7292	KAB-RB13-319-182/6	4385
KAB-RB13-319-193	4772	KAB-RB13-319-193/4	4425
KAB-RB13-319-194	5483	KAB-RB13-319-194/1	5166
KAB-RB13-321-185	8150	KAB-RB13-321-185/1	6248
KAB-RB13-325-200	10422	KAB-RB13-325-200/4	3038
KAB-RB13-326-207	7450	KAB-RB13-326-207/1	5130
KAB-RB13-327-48	9449	KAB-RB13-327-48/1	5257
KAB-RB13-327-92	12934	KAB-RB13-327-92/1	3857
KAB-RB13-329-165	6063	KAB-RB13-329-165/1	5487
KAB-RB13-331-113	9188	KAB-RB13-331-113/3	3441
KAB-RB13-334-29	13128	KAB-RB13-334-29/1	4337
KAB-RB13-336-63	11231	KAB-RB13-336-63/1	4648
KAB-RB13-338-41	13285	KAB-RB13-338-41/1	3773
KAB-RB13-341-143	7625	KAB-RB13-341-143/4	5463
KAB-RB13-343-184	8696	KAB-RB13-343-184/3	3642
KAB-RB13-343-189	5828	KAB-RB13-343-189/5A	6352
KAB-RB13-364-212	10311	KAB-RB13-364-212/2	3845
KAB-RB13-37-16	14999	KAB-RB13-37-16/1	4260
KAB-RB13-379-148	6162	KAB-RB13-379-148/1	3622
KAB-RB13-396-210	7778	KAB-RB13-396-210/1	2958
KAB-RB13-399-219	6393	KAB-RB13-399-219/5	4969
KAB-RB13-426-84	11576	KAB-RB13-426-84A/1	4718
KAB-RB13-46-124	10270	KAB-RB13-46-124/1	4736
KAB-RB13-471-117	11563	KAB-RB13-471-117/1	6078
KAB-RB13-522-73	7440	KAB-RB13-522-73/1	4689
KAB-RB13-62-9	6859	KAB-RB13-62-9/2	6227

Table 5.10 (continued)

Grain yield of runner bean genotypes (Kgha-1)			
Kabete			**OlJ**
2013			**2014**
KAB-RB13-85-18	7995	KAB-RB13-85-18A/4	2717
SUB-OL-RB13-177-3	9254	SUB-OL-RB13-177-3/3	3457
SUB-OL-RB13-226-251	10052	SUB-OL-RB13-226-251/4	5161
SUB-OL-RB13-275-248	7394	SUB-OL-RB13-275-248/3	3406
SUB-OL-RB13-275-249	6846	SUB-OL-RB13-275-249/5	3036
SUB-RB13-221-128	5825	SUB-RB13-221-128/3	4268
SUB-RB13-269-129	11452	SUB-RB13-269-129/3	5221
SUB-RB13-308-75	8309	SUB-RB13-308-75/2	4204
SUB-RB13-325-134	10260	SUB-RB13-325-134/5	3165
Checks		**Checks**	
Kin 2	2343	Dwarf 1	2612
Kin 3	3820	Dwarf 3	2524
Nyeri	_	Nyeri	6124
Mean	6753	Mean	4426
CV (%)	55.6	CV (%)	38.9
$LSD_{0.05}$	6034	$LSD_{0.05}$	2782.4

Figure 5. 4: High yielding runner bean lines at Kabete.

5.4 Discussion

5.4.1 Plant vigour

Most genotypes were very vigorous in both sites and years indicating the inherent ability of vigor among the genotypes under different locations. This also explains the vigorous nature of runner bean when planted in favorable climatic conditions (Zeven et al., 1993). The dry spell experienced at Kabete in the first season resulted in some genotypes showing intermediate vigor.

5.4.2 Days to 50 % flowering

The significant differences in days to flowering among genotypes in the second year could be due to environmental and genetic effects. In the second year, genotypes flowered earlier at Kabete than at Ol Joro-Orok due to the prevalent cooler conditions that delayed flowering at Ol Joro-Orok .The effect of temperature on plants has also been studied by Galloway and Etterson (2009) who found out that cooler temperatures tend to delay initiation of flowering and thus slows the reproductive phenology. Early experiments on temperature and photoperiod by Kornegay et al.(1993) revealed that sensitive common bean germplasm took shorter days to flower when planted at Palmira (warm area) and flowered late when grown at Popayan (cooler area).This results therefore suggest an overlap of genes in influencing the interaction between temperature and photoperiod response among photoperiod sensitive genotypes.

5.4.3 Raceme formation

The genetic effect and cooler temperatures in the second year influenced the genotypes ability to form many racemes at both sites. As observed by many authors (Hadjichristodoulou ,1990;, Zeven et al.,1993; Rodino et al., 2007 and Spataro et al.,2011), *Phaseolus Coccineus* is well adapted to cooler temperatures where adequate flower set is realized. Therefore, high temperatures limit flower set. The fewer numbers of racemes recorded at Kabete in the first season was due to water stress and high temperatures. This is well demonstrated by adequate number of racemes formed at the same location during favorable cool and moist conditions in the second year. The local landraces Nyeri, Dwarf 1 and Dwarf 2 had fewer racemes compared to the improved genotypes and this shows these germ plasm can easily flower and form many racemes under natural day length of 12 hours . In most cases, the dwarf landraces did not form racemes during the second flush due to the nature of bush growth habit which allows flowering to occur once.

5.4.4 Reaction of genotypes to diseases

The genotypes showed a higher resistance to the common bacterial blight, bean rust, bean common mosaic virus and powdery mildew. This ascertains the fact that runner bean is generally resistant

to a wide array of bean pathogens (Singh, 2001). These results therefore show that the studied lines can be a source of selection of resistant germplasm to be used in future breeding activities. The occurrence of one disease in one location and not the other could be due to presence of high inoculums and favorable conditions for the development of such disease. High humidity experienced at Kabete in June-August 2013 and 2014 resulted in infection by powdery mildew. As stated by Hagedorn, (1986) high humidity provides favorable environment for infection and development of powdery mildew.

5.4.5 Grain yield of genotypes

The grain yield varied significantly among genotypes due to genetic factors and climatic conditions. Genotypes yielded as much as at Ol Joro-Orok (cooler conditions) than Kabete (warmer) because of the inherent adaptability of *P. coccineus* to thrive well under cooler conditions. Besides, Freytag and Debouck (2002) also revealed that runner bean is mainly adapted to cooler and moist environment and therefore their performance in warmer conditions is constrained.

These results suggest that high yields can be achieved if cool temperatures prevail in the entire cropping season of runner beans. Nonetheless, some genotypes had satisfactory yields at Kabete indicating that they can be selected for utilization under such warmer climatic conditions. As indicated earlier, genotypes had many racemes at Ol Joro-Orok than Kabete in both seasons which consequently resulted into higher yields. The new lines combined better adaptability to short-day conditions and disease resistance hence resulting in higher yields than the local landraces. Among the local landraces, the dwarf cultivars were the low yielders and this could be linked to the fact that most dwarfing genes have pleiotropic effect on other plant characters. For instance, in soybean the dwarfism gene *df* has been found to cause reduction in leaf size and internode length hence resulting subsequent low seed yield per plant (Huyghe, 1999).

5.5 Conclusion

The new runner bean lines were highly vigourous under both warm and cool conditions.However, adequate and well distributed rainfall was necessary to maintain the vigor of the crop.

Grain runner bean lines flowered easily under the short-photoperiods. Early flowering lines were found to flower within 40 to 49 days at Kabete and 50 to 55 days at OL Joro-Oork. Most lines formed sufficient racemes however temperatures between 14^0C and 20^0C were found to favour raceme formation.

The new grain lines showed potential of resisting infection of prevalent bean disease in the two sites than the local landraces. Even though, artificial inoculation and screening the lines in areas withhigh disease pressure is necessary for selection of resistant lines.

The results of this study also showed that the locally developed genotypes had improved grain yield compared with the local landraces. Therefore, the selected grain runner bean lines can be used to develop high yielding and disease resistant short-day grain runner bean varieties.

CHAPTER SIX

VALIDATION OF MULTIPLE DISEASE RESISTANCE, POD YIELD AND QUALITY OF ADVANCED SNAP BEAN LINES DEVELOPED IN KENYA

Abstract

Production of snap or French bean (*Phaseolus vulgaris* .L.) in Kenya is severely constrained by diseases. Use of fungicides increases cost of production, reduces profitability and competitiveness of snap bean in domestic and export markets. Varieties with multiple disease resistance can reduce costs associated with use of chemicals and increase yields of smallholder farmers. The objective of the study was to validate multiple disease resistance to rust, anthracnose and angular leaf spot, market preferred pod quality and pod yield from locally developed advanced snap bean lines. About 231 $F_{6,}$ $F_{7.9}$ and F_8 lines previously selected for disease resistance from 31 populations were evaluated in a preliminary yield trial at Mwea in 2013 long rain season. Thirty lines were further evaluated in advanced trials at Mwea and Embu during the 2013 short rain season. Four commercial varieties were used as checks. Diseases were scored on a scale of 1 to 9, where scores of 1-3 were considered resistant, 4 to 6 intermediate and 7 to 9 susceptible. Plots were harvested three days a week for a period of four weeks and pods graded as extra-fine, fine and bobby using standard commercial criteria. Analysis of variance showed no significant differences for reaction to anthracnose, angular leaf spot and rust at both sites. However, significant sites effects were recorded. Mean disease scores for rust and anthracnose varied from 1-5, while angular leaf spot mean scores ranged between 1 and 6 at both locations. Six new lines with combined resistance to angular leaf spot, rust and anthracnose had better pod yield and pod quality compared with existing commercial varieties at both locations were identified. The mean disease score for these lines was 1-3 for the three diseases. These lines had fresh pod yield of up to 10,000 kg ha^{-1} compared to an average of 4,000 kg ha^{-1} realized in farmers' fields with current commercial varieties. None of the commercial check varieties exhibited multiple disease resistance. About 70% of evaluated lines combined multiple disease resistance and fine pod quality. About 80% of genotypes had extra fine and fine grades at Embu and 57% formed same grades at Mwea. These results indicate the potential of developing new high yielding snap varieties with multiple disease resistance and good pod quality. New varieties from these lines can increase incomes of smallholder farmers who are constrained by reliance on costly fungicides and enhance competitiveness of local products in export markets.

Key words: French bean, resistance, smallholder farmer, pod quality

6.1 Introduction

Snap bean also known as 'French bean, is a leading vegetable export crop from Kenya. Other countries in Africa that export snap bean is Tanzania, Uganda, Zambia, Zimbabwe and some in North Africa (Iruria et al., 2002). In Kenya, exports of French bean increased from 22,553 tonnes in 2012 to 31,973 tonnes in 2013 (HCDA, 2013).In the year 2013, snap bean was valued at kshs 1.8 billion in the export market. Kirinyaga, Murang' a, Taita-Taveta, Meru and Machakos are the leading counties in French bean production (HCDA, 2013). The crop is mainly grown by smallholder farmers with 90% of the produce being for export. Snapbean is gaining popularity in local markets (MOA, 2006), and are sold in most supermarkets, retail shops and local produce markets centers.

Production of snap bean has faced many challenges with diseases causing major economic losses. These diseases not only affect yield, but also the quality of the produce, making the crop produce less marketable (Monda et al., 2003). Kenyan farmers rely mainly on imported varieties which are susceptible to these diseases (Chemining'wa et al., 2012). Diseases of economic importance include rust, common bacterial blight, anthracnose and angular leaf spot. Farmers have no choice but to use chemicals as a remedy to reduce the disease pressure. High usage of pesticides by farmers led to strict safety and quality standards enforced by the Eurep Gap which demands low residue levels of chemicals on fresh produce. These stringent regulations have created new barriers and threatening access to European markets. Moreover, overuse of chemicals has increased the cost of production and reduced competitiveness of Kenyan produce in the export markets (Kimani et al., 2002).Therefore, research effort to manage diseases in eastern Africa has focused on host plant resistance which offers an effective, low cost strategy and sustainable approach to control bean diseases (Kimani et al, 2005a). Most breeding programs are focusing on resistance to one disease which in turn exposes the crop to other diseases and cause losses.

To address these constraints, snap bean breeding in Kenya started in 1998 at KARI-Thika currently referred to as KALRO with the support of CIAT (International Centre for Tropical agriculture) and Eastern and Central Africa Bean Research Network (ECABREN).The efforts of this work led to the development of line 'Kutuless' which was resistant to rust in 2000 (Chemining'wa et al., 2012). In 2006 a regional snap bean project supported by ASARECA to develop improved snap bean lines with high yield potential, resistance to biotic stresses and preferred pod characteristics for smallholder farmers was initiated (Kimani,2006; Kimani, 2009). In Kenya, breeding activities were carried out at Moi University in Eldoret, National Horticultural Research Centre at KALRO-Thika and at the University of Nairobi. The objective of snap breeding research at University of Nairobi was to select for bush and climbing snaps with multiple disease resistance to rust, angular leaf spot (ALS) and anthracnose (Kimani, 2010). The F_1 derived

from the crosses involving BelDakMi, L227, Beltigrade RR2, Awash 1, G2333, BelMiNeb and Roba-1 and nine susceptible commercial varieties (Amy, Paulista, Morelli, Morgan, Julia, Foskelly, Teresa, Vernandon, Kutuless and Alexandria) were advanced to F_4, F_5 and F_6.These advanced and segregating populations were artificially inoculated with rust, angular leaf spot and anthracnose pathogens (Wahome et al., 2011). From the evaluation, nine lines and 674 F_5 single plants showing multiple disease resistance were selected from the populations. Therefore, the objective of this study was to validate 231 $F_{6,}$ $F_{7.9}$ and F_8 lines through field evaluation to determine if they exhibit multiple disease resistance and market preferred pod quality.

6.2 Materials and Methods

6.2.1 Plant Materials

This study used 231 advanced bush snap lines which were selected from 31 populations developed by the University of Nairobi Bean Program (Wahome, 2011). These populations were developed from crosses between sources of resistance to rust (Beldakmi, Belmineb, and Beltgrade lines), angular leafspot (Mex 54 and L227-10), root rots (L227-10) and anthracnose (G2333), and susceptible commercial varieties (Amy, Paulista, Morelli, Morgan, Julia, Foskelly, Teresa, Vernandon, Kutuless and Alexandria). F_1's were advanced following the population bulk method to F_5 generation, or backcrossed to commercial parents to recover preferred pod, texture and other horticultural traits (Kimani, 2006).

The F_5 bulks were inoculated with isolates of rust, angular leaf spot and anthracnose at Mwea and Thika in 2009 and 2010. More than 650 single plants which showed resistance to the three diseases were selected and advanced to $F_{5:6}$, $F_{5:7}$ and $F_{5:8}$ in 2011. Selections were artificially inoculated with rust, ALS and anthracnose pathogens and further advanced to F_6, $F_{7.9}$ and F_8 as progeny one and two (Wahome et al., 2011). In this study 231 F_6, $F_{7.9}$ and F_8 single plants were selected from Progeny 1, and planted at Mwea during the long rain season in 2013 for preliminary evaluations. From the preliminary trials, 30 lines were selected based on their reaction to rust, angular leaf spot, anthracnose, pod quality, plant vigor and architecture. These lines were evaluated in advanced yield trials at Mwea and Embu during 2013 to 2014 short rain seasons.

6.2.2 Trial sites

Preliminary field evaluations of 231 F_6, $F_{7.9}$ and F_8 advanced lines were conducted in farmers' field at Wang'uru in Mwea and at Runyenjes in Embu .Trials at Mwea were conducted during the 2013 long rain season. F_6, $F_{7.9}$ and F_8 lines were further tested during the 2013 short rain season at both sites.

Wang'uru is located 100km northeast of Nairobi on longitude 37^0 21.9' E and latitude $0^0$36.1' S. The trial site was in a farmer's field in the lower altitude zones of Kirinyaga County. This area is an expansive low lying, wet savannah ecosystem at an altitude of 1204 m.a.s.l. The area receives an annual rainfall of 850 mm per annum with long rains rainfall occurring in March to June and short rains from October to December. The temperature ranges from 15.6^{0}C to 28.6^{0}C with a mean of about 22^{o}c. The soils at the site are red sandy loam, classified as nitisols, (Jaetzold et al., 2006).

Runyenjes site is located in the Upper Midlands 2 (UM2) agro-ecological zone of Embu county at 0° 25' S, 37° 28' E, and an altitude of 1494 m above sea level. Soils are humic nitisols, which are deep with moderate to high inherent fertility. It receives a mean bimodal rainfall of 909 to 1230 mm per annum. Long rains start late in March and end in June. Short rains occur between October and January. The mean temperature at Embu is 16^{o}C (but does vary with months). Over 65% of rains occur during the long rains (Jaetzold et al., 2006).

6.2.3 Experimental design and Crop management

Field experiments were conducted for at Mwea during 2013 long rains and short rains. The trials at Embu were conducted during the 2013 short rain season. Two hundred thirty-one advanced lines and four commercial checks were used in these trials. The check varieties were Samantha, Star 2053, Julia and Morelli.

The experiments were laid in a randomized complete block design with two replicates at each site. Test lines were grown in plots of 4 m length. Each plot had 4 rows and a spacing of 50cm between rows and 20 cm within rows. A plot had 60 plants, giving a plant population density of 200,000 plants. Before planting, diammonium phosphate fertilizer (18% N and 46% P_2O_5) was applied at a rate of 50 kg ha^{-1} in both sites.

Hand weeding was done when necessary at both sites. Aphids, white flies and leaf miners were controlled by alternate application of Cyclone® (10% Cypermethrin + 35% chlorpyriphos) and Confidor® (imidacloprid) at the rate of 1.5ml L^{-1}. Supplementary irrigation was provided by furrow irrigation at Mwea and with sprinklers at Embu. Trials were irrigated to field capacity. Two irrigations were done per week therefore a total of 12 irrigations were done per site for the entire growing period. Pod sampling started at the fifth week from planting immediately after formation of the first marketable pods. Harvesting was done three times each week for a period of four weeks at both sites.

6.2.4 Data collection

Data was collected on vigor, days to 50% flowering, disease resistance in the preliminary evaluation at Mwea. Data on marketable pod grades, pod length and pod yield was recorded in subsequent trials at both sites. Plant vigor was determined by sampling ten plants per plot and rating on basis of plant height and vegetative growth on a scale of 1 to 9, where 1=excellent vigor, 3=good vigor, 5= intermediate vigor, and 7=very poor vigor. Days to 50% flowering was recorded as the number of days after planting to the date when 50% of plants in a plot had one or more open flowers. Disease resistance was evaluated based on 1-9 disease severity scale, where scores of 1-3 were rated as resistant, 4-6 as intermediate and 7-9 as susceptible (van Schoonhoven and Pastor-Corrales, 1987). Disease scores were taken at flowering, at early pod stage and at late pod maturity. The most advanced disease scores (at late pod maturity) were subjected to analysis of variance.

Table 6.1: Disease severity scale used to evaluate the reaction of bean germplasm to fungal diseases (van Schoonhoven and Pastor-Corrales, 1987).

Rating	Category	Description	Comments
1-3	Resistant	No visible symptom or light symptoms (2% of the leaf)	Germ plasm useful as a parent or commercial variety.
4-6	Intermediate	Visible and conspicuous symptoms (2-5% of the leaf) resulting only in limited economic damage.	Germplasm can be used as commercial variety or source of resistance to disease.
7-9	Susceptible	Severe to very severe symptoms (10-25% of the leaf) causing yield losses or plant death.	Germplasm in most cases not useful as parent or commercial variety

Pods were harvested three times a week (Mondays, Wednesdays and Friday) for a period of four weeks from two inner rows only (with about 15-20 plants) during the short rains at Mwea and Embu. A total of 13 harvests were done. Freshly harvested pods were graded into three standard commercial categories defined by width of the pod as extra fine (6 mm), fine (6-8 mm) and bobby (>8 mm) and length of the pods above 10 cm (HCDA, 2009). Tender pods, seedless, with no strings and free from any defects, maximum width of the pod being less than 6mm, and minimum length of 10 cm were graded as '**extra-fine'.** Pods with small immature seeds and a diameter between 6 and 9 mm were graded as '**fine'.** Pods with few seeds were classified as '**bobby'**.Fresh pods from each plot were counted to establish number of pods per plant. To determine the pod yield distribution, pods of grade were weighed using an A&D top pan balance (Model EK-6100i-EC, Hong Kong, China). Cumulative yield was computed by combining the total yield of the three

grades. Pod length was determined as the mean length of two randomly sampled pods from each grade for eight harvests .The average length for the eight harvests was then computed for each market class. Pod colour was rated based on visual appearance as light green, green and purple. Pod curvature was rated as straight, curved or slightly curved (IPBGR, 1982). Seed was harvested at dry pod maturity from plants which were not used for sampling.

6.2.5 Data analysis

Quantitative data was subjected to ANOVA using Genstat software 14th edition (VSN International, 2011). Analysis of variance was done separately for each site in the preliminary evaluations and combined analysis done for both sites in the advanced evaluations. The differences among the means were compared using Fishers Protected Least Significance difference test at 5% probability level.

6.3 Results

6.3.1 Preliminary Yield trials

The 231 advanced snap bean lines were evaluated for vigor, reaction to diseases, number of pods, pod curvature and shape and seed yield at Mwea in 2013 (Appendix 12). About 13 lines did not germinate, while 24 lines grew up to early pod forming but were destroyed by excessive rains which resulted in water logging .Therefore, data of the destroyed lines was recorded as 0. Genotypes selected for advanced yield trials at Mwea and Embu in 2014 are presented in Table 6.2 while a result of all 231 genotypes is in Appendix 8.

6.3.1.1 Weather at Mwea and Embu

The weather data for 2013 at Mwea and Embu is presented in the Appendix 9 and 10. The preliminary trial was conducted from April to June 2013 at Mwea. During this period, mean monthly temperature for the three months was 22.4^{o}C while the total rainfall received was 6.7mm.The mean maximum temperatures at Mwea were 27.6^{o}C and a minimum of 17.1^{o}C for the entire cropping period. The low rainfall received could have affected the crop growth since snap bean production mainly thrives well under well distributed rainfall or continuous supplemented irrigation in area with less rainfall (Infornet Biovision, 2011). The dry conditions at Mwea were not favourable for disease development as most pathogenic diseases develop in moist and cool conditions.

6.3.1.2 Growth vigor

There were no significant differences ($P \leq 0.05$) in growth vigour among advanced lines and check varieties evaluated in growth vigor at Mwea (Appendix 12). The vigor of the test lines varied from 1 to 7. About 41% of lines good vigor (scores of 1-3), 53% intermediate vigor (4-6) and 6% had poor vigor (scores of 7-9). Among the check varieties, Samantha had poor growth vigor (7); while Morelli was the most vigorous (2) .It was evident that almost all tested lines had good to intermediate vigor except KNSB13-90-192, KSB13-26-209, and KSB13-7-97. Out of the evaluated lines (231 lines), 16 lines with good vigor and 11 lines with intermediate vigor were selected for further evaluation at Mwea and Embu. The most vigorous line was KSB13-38-27 with a vigor score of 1.

6.3.1.3 Reaction to rust

There were no significant differences ($P \leq 0.05$) among evaluated lines to reaction to rust infection at Mwea (Appendix 12). All the evaluated lines showed low rust scores which ranged from 1 to 2. One hundred and seventy seven lines had a score of 1, while 31 lines had a score of 2. Samantha and Morelli equally showed scores of 1 to 2(Table 6.2). There were no cases of intermediate resistance (scores of 4-6) or susceptibility (scores of 7-9) to rust infection. The disease scores were low suggesting low disease pressure during the field evaluation.

6.3.1.4 Reaction to angular leaf spot

There were significant differences ($P \leq 0.05$) in reaction to test lines to angular leaf spot infection (Appendix 12). However, disease pressure appeared low. Angular leaf spot scores varied from 1 to 3. Among the lines, 51 lines had a score of 1, 78 lines had a score of two, and 79 lines had a score of three. Morelli and Samantha also had a score of one (Table 6.2).

6.3.1.5 Reaction to anthracnose

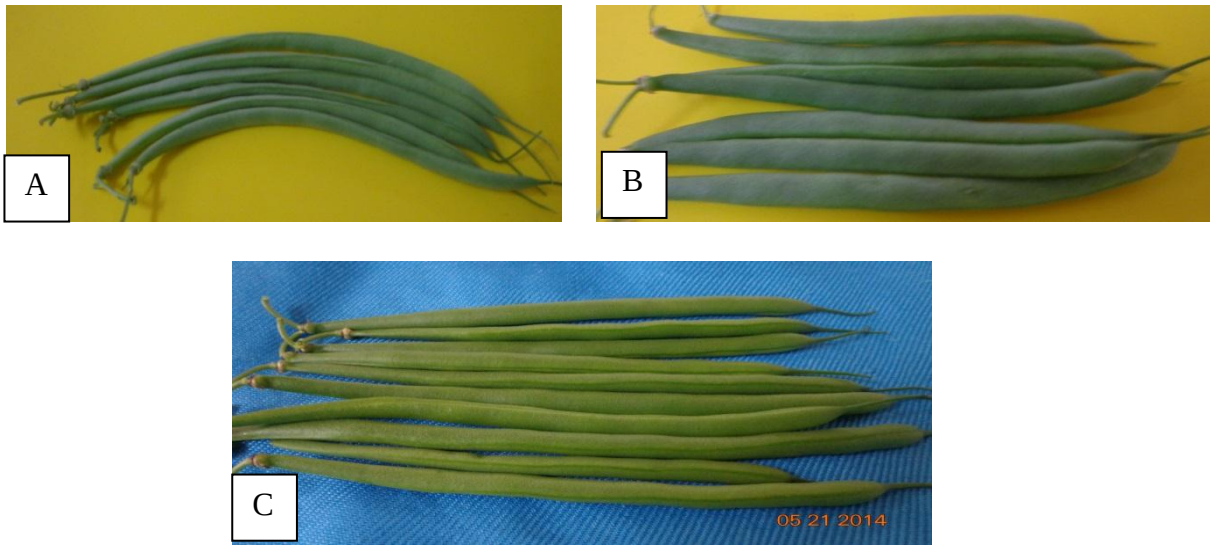
There were significant differences in reaction of the test lines to anthracnose infection. However, disease pressure was low (Appendix 12). Disease scores varied from 1 to 4. Only one line had a score of 4 (KSB13-23-177) suggesting it was more susceptible to anthracnose (Table 6.2). About 85 lines had a score of 1, 100 a score of 2, and 23 lines had a score of 3.In this preliminary evaluation, disease pressure was very low for all the three diseases as shown by the susceptible checks also being rated as resistant (Table 6.2).

6.3.1.6 Number of pods and seed yield

Significant differences in pod formation and seed yield (kg ha^{-1}) were detected among the 231 lines at Mwea (Appendix 12). Number of pods per plant varied from 1 to14 with a mean of four pods. About 52% of the lines formed one to four pods per plant, 41% had five to nine pods per plant, and 7% had a mean of ten to fourteen pods per plant (Table 6.2). Among the 231 lines, 183 lines had 13 pods per plant, 12 lines had had 5 to 8 pods per plant and 17 lines had 1 to 4 pods per plant (Table 6.2 and Fig 6.2).The seed yield of lines ranged from 0 to 2635.5 kg ha^{-1}. About 29 lines yielded within the range of 1000 – 2636 $kgha^{-1}$, 65 lines had seed yield ranging from 500 to 1000 $kgha^{-1}$ and 100 lines had yield between 31 and 490 $kgha^{-1}$. Thirty seven lines did not yield at all. The seed yield of selected lines varied from 120-1664 kg ha^{-1}. Selection for best lines was based on yield and pod charcateristics. Therefore, lines that yielded more than 1664kg ha-1 but had poor pod quality were not selected for advancement in the second season (Table 6.2 and Fig 6.3).

6.3.1.7 Pod characteristics

The test lines showed considerable variability for pod curvature and pod shape. Of the 231 lines, 79 formed curved pods; 80 had slightly curved pods, while 54 lines had straight pods (Figure 6.1). 90% of evaluated lines had the preferred round (Round) cross-sectional shape. However, nine lines had flat pods (Table 6.2 and Appendix 8). Morelli had straight and Round pods, while Samantha formed slightly curved pods with round shape.



A. Slightly curved pods, B. Flat pods and C. Round pods

Figure 6.1: Pod shape of the new locally developed snap bean lines.

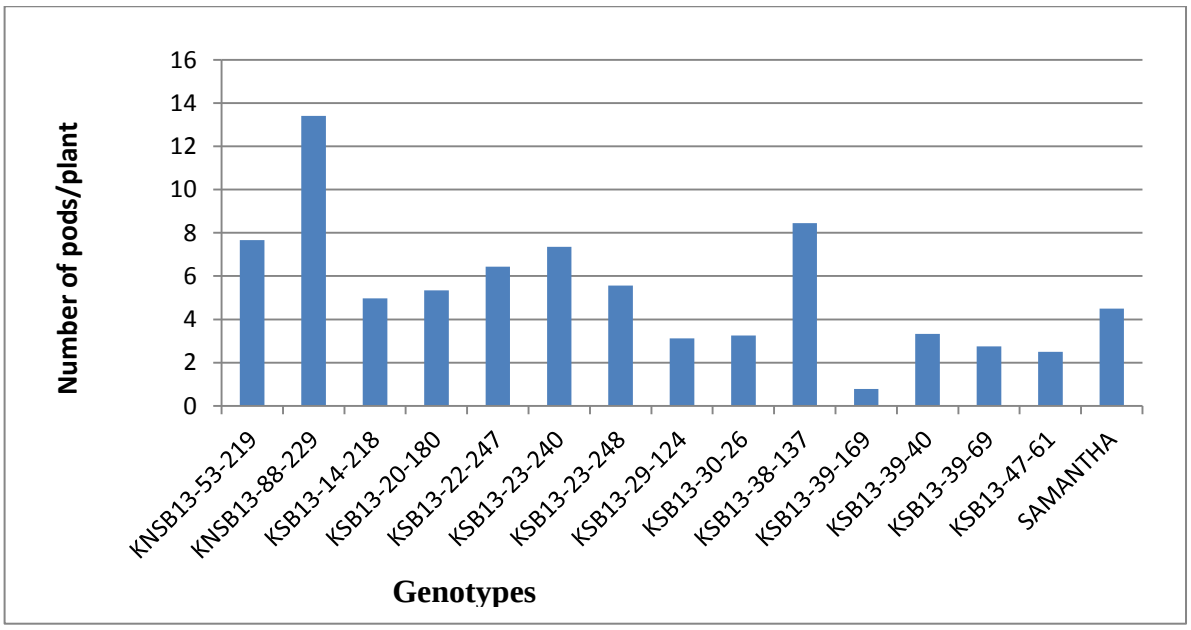


Figure 6.2: Number of pods of selected snap bean lines in the preliminary trial at Mwea

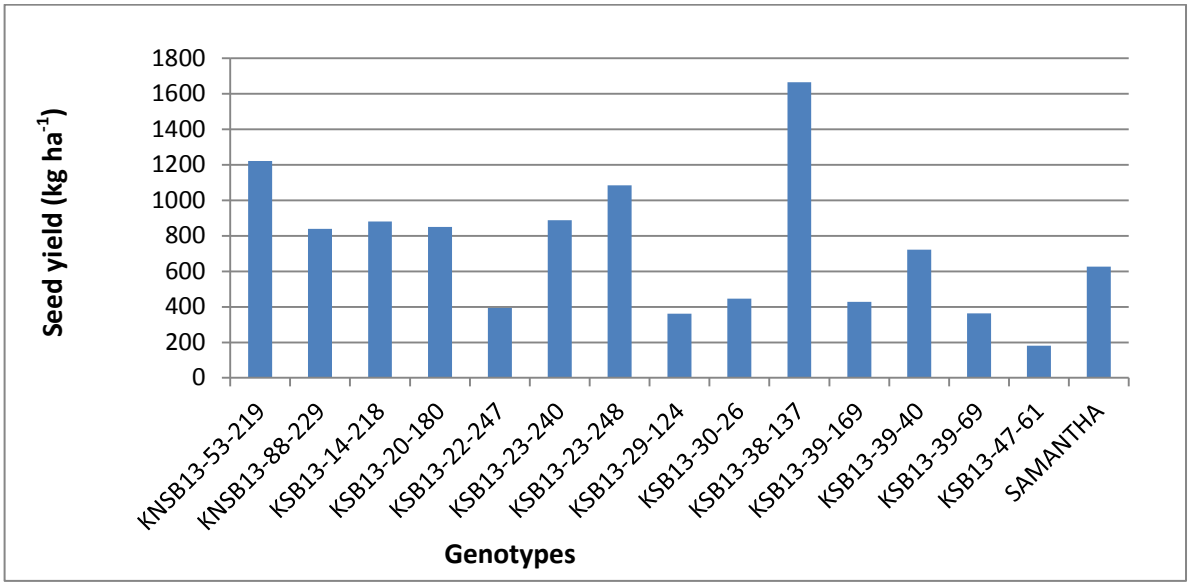


Figure 6.3: Seed yield (kg ha^{-1}) of selected snap bean lines in the preliminary trial at Mwea

Table 6.2: Performance of selected snap bean lines during preliminary evaluationat Mwea, Kirinyaga County in 2013 short rains.

Genotypes	Vigor	Rust	ALS	Anthracnose	No of pods/Plant	Seed yield (kg ha^{-1})	Pod curvature	Pod shape
KNSB13-53-219	3.0	1.0	2.0	1.5	7.7	1221.2	slightly curved	Round
KNSB13-78-227	4.0	1.5	2.5	2.5	6.8	838.4	curved	Round
KNSB13-88-229	4.0	1.5	1.5	1.5	13.4	838.8	slightly curved	Round
KNSB13-90-188	4.0	1.0	2.0	2.0	7.3	354.6	slightly curved	Round
KSB13-14-218	4.0	1.0	2.5	1.5	5.0	881.6	slightly curved	Round
KSB13-17-182	4.0	2.0	1.0	0.5	3.8	625.0	straight	Round
KSB13-20-180	3.0	1.0	3.0	1.5	5.3	850.8	Slightly curved	Round
KSB13-20-208	5.0	2.0	2.5	1.5	7.7	1177.7	slightly curved	Round
KSB13-22-247	5.0	1.0	2.0	1.5	6.4	394.5	straight	Round
KSB13-23-239	2.0	2.0	3.0	2.0	5.6	545.3	straight	Round
KSB13-23-240	3.0	1.0	2.0	2.5	7.4	887.8	straight	Round
KSB13-23-241	2.0	1.0	2.5	2.5	7.8	1004.5	slightly curved	Round
KSB13-23-248	3.0	1.0	2.5	1.0	5.6	1084.8	straight	Round
KSB13-23-78	2.5	0.5	1.0	1.0	5.0	271.0	straight	Round
KSB13-29-124	6.0	0.5	1.0	1.5	3.1	361.0	straight	Round
KSB13-30-145	4.0	1.0	3.0	2.5	1.2	434.3	slightly curved	Round
KSB13-30-26	4.0	1.5	2.0	1.0	3.3	446.0	slightly curved	Round
KSB13-30-27	0.5	0.5	1.5	1.0	3.5	119.9	slightly curved	Round
KSB13-38-137	1.5	1.0	2.0	1.5	8.5	1664.8	slightly curved	Round
KSB13-39-121	1.5	1.0	1.5	1.5	6.7	565.5	curved	Round
KSB13-39-168	1.5	1.0	3.0	3.0	4.0	225.0	Slightly curved	Round
KSB13-39-169	2.5	1.0	1.5	0.5	0.8	427.7	curved	Round
KSB13-39-39	4.0	1.0	2.5	1.5	4.0	562.2	slightly curved	Round
KSB13-39-40	3.0	1.0	2.5	1.5	3.3	722.4	slightly curved	Round
KSB13-39-41	3.0	0.5	1.5	1.5	1.7	427.7	straight	Round
KSB13-39-44	1.5	0.5	1.5	1.0	2.6	293.9	slightly curved	Round
KSB13-39-69	5.0	1.0	2.5	1.5	2.8	363.0	straight	Round
KSB13-45-101	1.5	1.0	0.5	1.0	2.1	523.2	straight	Round
KSB13-47-61	1.5	0.5	1.5	1.0	2.5	182.0	slightly curved	Round
KSB13-47-64	1.5	0.5	1.5	1.0	2.5	156.2	straight	Round
Checks								
Samantha	7.0	0.5	1.0	1.0	4.5	627.5	slightly curved	Round
Star 2053	1.5	0.5	1.5	0.5	5.7	1896.3	curved	Round
Trial mean	3.3	0.8	1.7	1.3	4.0	511.0		
CV (%)	69.7	69.7	66.7	71.5	91.4	113.1		
$LSD_{0.05}$	4.6	1.2	2.2	1.8	7.2	1139.9		

6.3.2 Advanced Yield Trials

From the preliminary trials, 30 lines which showed resistance to rust, anthracnose and angular leaf spot were selected. These lines also showed high potential for yield and preferred pod traits. The selected lines were evaluated in advanced yield trials at Mwea and Embu during the 2013 short rain seasons. The evaluations in Mwea were conducted between August and October and from November to January at Embu.

6.3.2.1 Plant vigor

There were no significant location, and genotypic effects ($p \leq 0.05$) on plant vigor at both sites (Appendix 11). The plant vigor of genotypes ranged from 1 - 5 at both locations. About 70% of genotypes showed good vigor (scores of 1-3) with at the two locations recording an average vigor score of two. About 24% of the lines at Embu, and 18% Mwea, had intermediate vigour scores (Table 6.3). Six lines had excellent vigor (score of 1) at both sites. Another 19 genotypes showed good vigor (score of 3) at Mwea and Embu. The check varieties, Samantha and Teresa had intermediate vigor (score of 4 -5) at both sites. The growth vigor mean scores are presented in Table 6.3.

Table 6.3: Plant vigor mean scores of advanced snap bean lines at Mwea and Embu during short rains in 2013.

Genotypes	Plant vigor scores		
	Embu	Mwea	Mean
KNSB13-53-219	2.0	2.0	2.0
KNSB13-78-227	2.0	2.0	2.0
KNSB13-78-227a	2.0	1.0	1.5
KNSB13-78-227b	2.0	1.0	1.5
KNSB13-88-229	1.0	1.0	1.0
KNSB13-90-188	1.0	2.0	1.5
KSB13-14-218	4.0	1.5	2.8
KSB13-17-182	2.0	1.0	1.5
KSB13-20-180	2.0	2.0	2.0
KSB13-20-208	4.0	1.0	2.5
KSB13-22-247	4.0	1.0	2.5
KSB13-23-239	2.0	2.0	2.0
KSB13-23-240	1.0	3.0	2.0
KSB13-23-241	1.0	1.0	1.0
KSB13-23-248	2.0	1.0	1.5
KSB13-23-78	1.0	1.0	1.0
KSB13-29-124	1.0	3.0	2.0
KSB13-30-145	1.0	3.0	2.0
KSB13-30-26	5.0	1.0	3.0
KSB13-30-27	1.0	3.0	2.0

Genotypes	Plant vigor scores		
	Embu	Mwea	Mean
KSB13-39-121	4.0	2.0	3.0
KSB13-39-168	2.0	2.0	2.0
KSB13-39-169	1.0	1.0	1.0
KSB13-39-39	5.0	3.0	4.0
KSB13-39-40	2.0	2.0	2.0
KSB13-39-41	2.0	1.0	1.5
KSB13-39-44	3.0	4.0	3.5
KSB13-39-69	3.0	1.0	2.0
KSB13-45-101	1.0	1.0	1.0
KSB13-47-61	1.0	1.0	1.0
KSB13-47-64	2.0	2.0	2.0
Checks			
Samantha	4.0	5.0	4.5
Teresa	4.0	5.0	4.5
Mean	2.3	1.9	2.1
CV %	66.0		
$LSD_{0.05}$ Genotype	1.94		

Gen= Genotype, Loc = Location, $LSD_{0.05}$ location= 0.47 and $LSD_{0.05}$ Gen x Loc= 2.74

6.3.2.2 Days to 50% flowering

There were significant differences at ($p \leq 0.05$) in number of days to 50% flowering due to locations effect (Appendix 11). However, genotypic effects and interactions were not significant .Flowering was delayed by about nine days at Embu. The test lines reached 50% flowering in 29 days at Mwea compared to 38 days at Embu. At both sites flowering was complete within three days. Genotypes flowered in 29 to 31days at Mwea and 37 to 39 days at Embu (Table 6.4). At Embu three lines KNSB13-53-219, KNSB13-90-188 and KSB13-39-44 were early flowering. These lines flowered in 37 days while 24 genotypes flowered later in 38 to 39 days. At Mwea, KSB13-14-218, KSB13-17-182, KSB13-20-180, KSB13-20-208, KSB13-23-248 and KSB13-39-169 were found to flower early in 29 days, while KSB13-30-145 and Samantha flowered late (31 days). Samantha and Teresa flowered late at both Embu (39 days) and Mwea (30-31 days) as presented in (Table 6.4).

Table 6.4: Days to 50% flowering of genotypes at Mwea and Embu.

Genotypes	Days to 50% flowering		
	Embu	Mwea	Mean
KNSB13-53-219	37.0	30.0	33.5
KNSB13-78-227	39.0	29.5	34.3
KNSB13-78-227a	38.5	29.5	34.0
KNSB13-78-227b	39.0	29.5	34.3
KNSB13-88-229	37.5	30.0	33.8
KNSB13-90-188	37.0	30.0	33.5
KSB13-14-218	39.0	29.0	34.0
KSB13-17-182	39.0	29.0	34.0
KSB13-20-180	38.5	29.0	33.8
KSB13-20-208	39.0	29.0	34.0
KSB13-22-247	39.0	29.5	34.3
KSB13-23-239	38.5	30.0	34.3
KSB13-23-240	38.5	29.5	34.0
KSB13-23-241	39.0	30.0	34.5
KSB13-23-248	38.5	29.0	33.8
KSB13-23-78	39.0	29.5	34.3
KSB13-29-124	38.0	29.5	33.8
KSB13-30-145	38.0	31.0	34.5
KSB13-30-26	38.5	29.5	34.0
KSB13-30-27	38.5	29.5	34.0
KSB13-38-137	37.5	30.5	34.0
KSB13-39-121	38.5	30.0	34.3
KSB13-39-168	39.0	29.5	34.3
KSB13-39-169	38.5	29.0	33.8
KSB13-39-39	38.0	29.5	33.8
KSB13-39-40	38.5	29.5	34.0
KSB13-39-41	39.0	29.5	34.3
KSB13-39-44	37.0	29.5	33.3
KSB13-39-69	38.5	30.0	34.3
KSB13-45-101	37.5	30.0	33.8
KSB13-47-61	38.5	29.5	34.0
KSB13-47-64	38.5	29.5	34.0
Checks			
Samantha	39.0	30.5	34.8
Teresa	39.0	30.0	34.5
Mean	38.4	29.7	34.1
CV %	2.2		2.2
$LSD_{0.05}$Genotype	1.06		

Gen= genotype, Loc= location, $LSD_{0.05}$ Loc=0.3 and $LSD_{0.05}$ Gen x Loc=1.49

6.3.2.3 Reaction of genotypes to rust

Analysis of variance showed that there were significant differences ($P \leq 0.05$) to rust infection between the two locations (Appendix 11). However, genotypic effects and the interaction between genotypes and locations were non significant (Table 6.5). The disease infection was observed at late flowering and continued up to pod maturity. Rust infection had a mean of 2.4 at Embu and 1.7 at Mwea. Advanced rust infection was observed at Embu with great variation of intermediate (scores of 4-6) to high resistance (scores of 1-3) than Mwea where 90% of genotypes were highly resistant with scores of 1-3 (Table 6.5). Among the genotypes, 27 and 32 genotypes showed scores of 1-3 at Embu and Mwea, respectively. At the same time, intermediate resistance (score of 4) was observed in eight genotypes at Embu, and in KSB13-29-124 at Mwea. Samantha and Teresa had scores of 2 at Mwea and intermediate resistance of (score of 4) at Embu.

Table 6.5: Mean rust severity scores of genotypes at Mwea and Embu during 2013 short rain season.

Genotypes	Rust scores		
	Embu	Mwea	Mean
KNSB13-53-219	2.0	1.5	1.8
KNSB13-78-227	2.5	1.5	2.0
KNSB13-78-227a	2.0	3.0	2.5
KNSB13-78-227b	3.0	1.5	2.3
KNSB13-88-229	2.0	3.0	2.5
KNSB13-90-188	3.0	2.0	2.5
KSB13-14-218	3.5	1.0	2.3
KSB13-17-182	3.5	2.0	2.8
KSB13-20-180	3.0	1.0	2.0
KSB13-20-208	4.0	2.0	3.0
KSB13-22-247	1.5	1.0	1.3
KSB13-23-239	3.0	3.0	3.0
KSB13-23-240	2.0	1.5	1.8
KSB13-23-241	1.0	1.5	1.3
KSB13-23-248	2.0	1.5	1.8
KSB13-23-78	2.0	1.0	1.5
KSB13-29-124	3.5	4.0	3.8
KSB13-30-145	3.0	1.5	2.3
KSB13-30-26	3.5	2.5	3.0
KSB13-30-27	1.0	1.0	1.0
KSB13-38-137	1.5	3.0	2.3
KSB13-39-121	2.0	1.5	1.8
KSB13-39-168	2.0	1.5	1.8
KSB13-39-169	2.0	1.0	1.5
KSB13-39-39	2.5	1.5	2.0
KSB13-39-40	1.0	1.0	1.0
KSB13-39-41	1.5	1.0	1.3

Table 6.5 (continued)

Genotypes	Rust scores		
	Embu	Mwea	Mean
KSB13-39-44	2.5	2.5	2.5
KSB13-39-69	3.5	1.5	2.5
KSB13-45-101	1.0	1.0	1.0
KSB13-47-61	2.0	1.0	1.5
KSB13-47-64	1.5	1.5	1.5
Checks			
Samantha	3.5	1.5	2.5
Teresa	4.0	2.0	3.0
Mean	2.4	1.7	2.1
CV %	58.2		
$LSD_{0.05}$ Genotype	1.84		

Gen=genotype, Loc= location, $LSD_{0.05}$ location=0.4 and $LSD_{0.05}$ Gen x Loc= 2.59

6.3.2.4 Angular Leaf Spot

Significant effects at ($P \leq 0.05$) on angular leaf spot infection were only found in locations and not among genotypes or the interaction between genotype and location (Appendix 11).Angular leaf spot infection on genotypes started at early flowering and advanced to pod maturity. Angular leaf spot severity was higher at Embu with an average score of 4 (moderate resistance) than Mwea which had an average score of 2(Table 6.6). No cases of susceptibility to angular leaf spot were recorded at both sites. It was observed that angular leaf spot was the most severe disease among the three diseases. The resistance to angular leaf spot among lines varied significantly with score ranging from 1 to 4 at Mwea and 2 to 6 at Embu. All the test genotypes were highly resistant at Mwea thus recording scores of 1 to 3. Samantha and Teresa showed moderate resistance (Scores of 4 to 6). On the contrary, 67% of genotypes showed intermediate resistance (scores of 4-6) while 36% of genotypes were highly resistant at Embu. KSB13-39-69 was severely infected with angular leaf spot and recorded the highest score of (6) at Embu (Table 6.6).

Table 6.6: Mean severity scores of angular leaf spot on genotypes grown at Mwea and Embu during 2013 short rain season

Genotypes	Angular leaf spot mean scores		
	Embu	Mwea	Mean
KNSB13-53-219	2.0	1.5	1.8
KNSB13-78-227	3.5	1.5	2.5
KNSB13-78-227a	4.0	1.5	2.8
KNSB13-78-227b	4.0	1.5	2.8
KNSB13-88-229	2.5	1.0	1.8
KNSB13-90-188	2.5	2.0	2.3
KSB13-14-218	4.0	2.0	3.0
KSB13-17-182	4.0	2.0	3.0

Table 6.6(continued)

Genotypes	Angular leaf spot mean scores		
	Embu	**Mwea**	**Mean**
KSB13-20-180	3.0	2.0	2.5
KSB13-20-208	3.5	2.0	2.8
KSB13-22-247	3.0	2.0	2.5
KSB13-23-239	2.0	1.5	1.8
KSB13-23-240	5.0	1.5	3.3
KSB13-23-241	4.0	2.0	3.0
KSB13-23-248	3.5	2.0	2.8
KSB13-23-78	1.5	3.0	2.3
KSB13-29-124	3.5	1.0	2.3
KSB13-30-145	2.5	2.0	2.3
KSB13-30-26	2.5	2.5	2.5
KSB13-30-27	3.0	3.0	3.0
KSB13-38-137	2.5	2.5	2.5
KSB13-39-121	4.0	1.5	2.8
KSB13-39-168	3.0	1.0	2.0
KSB13-39-169	4.0	2.5	3.3
KSB13-39-39	4.0	1.5	2.8
KSB13-39-40	3.5	1.5	2.5
KSB13-39-41	4.0	2.0	3.0
KSB13-39-44	5.0	2.5	3.8
KSB13-39-69	6.0	1.5	3.8
KSB13-45-101	3.5	2.0	2.8
KSB13-47-61	5.0	2.5	3.8
KSB13-47-64	4.0	1.5	2.8
Checks			
Samantha	4.0	4.0	4.0
Teresa	4.0	4.0	4.0
Mean	3.5	2.0	2.8
CV %	47.1		
$LSD_{0.05}$ Genotype	1.84		

Gen= genotype, Loc= location, $LSD_{0.05}$ Loc=0.5 and $LSD_{0.05}$ Gen x loc=2.59

6.3.2.5 Anthracnose

Genotypes did not show significant differences ($P \leq 0.05$) in reaction to anthracnose however location effects were significant (Appendix 11).Disease symptoms were only evident at Embu since all genotypes at Mwea recorded a mean score of one(Table 6.7). Nonetheless, the disease pressure at Embu was very low as indicated by the low anthracnose incidence. Twenty two genotypes had score of 1 to 3 whereas 10 genotypes had scores of 4 to 5. Samantha had a score of 3 while Teresa had intermediate resistance (score of 4) at Embu (Table 6.7).

Table 6.7: Anthracnose severity scores on snap bean lines at Mwea and Embu during 2013 short rain season

Genotypes	Anthracnose scores		
	Embu	Mwea	Mean
KNSB13-53-219	2.0	1.0	1.5
KNSB13-78-227	2.5	1.0	1.8
KNSB13-78-227a	2.0	1.0	1.5
KNSB13-78-227b	2.5	1.0	1.8
KNSB13-88-229	2.0	1.0	1.5
KNSB13-90-188	4.0	1.0	2.5
KSB13-14-218	2.5	1.0	1.8
KSB13-17-182	2.0	1.0	1.5
KSB13-20-180	3.0	1.0	2.0
KSB13-20-208	3.5	1.0	2.3
KSB13-22-247	4.0	1.0	2.5
KSB13-23-239	3.5	1.0	2.3
KSB13-23-240	2.0	1.0	1.5
KSB13-23-241	3.5	1.0	2.3
KSB13-23-248	3.5	1.0	2.3
KSB13-23-78	4.5	1.0	2.8
KSB13-29-124	2.0	1.0	1.5
KSB13-30-145	2.0	1.0	1.5
KSB13-30-26	3.0	1.0	2.0
KSB13-30-27	2.5	1.0	1.8
KSB13-38-137	4.5	1.0	2.8
KSB13-39-121	2.5	1.0	1.8
KSB13-39-168	2.5	1.0	1.8
KSB13-39-169	3.0	1.0	2.0
KSB13-39-39	3.5	1.0	2.3
KSB13-39-40	2.5	1.0	1.8
KSB13-39-41	2.0	1.0	1.5
KSB13-39-44	2.5	1.0	1.8
KSB13-39-69	2.5	1.0	1.8
KSB13-45-101	2.0	1.0	1.5
KSB13-47-61	3.0	1.0	2.0
KSB13-47-64	2.5	1.0	1.8
Checks			
Samantha	3.0	1.0	2.0
Teresa	3.5	1.0	2.3
Mean	2.8	1.0	1.9
CV %	47.5		
$LSD_{0.05}$ Genotype	0.4		
$LSD_{0.05}$ Location	0.3		
$LSD_{0.05}$ Gen x Loc	0.91		

Gen=genotype, loc= location, $LSD_{0.05}$Loc= 0.3 and $LSD_{0.05}$ Gen X Loc=0.3

6.3.2.6 Pod yield and quality distribution

There were no significant differences ($P \leq 0.05$) among genotypes in total pod yield however significant effects due to location and genotype x location interaction were recorded as shown in Appendix 11. Pod yield varied from 2,377 to 18,726 kg ha-^{1} at Embu and from 2,573 to 13,081 kg ha-^{1} at Mwea. Most advanced lines out-yielded the check varieties in both sites with 52% of evaluated lines having a total yield of more than 7,000 kg ha^{-1}. Pod yield was higher at Embu than Mwea.

The mean pod yield at Embu was 10,260 kg ha^{-1} compared to a mean of 7,495 kg ha^{-1}at Mwea. Sixteen lines yielded more than 10,000 kg ha-^{1} at Embu, while such yield was realized in only five genotypes at Mwea (Figure 6.4 and 6.5). KSB13-220-247, KSB13-30-1145, KSB13-88-229, KSB13-38-137, KSB13-23-78, KSB13-23-241, KSB13-30-26, KNSB13-78-227b and KNSB13-90-188 were best yielding lines with a yield range of 11,300 to 18,726 at Embu. KNSB13-39-39, KSB13-39-41, KSB13-22-247 and KSB13-14-218 were regarded as the high yielding at Mwea (Figure 6.4 and 6.5). The lowest pod yield was recorded by KSB13-39-40 at Embu. KSB13-38-137, KSB13-22-247 and KSB13-14-218 had remarkable pod yield of more than 10,000 kg ha-^{1} at both sites. The pod yield of check varieties also varied significantly with locations. Samantha had 3824 kg ha^{-1} at Mwea, and 9724 kg ha^{-1} at Embu, while Teresa had 5723 kg ha^{-1} at Mwea compared with 8224 kg ha^{-1} at Embu.

The advanced lines showed a yield advantage of up to 50% at Embu and 57% at Mwea over the check commercial varieties. Pod distribution varied across genotypes and sites. About 51% of genotypes total pod yield was fine grade at both locations. At Mwea most genotypes formed fine and bobby pods while at Embu genotypes had more of extra fine and fine pods. About 80% of genotypes at Embu produced the highest proportion of fine and extra fine whereas at Mwea 57% of genotypes produced fine grades. Samantha concentrated 59% of the pod yield on fine grade and 25% on extra fine at Embu and 10 5 of extra fine and 30% of fine at Mwea. Teresa formed 19% extra fine pods and 57% fine grades at Embu and 15% extra fine and 37% fine pods at Mwea. (Table 6.8).

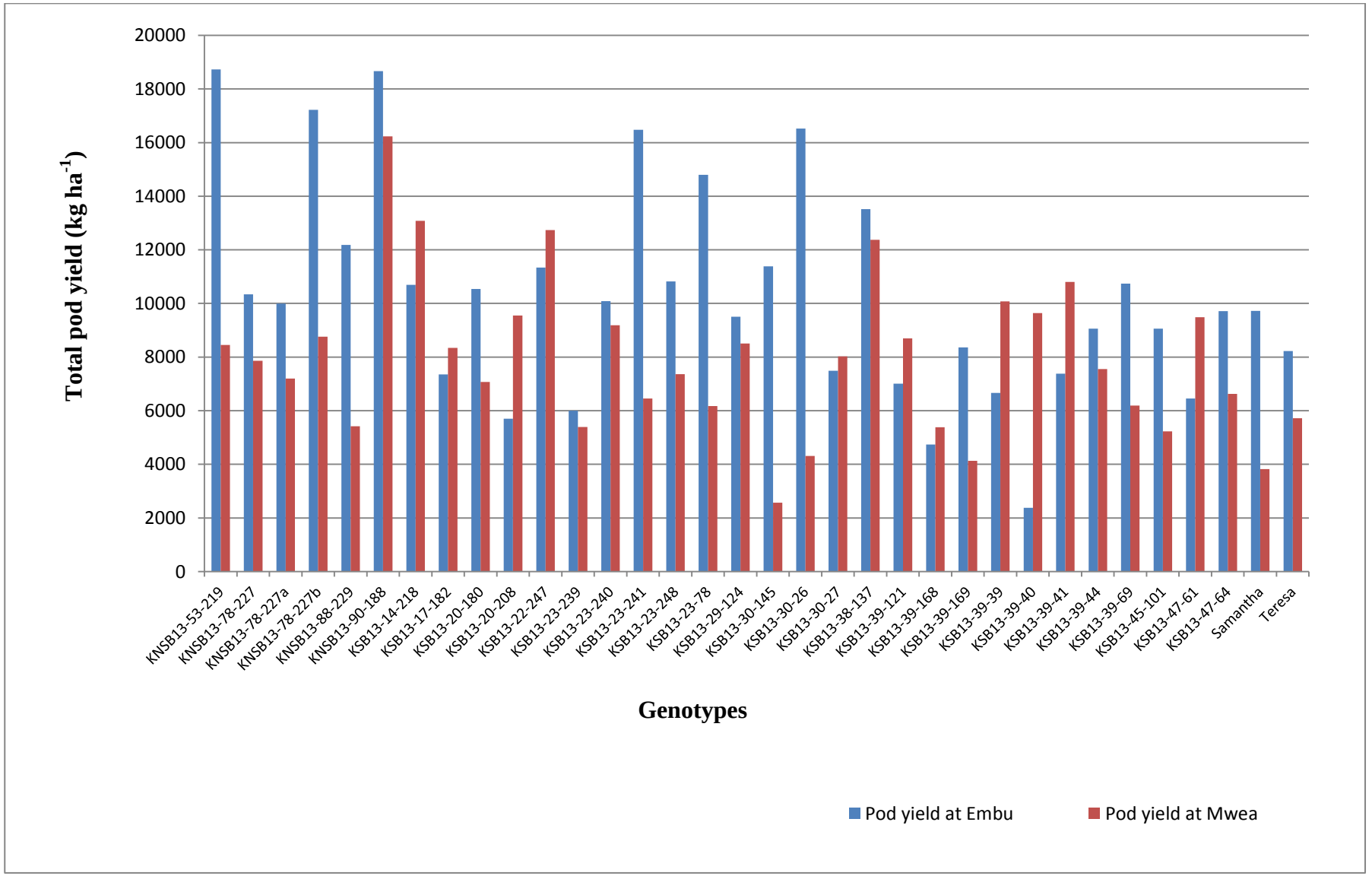


Figure 6.4: Pod yield of advanced snap bean lines at Mwea and Embu during the long rains

Table 6.8:Pod yield (kg ha^{-1}) of snap bean lines and distribution among market classes at Mwea and Embu in 2013 short rains

Genotypes	Total pod yield(kg/ha) and % proportions distribution among market class							
	Embu				Mwea			
	Pod yield (kg ha^{-1})	%Extra fine	%Fine	%Bobby	Pod yield (kg ha^{-1})	%Extra fine	%Fine	%Bobby
KNSB13-53-219	18726	20.1	70.9	9.0	8456	14.3	34.4	51.3
KNSB13-78-227	10341	25.6	48.4	26.0	7865	21.6	33.9	44.6
KNSB13-78-227a	9991	23.2	50.3	26.5	7201	22.9	40.4	36.7
KNSB13-78-227b	17219	26.2	58.4	15.3	8761	24.7	38.6	36.8
KNSB13-88-229	12187	24.4	58.7	16.9	5416	17.2	40.6	42.3
KNSB13-90-188	18663	15.6	72.3	12.1	16,229	29.6	29.6	40.8
KSB13-14-218	10690	23.0	37.9	39.0	13,081	16.8	27.9	55.3
KSB13-17-182	7355	40.9	40.9	18.2	8346	29.1	49.6	21.3
KSB13-20-180	10541	40.4	46.0	13.6	7076	23.9	54.7	21.4
KSB13-20-208	5705	22.2	53.3	24.5	9547	17.0	33.4	49.5
KSB13-22-247	11342	34.0	54.6	11.4	12733	32.9	49.3	17.8
KSB13-23-239	6003	30.6	53.3	16.2	5389	30.6	43.9	25.6
KSB13-23-240	10082	32.3	54.9	12.8	9185	23.9	53.8	22.3
KSB13-23-241	16474	21.0	40.1	38.9	6452	26.1	19.9	54.0
KSB13-23-248	10818	30.4	44.4	25.2	7358	29.3	36.9	33.8
KSB13-23-78	14795	35.1	56.8	8.1	6173	22.2	47.3	30.6
KSB13-29-124	9502	28.2	55.8	15.9	8505	23.5	34.5	41.7
KSB13-30-145	11384	31.2	57.5	11.3	2573	23.6	43.8	32.6
KSB13-30-26	16527	37.2	47.0	15.8	4311	15.3	49.9	34.8
KSB13-30-27	7489	23.4	57.1	19.6	8024	16.9	41.8	41.2
KSB13-38-137	13519	19.3	57.7	23.0	12373	13.5	35.9	50.6
KSB13-39-121	7011	20.9	43.8	35.3	8693	21.6	38.5	39.9
KSB13-39-168	4739	26.2	46.9	26.9	5383	29.3	36.9	33.8
KSB13-39-169	8358	26.4	60.2	13.4	4133	11.6	40.9	47.6
KSB13-39-39	6664	28.7	51.9	19.3	10081	24.9	38.2	36.9
KSB13-39-40	2377	18.7	37.9	43.4	9643	18.0	47.0	34.9
KSB13-39-41	7385	24.2	55.6	20.2	10803	26.5	58.6	14.9
KSB13-39-44	9056	29.2	50.8	19.9	7554	30.9	39.9	29.3
KSB13-39-69	10738	20.8	39.9	39.2	6187	20.8	42.8	36.5
KSB13-45-101	9056	26.8	34.8	38.4	5227	10.9	36.3	52.8
KSB13-47-61	6456	31.9	50.1	17.9	9483	28.5	45.6	25.9
KSB13-47-64	9714	31.3	45.7	23.0	6630	19.6	34.6	45.7
Checks								
Samantha	9724	25.4	59.4	15.2	3824	10.4	30.4	59.1
Teresa	8224	19.1	53.5	27.4	5723	15.1	37.8	47.2
Mean	10,260				7495			
CV %	39.4							
$LSD_{0.05}$ Genotype	4931.6							

Gen= Genotype, Loc= Location, $LSD_{0.05}$ Loc=1196.1 and $LSD_{0.05}$Gen x Loc=6974.4

6.3.2.7 Pod yield per harvest

Harvesting was done for a period of four weeks at two sites. Pod harvesting was done on 3 days a week and started on the fifth week from planting and continued up to the eight week. Therefore a total of 13 harvests were done at each site. Significant effects on pod yield among locations and harvests were observed. Pod yield per harvest was higher at Embu (770.79kgha^{-1}) compared to Mwea (576.58kgha^{-1}).Pod yield was low at first harvest and then peaked on the fourth to the seventh harvests after which the yield declined again to the thirteenth harvest at both sites at Embu (Figure 6.5) . Pod yield at Mwea fluctuated significantly as yield sporadically increased and decreased and peaks were observed on the second, fifth and eighth week. The peak harvesting period was from the fourth to the seventh week at Embu and from the fifth to the eighth week at Mwea (Figure 6.5).

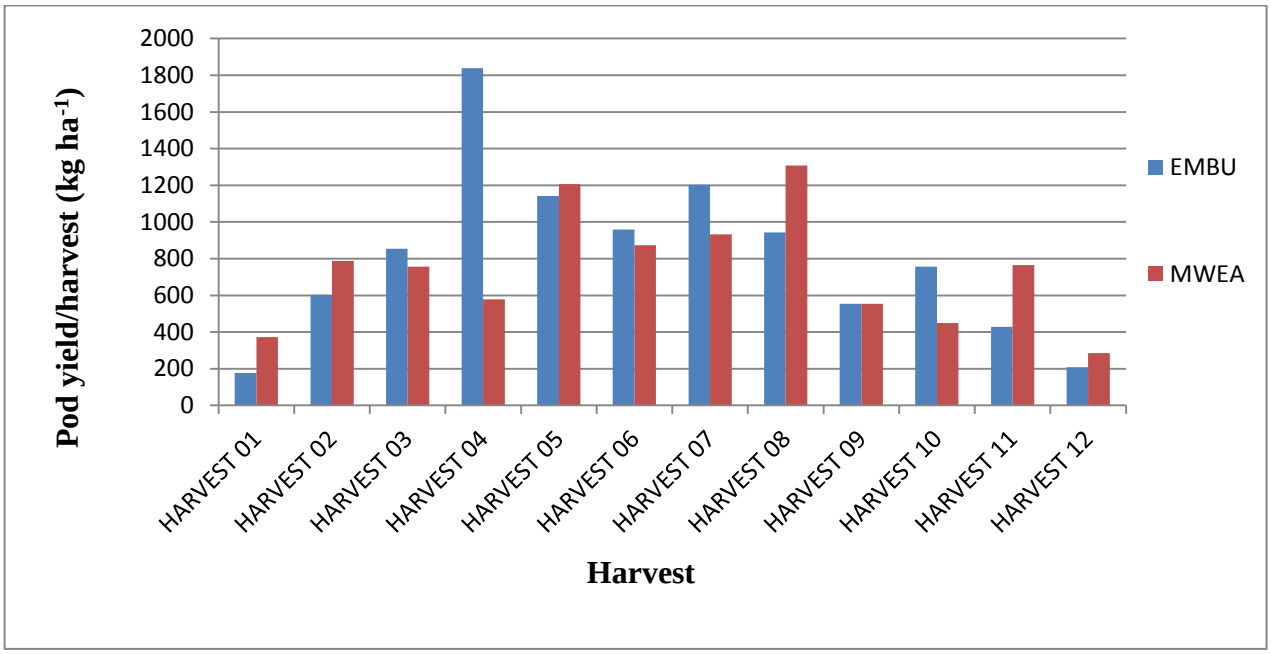


Figure 6.5: Pod yield (kg ha^{-1}) of snap bean lines per harvest at two locations

6.3.2.8 Pod length of snap bean lines

Significant differences (P≤ 0.05) for pod length was detected among genotypes and market grades at both sites (Appendix 11). Genotypes formed longer pods at Embu (average length of 10.1cm) than Mwea (average length of 8.8cm). Bobby and extra-fine pods were 9cm in length and fine pods measured 11cm at Embu, while at Mwea bobby and fine pods were 9 and 10cm in length (Table 6.9). While extra-fine were 8cm in length. At least 50% of advanced lines had the minimum length of 10cm for all marketable grades at both sites (Table 6.9). Samantha had market grades that were less than the minimum length of 10cm at both sites except for fine grade that met the requirement at Embu. On the other hand, Teresa produced fine grade that was more than 10cm at

both sites as well as bobby at Mwea (Table 6.9). On averaging the three grades, 12 lines met the minimum criteria.However the average pod length was less than 10cm in Samantha and Teresa.

Table 6.9: Pod lengths of advanced snap bean lines grown at two locations during 2013 short rains

Genotypes	Pod lengths of genotypes for each market grades							
	Embu				Mwea			
	Ex-fine	Fine	Bobby	Mean	Ex-fine	Fine	Bobby	Mean
KNSB13-53-219	8.6	10.4	9.1	9.4	7.1	8.8	9.5	9.0
KNSB13-78-227	8.0	10.2	9.8	9.3	6.7	7.9	9.5	8.8
KNSB13-78-227a	9.4	11.6	10.9	10.6	8.3	10.9	10.8	10.4
KNSB13-78-227b	8.9	9.4	9.0	9.1	6.5	9.1	9.3	8.8
KNSB13-88-229	5.6	5.4	3.2	4.7	5.6	8.8	9.3	6.1
KNSB13-90-188	6.8	9.1	6.3	7.4	3.5	4.7	4.9	6.1
KSB13-14-218	6.4	7.6	7.0	7.0	5.3	5.3	7.3	6.6
KSB13-17-182	7.4	8.4	4.4	6.7	13.0	12.6	11.1	9.1
KSB13-20-180	9.3	12.0	8.6	10.0	10.4	12.8	7.2	10.0
KSB13-20-208	6.5	10.7	9.0	8.7	7.2	6.8	8.9	8.3
KSB13-22-247	10.4	11.3	11.2	11.0	11.6	13.5	10.5	11.4
KSB13-23-239	9.4	12.7	9.7	10.6	8.9	9.7	8.5	9.9
KSB13-23-240	10.2	14.6	10.5	11.8	9.5	11.4	11.0	11.3
KSB13-23-241	10.9	14.8	15.0	13.6	5.3	4.2	6.3	10.0
KSB13-23-248	11.0	13.8	13.2	12.7	7.5	10.3	9.8	11.2
KSB13-23-78	12.5	15.2	8.9	12.2	10.6	13.7	7.5	11.5
KSB13-29-124	10.5	12.9	10.0	11.1	7.2	9.6	9.3	10.1
KSB13-30-145	10.1	12.9	8.7	10.6	6.1	6.8	5.5	8.7
KSB13-30-26	9.6	12.5	7.0	9.7	5.2	9.4	5.9	8.5
KSB13-30-27	10.1	10.8	7.9	9.6	8.5	8.4	7.4	9.0
KSB13-38-137	9.5	11.2	8.9	9.9	6.3	7.8	9.9	9.1
KSB13-39-121	8.2	10.6	9.9	9.6	8.0	9.8	7.7	9.1
KSB13-39-168	7.6	8.9	8.2	8.2	8.7	12.0	9.7	9.0
KSB13-39-169	10.1	13.5	9.9	11.2	4.9	7.7	9.6	9.6
KSB13-39-39	9.9	12.7	11.6	11.4	10.1	13.0	11.3	11.4
KSB13-39-40	6.5	8.2	6.3	7.0	10.4	13.3	12.7	9.2
KSB13-39-41	8.4	11.1	7.1	8.9	11.0	13.9	14.4	10.7
KSB13-39-44	10.1	13.1	8.8	10.7	8.6	12.5	11.5	10.8
KSB13-39-69	11.1	14.4	12.0	12.5	7.8	9.5	6.0	10.5
KSB13-45-101	8.6	9.6	9.4	9.2	5.8	7.8	9.3	8.5
KSB13-47-61	10.7	12.8	5.1	9.5	9.6	10.8	7.1	9.4
KSB13-47-64	11.1	13.6	12.2	12.3	6.6	7.1	6.0	9.8
Checks								
Samantha	8.2	10.1	9.9	9.4	4.8	5.4	7.7	7.9
Teresa	8.4	10.0	8.4	8.9	7.2	10.0	12.0	9.3
Mean	9.1	11.4	9.0	9.8	7.8	9.6	9.0	9.4
$LSD_{0.05\,(}$Genotype)	1.9							

6.3.2.9 Pod shape, curvature and colour of Snap bean lines

All the genotypes had straight pods .However, the pod colour varied among snap lines with some having either green, light green or green/purple pods (Table 6.10 and Fig 6.6). The purple colour formed a strip along the suture of the pod or small patches along the pods. The intensity purple colouration increased and the pods became completely purple as the crop approached maturity. This purple pod colourations was observed in KSB13-29-124, KSB13-39-121, KSB13-47-61, KSB13-47-64 and KSB13-23-248 (Table 6.10) Samantha had flat pods while the rest of the lines had round pods (Table 6.10).

Table 6.10: Pod curvature, shape and colour of advanced snap bean lines at Mwea and Embu

Genotypes	Pod shape	Pod curvature	Pod colour
KNSB13-53-219	straight	round	green
KNSB13-78-227	straight	round	green
KNSB13-78-227a	straight	round	green
KNSB13-78-227b	straight	round	light green
KNSB13-88-229	straight	round	green
KNSB13-90-188	straight	round	green
KSB13-14-218	straight	round	green
KSB13-17-182	straight	round	green
KSB13-20-180	straight	round	light green
KSB13-20-208	straight	round	light green
KSB13-22-247	straight	round	light green
KSB13-23-239	straight	round	green
KSB13-23-240	straight	round	green
KSB13-23-241	straight	round	green
KSB13-23-248	straight	round	green/purple
KSB13-23-78	straight	round	light green
KSB13-29-124	straight	round	green/purple
KSB13-30-145	straight	round	green
KSB13-30-26	straight	round	green
KSB13-30-27	straight	round	light green
KSB13-38-137	straight	round	light green
KSB13-39-121	straight	round	green/purple
KSB13-39-168	straight	round	light green
KSB13-39-169	straight	round	light green
KSB13-39-39	straight	round	light green
KSB13-39-41	straight	round	light green
KSB13-39-44	straight	round	green
KSB13-39-69	straight	round	light green
KSB13-45-101	straight	round	green/purple
KSB13-47-61	straight	round	green

Table 6.10 (continued)

Genotypes	Pod shape	Pod curvature	Pod colour
KSB13-47-64	straight	round	green/purple
Checks			
Samantha	straight	flat	light green
Teresa	straight	round	light green

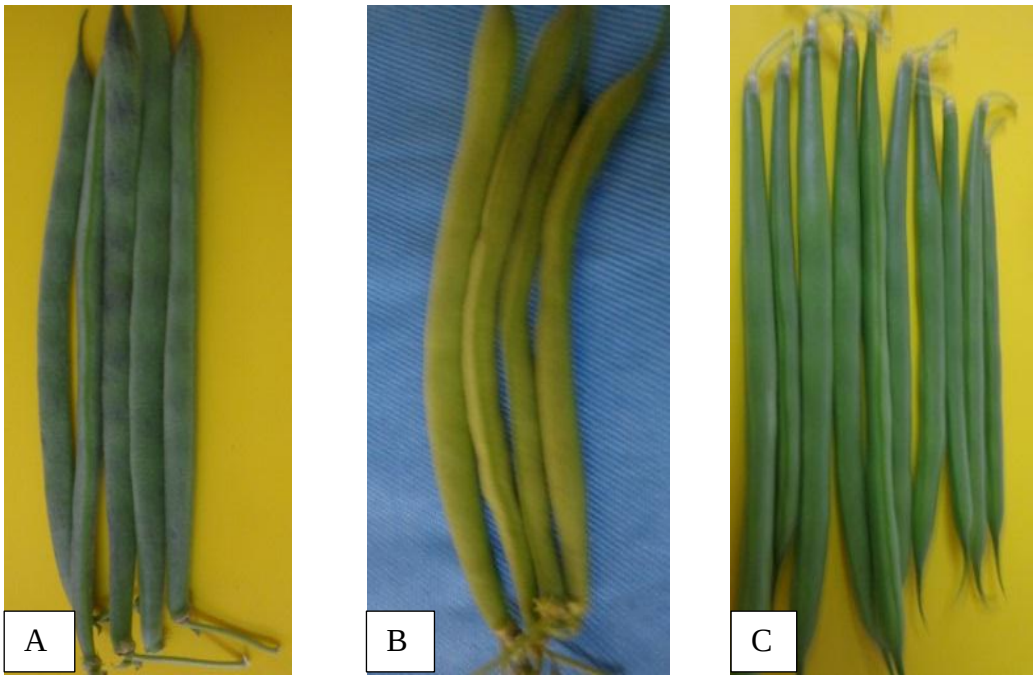
6.3.2.9. Selection of best snap bean lines

The best fifteen lines were identified on basis of yield, pod traits (pod shape, length and curvature) and disease resistance in descending order of importance (Table 6.11). The index selection was based on the mean performance of the lines at the two sites for all studied traits except for disease resistance which was based on performance of genotypes per location. The cumulative pod yield of these lines was significantly higher than commercial varieties used as checks and ranged from 8,800 to 13,591kgha^{-1} at both sites (Table 6.11).These lines flowered in 34 to 35 days at both sites. All selected lines had straight pods with a round cross sectional pod shape. This pod shape and curvature was similar to check varieties except for Samantha which had flat pods. Among the selected lines, six were found to have light green pods, seven had green pods and two lines had green/purple pods.

The selected lines apportioned much of the pod yield to extra fine and fine pods at Embu and fine and bobby pods at Mwea (Table 6.8).The lines also met the required minimum length of 10cm except six lines. Although disease pressure was low, the selected linesad disease scores ranging from 1 to 6 for the three diseases (Table 6.11).

Table 6.11:Selection of best advanced lines based on index selections for preliminary and advanced trials at Mwea an Embu

Genotypes	Overall performance of the top 15 selected lines											
							Rust scores		ALS scores		Anthracnose scores	
	Pod Yield (kg $^{-1}$ ha $^{}$)	Pod length (cm)	Days to flowering	Pod shape	Pod curvature	Pod colour	Embu	Mwea	Embu	Mwea	Embu	Mwea
KSB13-20-180	8809	10.0	34	straight	Round	light green	3.0	1.0	3.0	2.0	3.0	1.0
KSB13-29-124	9004	10.6	34	straight	Round	green/purple	3.5	4.0	3.5	1.0	2.0	1.0
KSB13-23-248	9088	11.9	34	straight	Round	green/purple	2.0	1.5	3.5	2.0	3.5	1.0
KSB13-39-41	9094	10.0	34	straight	Round	light green	1.5	1.0	4.0	2.0	2.0	1.0
KNSB13-78-227	9103	9.1	34	straight	Round	green	2.5	1.5	3.5	1.5	2.5	1.0
KSB13-23-240	9634	11.6	34	straight	Round	green	2.0	1.5	5.0	1.5	2.0	1.0
KSB13-30-26	10419	9.1	34	straight	Round	green	3.5	2.5	2.5	2.5	3.0	1.0
KSB13-23-78	10484	11.9	34	straight	Round	light green	2.0	1.0	1.5	3.0	4.5	1.0
KNSB13-90-188	10646	6.8	34	straight	Round	green	3.0	2.0	2.5	2.0	4.0	1.0
KSB13-23-241	11463	11.8	35	straight	Round	green	1.0	1.5	44.0	2.0	3.5	1.0
KSB13-14-218	11886	6.8	34	straight	Round	green	3.5	1.0	4.0	2.0	4.0	1.0
KSB13-22-247	12038	11.2	34	straight	Round	light green	1.5	1.0	3.0	2.0	4.0	1.0
KSB13-38-137	12946	10.0	34	straight	Round	light green	1.5	3.0	2.5	2.5	4.5	1.0
KNSB13-78-227b	12990	8.9	34	straight	Round	light green	3.0	1.5	4.0	1.5	2.5	1.0
KNSB13-53-219	13591	9.2	34	straight	Round	green	2.0	1.5	2.0	1.5	2.0	1.0
Samantha	6774	8.6	35	straight	Flat	light green	3.5	1.5	4.0	4.0	3.0	1.0
Teresa	6974	9.1	35	straight	Round	light green	4.0	2.0	4.0	4.0	3.5	1.0



A. Green/purple pods **B**. Light green pods and **C.** Dark green pods

Figure 6.6: Pod colour of snap bean lines

6.4 Discussion

6.4.1 Preliminary evaluation of snap bean lines at Mwea

The 30 selected lines were vigorous even under water logging stress indicating the vegetative vigor as a function of host plant resistance to diseases .Even though intermediate resistance was observed in some lines, the selected lines had mean disease scores of 1 to 3 for all the three diseases which showed that the lines carried resistance genes to rust, angular leaf spot and anthracnose. Selected lines had more pods and higher seed yield. The selected lines had straight pods or slightly curved with round cross-section.Myers (1999) noted that such pod characteristics were the most important aspects of snap bean cultivars. Out of the 231 lines that were evaluated at Mwea, 33 lines resistant to angular leaf spot, anthracnose and rust and had good pod quality were selected for further evaluation at two locations.

6.4.2 Advanced yield evaluation at Mwea and Embu

6.4.2.1 Growth vigor

There were no significant difference in growth vigor among genotypes and sites indicating that these genotypes can perform well under similar field environments. Intermediate vigor observed in

some genotypes and among check varieties was attributed to adverse climatic conditions and disease effect. Stenglein et al. (2003) reported that angular leaf spot causes serious and premature defoliation resulting in poor vigor, shriveled pods, shrunken seeds and yield losses of up to 80%.Most genotypes were highly vigorous (score 1-3) and therefore selection of such genotypes is an important prerequisite to high yields.

6.4.2.2 Days to 50% flowering

The results showed that advanced lines and check varieties flowered almost at the same time. However, duration to flowering was influenced by location. Great variations were due to site effects therefore, genotypes flowered earlier at Mwea that is mainly warm with temperatures of up to 28^{o}C and delayed flower induction as opposed to Embu due to cooler conditions (mean temperature 16^{o}C). Wallace et al. (1991) reported that bean genotypes flowered significantly earlier when temperatures were increased within the range of 12-28^{o}C. The early flowering genotypes at both sites could be selected.

6.4.2.3 Reaction of snap bean lines to rust infection

In this study the severity of rust was very low at both locations. The advanced lines showed a high level of resistance to rust infection than the check varieties which were moderately resistance under the test environments. Although rust is the most serious disease of snap beans, its occurrence can be erratic depending on prevailing weather conditions (Monda et al., (2003); Wahome et al. (2011). In Kenya, Arunga et al. (2012) revealed that the rust races in Western regions (Kisii, Kitale and Eldoret) were more virulent than races in central region of Embu, Mwea and Thika where the study sites were located. The low disease scores observed in this study could be due to the reported low incidence of rust and the drier conditions experienced in these sites. Results suggested that the studied genotypes possess rust genes which confer resistance to races present in these locations. Teresa has been reported by Wasonga et al. (2010) to possess *Ur-5* gene which is effective to 70 races of rust. However, the intermediate resistance observed at Embu shows the loss of resistance among commercial varieties. Pastor Corrales et al. (2010) has also shown that break down of resistance among released varieties due to appearance of new races. Also, the moderate resistance of Teresa at Embu may imply that the race that overcomes *Ur-5* gene is present at this site at relatively low frequencies. Rust infection was more advanced at Embu than Mwea due to favourable cooler environmental conditions. Alzte-marin et al. (2004) that sporulation of rust is increased when plants are exposed to high humidity. Twenty two lines which were highly resistant to rust were identified.

6.4.2.4 Reaction of snap bean lines to angular leaf spot

Angular leaf spot (ALS) was the most severe disease at both sites. The genetic variation among genotypes showing resistance and moderate resistance in reaction to infection by angular leaf spot disease in this study indicates the greater variability that is in *Pseudocercospora griseola* (causal agent of ALS). Silva et al., (2008) reported that *P.griseola* is highly variable and has several physiological races. Mwang'ombe et al. (2007) reported that angular leaf spot is highly prevalent and often severe across all agro-ecological zones and altitudes in Kenya where bean are grown. The higher disease severity at Embu than Mwea was attributed to climatic conditions and irrigation effect. Furrow irrigation was used at Mwea however the sprinkler irrigation used at Embu may have contributed to a more humid environment favourable for disease development. According to Rotem (1969) sprinkler irrigation in particular enhances diseases development by creating humid conditions that favour host infection therefore accelerating foliar disease development. Monda et al. (2003) showed similar results that foliar fungal diseases such as rust and angular leaf spot were a major problem where overhead irrigation was practiced. Regardless, of the favourable climatic conditions no susceptible lines were observed. Thirteen lines resistant to angular leaf spot were selected. These lines may have inherited resistant genes to angular leaf spot from Mex 54 which has been found to be resistant to most African *P. griseola* isolates that have been characterized (Mahuku et al., 2009).The intermediate resistance observed in commercial varieties Samantha and Teresa confirms results obtained by Wahome et al.(2011).

6.4.2.5 Reaction of snap bean lines to anthracnose

The high temperatures and low rainfall at Mwea were not favourable for development of anthracnose. Anthracnose development is favoured by by cooler conditions, relative humidity of 85% combined with frequent heavy rainfall cooler conditions (Mohammed and Somsiri 2007). In contrast cooler conditions at Embu (1494m.a.s.l) may have contributed to higher anthracnose infection compared to Mwea (1204m.a.s.l). Twenty one lines that showed high levels of resistance to anthracnose at both sites were selected .These lines have carried *Co* genes for resistance to anthracnose from G2333 used during population development. G2333 has *Co-4*, *Co-4*, *Co-5* and *Co-6* which have been widely used in breeding programs (Kelly and Vallejo, 2004).

6.4.2.6 Pod yield

Results of this study showed that there were significant genotypic and location effects for pod yield among the test lines. The lines at Embu had a mean yield advantage of 58% compared to Mwea. The higher pod yield at Embu was probably due to cooler conditions and relatively more fertile soils thus most advanced lines had higher pod yields at Embu than Mwea. According to

HCDA (1996) French bean give higher yields in cool weather and its production is best suited to friable loam soil that is well drained with high levels of organic matter. Kamanu et al. (2012) reported that soils in Mwea have very low nitrogen levels (0.09 to 0.12 %) and that yields can be increased by application of fertilizers with high nitrogen concentrations such as diammonium phosphate and Calcium ammonium nitrate.

Warmer temperatures at Mwea resulted in early flowering which may have further caused flower and pod abscission and reduce yields. Gross and Kigel (1994) found that the poorest pod setting was observed in common been exposed to high temperatures before flowering. Extreme temperatures and low rainfall can result in poor flower development and poor pod set (Infonet Biovision, 2011). Resistant varieties achieve higher yields even when under disease pressure (Mooney, 2007). This is well demonstrated by advanced lines out yielding check varieties which had intermediate resistance at Embu. Also, the high organic matter and ambient cooler temperatures provided suitable conditions for snap bean production.

The results of this study showed that these lines can be harvested up to 13 harvests. Therefore, the duration of pod picking in these lines can be up to a month if harvesting is done three days in a week as observed in this study but when harvesting is done twice a week then pod picking can be extended to two months. However, pod yield increase to a peak bythe fourth harvest and can extend tothe eight harvest. Harvesting should be done at this stage to avoid over grown pods which may not meet market demands. The study also showed that frequency of harvesting the test lines affected the pod set. For instance, the one day interval to harvesting that was done in this study enhanced pod set and reduced harvesting of overgrown or immature pods. It was observed that grade distribution varied with the number of harvests. In the first eight harvests, the lines yielded extra fine and fine grades but as harvesting continued the yield of premium grades decreased and bobby pods were formed. This was observed among the test lines and across locations. Based on the results of this study, the optimum pod yield of the test lines is at the fourth and eighth harvests therefore harvesting can be done within a month to achieve economical yields.

6.4.2.7 Pod characteristics

The preferred pod requirements for export market are pods that are extra fine (6 mm), fine (6-8 mm) and bobby (>8 mm) with length above 10 cm (HCDA, 2009). Majority of the test lines satisfied these conditions and had quality pods that could meet the export standard. Twelve lines at Mwea and 22 lines at Embu satisfied these specifications while 11 lines at both sites met all the preferred requirements.

These results indicate that these parental traits were successfully recombined and transmitted to the progeny. For instance, lines apportioned much of the yield to fine and extra fine grade which are the main marketable grades for export market. Ndegwa et al. (2009) has also revealed that most commercial snap bean cultivars are meant to produce extra fine and fine pods. The lines that had pods more than 10cm were selected as the minimum length requirement of snap beans. Most lines met the minimum 10cm pod length requirement of snap bean as reported by (Muchui, 2001). Snap bean lines formed longer pods at Embu than Mwea due to the interplay of prolonged soil moisture, good soil fertility and adequate rainfall. All advanced lines had straight and round pods which is a unique specification for quality snap varieties. The advanced lines varied in pod colour from light green, green, dark green and purple. This is attributed to the fact that the advanced lines could have inherited pod colour from the parents. Myers (1999) reported that pod colour of snap bean ranges from light green, green to dark green. He also noted that the purple podded snap cultivars exist but are not used commercially; therefore these lines can be exploited for production of purple pods which can be used for salads.

6.4.2.8 Multiple disease resistance combined with high yield and market preferred pod quality

Fifteen lines were identified to combine multiple resistances to rust, angular leaf spot and anthracnose with high yield and marketable pod traits at both locations. These results show the existence of resistance genes to the three diseases among these lines. Growing cultivars that possess multiple disease resistance has been known to minimizes crop losses, reduces the need for agrochemicals, and lowers production costs (Nene 1988; Fininsa and Tefera, 2007).Therefore, these identified lines as shown by their yield performance and pod traits are promising enough to be sources of resistance and should be evaluated in national performance trials were there is high disease pressure.

6.5 Conclusion

The advanced lines were found to flower within 29 to 31 days at Mwea and 37 to 39 days at Embu.Therefore, flowering of these lines is earlier in warmer areas like Mwea.

Results of this study indicate that it was possible to combine multiple resistance to major diseases (rust, angular leaf spot and anthracnose), high pod yield and pod quality in snap beans.

Most lines performed better under moist and cooler conditions of Embu than warmer conditions of Mwea.Most of the developed snap bean lines out yielded the existing commercial varieties. From the study, these lines can be harvested in a period of 4 weeks.

The selected lines as shown by their resistance to diseases, pod yield performance and market preferred characteristics merit them to be exploited in development of resistant snap bean varieties. The new types of pod colour green/purple and light green can be utilized in salads.

CHAPTER SEVEN

PARTICIPATORY VARIETY SELECTION (PVS) OF SHORT-DAY ADAPTED GRAIN RUNNER BEAN LINES

Abstract

Runner bean is an underutilized vegetable and grain legume crop that performs well in areas that are often marginal for common bean production. Little is known about the grain type runner bean since most research work has focused on other grain legumes. The small number of runner bean growers and processors rely on unimproved local landraces which are low yielding. Participatory breeding can enhance awareness, sustainable access and adoption of new varieties by farmers and other end-users. The objective of this study was to involve farmers in evaluation and selection of new high yielding grain type runner bean lines and familiarize them with commercial production of vegetable runner beans. This experiment was laid in completely randomized design during the 2012 long rain season at Ol Joro-Orok-KALRO station in Nyandarua County. $F_{6.7}$ single plant selections from the 2011 lines planted during 2012 long rains were the plant materials used. These lines had been initially developed from crosses between short-day local landraces and high yielding vegetable long-day varieties. At pod maturity test lines were evaluated for farmer preferences. The exercise involved 12 farmers from five sub-locations around Ol Joro-Orok area. The ribbon method of PVS was demonstrated and farmers were allowed to use their own evaluation criteria to select for preferred and non-preferred lines. The data was analyzed based on the counts of votes cast by farmers. Results showed that the positive criteria used by farmers in selecting runner bean were based on earliness to maturity, uniform pod distribution per plant, good climbing ability, white grain colour, many pods per plant, good plant stand count and pods with well filled grains. Negative criteria included late maturity, other seed colours apart from white seeds, few pods per plant and shorter pods with no grains. About 99 % of farmers were not aware of the local production of vegetable runner bean and showed great interest of participating in the production for export. Men preferred lines that retain foliage even at maturity which can be used as livestock feed. Women preferred lines that shed leaves at maturity and preferred white coloured seed over other colours. The findings show that scientists should consider developing runner bean varieties which are early maturing, have many pods per plant, longer pods with well filled seeds, and high seed yield to improve adoption of new varieties by farmers. The selected lines by farmers from this study can be utilized for further evaluations or improvement of runner bean since they possess farmer preferred traits.

Key words; Runner bean, participatory variety selection

7.1 Introduction

Runner bean (*Phaseolus coccineus*) is produced for both dry grain and fresh pods. In Kenya, runner bean is produced in Nyandarua County for immature seed or dry grain. In Timau and Nanyuki regions on the slopes of Mt. Kenya, and Naivasha the crop is produced as vegetable pods for export. The dry seeds or immature beancan be consumed in mixtures with maize or made into stews for other meals. Despite its potential as an alternative grain legume, runner bean has received little attention compared to other legumes grown in Kenya. Small scale farmers who produce grain type runner beanmainly rely on local landraces which are low yielding and seeds are mixed. Production of vegetable runner bean pods is mainly done by large scale producers who install costly artificial additional light to enhance flowering of imported long-day varieties.

To overcome these constraints, a breeding program was started at the University of Nairobi in 2004 to develop tropically adapted short-day high yielding and disease resistant grain and vegetable type runner bean (Kimani et al., 2005a). Runner bean populations were developed in 2004 from crosses between five short-day local landraces (Kin 1, Kin 2, Kin 4, Kenya local and Nyeri) as male parents and one female imported variety White Emergo (Kimani et al., 2005b). Progenies from the crosses were advanced through bulk population method up to F_5 generation when selection began. About 1154 single plant selections with good pod quality were selected from F_5 bulk populations and grown at Ol Joro-orok, Subukia and Kabete Field Station during the 2009 long rain season. These single plant selections were used to establish progeny rows during the 2009 short rain season and families during 2010 long rain season (Kimani, 2009). Selections within and among families continued up to $F_{6.7}$ generation. Selected families were then constituted into a working collection that was used in this study.

However, farmers were not involved in the previous stages of the runner breeding program in Kenya. Gemechu et al. (2004) emphasized that farmers should participate in breeding process right from the beginning because they have their own selection criteria regardless of the yield potential of varieties released by breeders. Doss (2005) reported that the reasons as to why farmers do not adopt new technologies or varieties is because they are not aware of them or the technologies are not available to them or that they don't meet their preferences. Farmer preferences to be incorporated in new varieties can be identified through participatory variety selection (PVS). This approach is a selection process of testing released or promising genotypes in farmer's field (Yadaw et al., 2006). PVS has been identified as an effective method that helps to identify acceptable varieties and hence overcome reliance on obsolete varieties (Witcombe et al., 1996).This process has also been proved to increase efficiency of research scientist, farmers' knowledge and adoption rate of new varieties (Bellon, 2001).Knowledge of farmers is therefore necessary in developing strategies of improving runner bean in Kenya. In the quest of knowing the

farmers interest and selection, a PVS on locally developed runner beanwas done with collaboration with Ol Joro-Orok (KALRO) station. The objective of the study was to identify farmer preferences and selection criteria for grain runner bean varieties.

7.2 Materials and Methods

7.2.1 Plant materials used

The study materials were 86 $F_{6.7}$ lines which were initially developed from crosses between short-day local landraces from Nyeri, Kinangop and Ol Joro-Orok parents and one long-day parent (White Emergo). Progenies from the crosses were advanced through bulk population method up to F_5 generation when selections began. About 1154 single plant selections were selected from F_5 bulk populations which were grown at Ol Joro-Orok, Subukia and Kabete Field Station during the 2009 long rain season. These single plant selections were used to establish progeny rows during the 2009 short rain season and families during 2010 long rain season. Continuous selections were again done within and among families up to $F_{6.7}$ generation that was planted during 2012 long rains for this study. These populations had not been previously selected by farmers and other end users.. It was therefore necessary to involve farmers' selection criteria alongside the breeder's objectives to facilitate efficiency of the research and adoption of improved varieties.

7.2.2 Farmer Selection

The farmers who were involved in production of grain type runner bean for subsistence or sale in local markets were selected for this study. A total of twelve farmers were recruited for the exercise. These farmers included 6 men and 6 women representing 5 sub locations around the Ol Joro-Orok (Nyandarua County) area namely; Ol Jabet, Gathanji, Nyakarianga, Bahati and Gatumbiro.

7.2.3 Trial sites

The experiment was conducted at Ol Joro-Orok- KALRO station which located in Nyandarua County at an altitude of 2300m a.s.l. The mean annual rainfall is 1000mm, distributed in a bimodal pattern which permits two cropping seasons in March to August and October to December as shown in Table 7.1. The mean maximum temperatures are 22^{o}C and mean minimum temperatures are 10-16^{o}C .The soils dominating the area are planosols (Jaetzold et al., 2006). These soils are deep, imperfectly drained, firm and very dark greyish brown in colour. The area has favorable climatic conditions for the production of runnerbeanfor both domestic consumption and for commercial purposes. The area accounts for 77% of total runner bean production in Kenya (HCDA, 2013).

Table 7.1 Runner bean cropping calendar during long rains at Ol Joro-Orok

	2012												2013	
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb
Planting														
Weeding														
Harvesting														
Rainfall reliability														
PVS Exercise														

7.2.4 Experimental design and crop husbandry

This trial was conducted between April 2012 long rains to January 2013. Genotypes were planted in April 2012and harvested in January 2013. The experiment was laid in a randomized complete block design with three replications. A plot size comprised of a single row of 2m length with spacing of 75 x 30 cm. The lines were planted using pod to progeny row method. Each plot was planted with seeds from a single plant. The crop was weeded as necessary. The experiments were planted as bean monoculture using wooden stakes to support each individual plant. Insect pests were controlled by alternate application of Cyclone® (10% cypermethrin + 35% chlorpryphos) and Confidor® (imidacloprid) at the rate of 1.5ml L^{-1}. The pods were allowed to dry while on the plant.

7.2.5 Preparation for the participatory selection

Each plot was clearly numbered by tagging on wooden pegs (Fig 7.1). Each row had a maximum of 5 seeds put in a transparent zip lock bag and placed below the tag for easy visibility of the seed colour. Medium sized polythene paper bags were tied on one of the first plant of each line (Fig 7.6). The lines were evaluated when at pod maturity and ready for harvesting. The two types of pod shapes (curved and straight) were clearly distinguished. Four types of threads; red, black, white and yellow were used for selection as shown below in Figure 7.1.

Figure 7.1: Grain runner bean seeds used in PVS

7.2.5 Selection Procedure

Farmers were explained about the trial design and field layout. They were allowed to familiarize with the field layout before evaluating the lines (Fig 7.2C). After that, farmers were grouped based on gender. Farmers were allowed to select a colour denoting a 'like', and the other a 'dislike'. Men chose yellow ribbons color for 'like', and red ribbons for 'dislike'. Women chose white for 'like' and black for 'dislike' (Figure 7.2B). Each male and female farmer was provided with two ribbons of different colors.

A. Ribbons used for selection, B. farmers select ribbons and C. familiarize with the field

Figure 7.2:Farmers are familiarized with the field and selection ribbons before PVS exercise

Each farmer received at least 20 ribbons for 'likes' and 20 for 'dislikes'. Farmers were then allowed to evaluate the lines and were asked to select 20 best lines that they liked; and the worst 20 lines that they disliked very much based on their own criteria. A demonstration was done on how to put the ribbons in the polythene bags tied on the first plant of each plot. Later, the ribbons were removed and tied on wooden pegs placed near each plot. Farmers were advised to make individual choices based on their taste and preferences without the influence of others as shown in the picture below. After the selections were done, all the ribbons in each polythene bag were removed and tied on the wooden peg for that plot.

Figure 7.3: Female and male farmers evaluating the new grain runner bean lines at dry pod maturity

7. 3 Results

The crop was planted during the onset of long rains in April 2012 at Ol Joro-Orok. This is the period when rainfall is very reliable in the entire cropping season. This provided good crop growth conditions accompanied by the low temperatures at the location. Therefore the conditions were favourable for crop growth (Table 7.1). Before the exercise, farmers were asked of their knowledge on vegetable runner bean. From the responses only one farmer was aware of vegetable runner bean produced by large scale companies for export. From the PVS exercise 86 lines were evaluated by farmers (Table 7.2).

Farmers used agronomic performance attributes when selecting the genotypes. Farmers' preference of a line was based on number of pods, good grain fill, uniformity at pod maturity, earliness, uniform pod distribution on the plant (base to top of plant), high stand count per row, grain colour (mostly white). Both men and women gave much priority on many pods per plant, good stand count and longer pods with filled seeds. 40 lines were liked by all farmers who cast their votes and 20 were disliked by 80% of the farmers. SUB-OL-RB-10-275-2 was the most disliked line by farmers due to low pod yield (Table 7.2).

It was noted that 70% of farmers preferred the white coloured seeds and pods that were curved or slightly curved. Men and women differed in their preferences and hence selection criteria (Table 7.3). For example, male farmers preferred lines that were early maturing, had good pod distribution and retained foliage at maturity as alternative form of fodder to animals. On the other hand, women preferred lines with good climbing ability, lines that were completely dry with no foliage at maturity for easy harvesting and white coloured beansbecause they take less time to cook when used in local dishes as 'Githeri'.

Both male and female farmers rejected lines that had few or no pods, shriveled pods, short pods and had more vegetative foliage with very few pods. It emerged that farmers gave more priority to pod yield (many pods per plant), good pod distribution within the plant, uniformity at pod maturity, stand count, grain filling, earliness to maturity, pod length (long pods with more grains were preferred most and pod size (big pods with filled grains were preferred most). Less priority was given to pod shape and curvature (whether straight or curved), diseases and industrial purposes (straight pods as vegetable runner bean for export).

Table 7.2: Votes of preferred and non-preferred lines as selected by farmers

Genotypes	Preferred by men	Preferred by women	Not preferred by men	Not Preferred by women	Total preferred votes	Total non-preferred votes	Total votes cast	Grain color	Pod shape
KAB-RB-09-83/1-2	5	6	0	0	11	0	11	White	slightly curved
OL-OL-RB-10-38-2	5	6	0	0	11	0	11	White	slightly curved
OL-OL-RB-10-22-1	3	8	1	0	10	1	12	White	Curved
OL-OL-RB-10-10-3	4	6	0	0	10	0	10	Black/Purple speckled	Curved
OL-OL-RB-10-21-2	5	5	0	0	10	0	10	White	slightly curved
OL-OL-RB-10-30-3	6	4	0	0	10	0	10	White	Curved
OL-OL-RB-10-33-3	5	5	0	0	10	0	10	White	Curved
SUB-OL-RB-10-186-2	4	6	0	0	10	0	10	White	slightly curved
SUB-OL-RB-10-226-3	4	6	0	0	10	0	10	Black/Purple speckled	Curved
SUB-OL-RB-10-305-3	5	5	0	0	10	0	10	White	Straight
OL-OL-RB-10-21-1	4	6	0	0	10	0	10	White	Straight
KAB-OL-RB-10-446-2	4	6	0	0	10	0	10	White	slightly curved
KAB-OL-RB-10-426-2	4	5	0	0	9	0	9	Black/Purple speckled	Curved
KAB-OL-RB-10-522-1	4	5	0	0	9	0	9	Black/Purple speckled	Straight
KAB-OL-RB-10-547-3	4	5	0	0	9	0	9	Black	Curved
SUB-OL-RB-10-186-3	4	5	0	0	9	0	9	Black/Purple speckled	Curved
SUB-OL-RB-10-323-3	6	3	0	0	9	0	9	Black/Purple speckled	Curved
OL-OL-RB-10-33-1	3	6	0	0	9	0	9	White	Curved
OL-OL-RB-10-38-3	6	3	0	0	9	0	9	Purple/Black speckled	slightly curved
SUB-OL-RB-10-288-2	3	6	0	0	9	0	9	White	slightly curved
SUB-OL-RB-10-305-1	5	4	0	0	9	0	9	White	Straight
OL-OL-RB-10-38-1	5	4	0	0	9	0	9	Black/Purple speckled	slightly curved
KAB-OL-RB-10-606-2	3	6	0	0	9	0	9	White	slightly curved
SUB-OL-RB-10-190-2	5	4	1	1	9	2	11	White	slightly curved
SUB-OL-RB-10-209-1	4	5	1	1	9	2	11	Black/Purple speckled	Curved
SUB-OL-RB-10-221-1	5	4	1	1	9	2	11	Purple/Black speckled	Curved
SUB-OL-RB-10-228-3	4	5	0	0	9	0	9	White	Curved

Table 7.2 (continued)

Genotypes	Preferred by men	Preferred by women	Not preferred by men	Not Preferred by women	Total preferred votes	Total non-preferred votes	Total votes cast	Grain color	Pod shape
KAB-OL-RB-10-440-1	6	2	0	0	8	0	8	White	slightly curved
KAB-OL-RB-10-660-2	3	5	2	0	8	2	10	Black	Curved
SUB-OL-RB-10-283/1-2	5	3	0	0	8	0	8	Black	Curved
SUB-OL-RB-10-318-3	3	5	0	0	8	0	8	Black/Purple speckled	Straight
SUB-OL-RB-10-331-3	2	6	0	0	8	0	8	White	slightly curved
KAB-OL-RB-10-470-2	3	5	0	0	8	0	8	Black/Purple speckled	Straight
OL-OL-RB-10-22-2	2	6	0	0	8	0	8	White	slightly curved
OL-OL-RB-10-34-1	3	5	0	0	8	0	8	White	Curved
SUB-OL-RB-10-212-1	5	3	0	1	8	1	9	White	slightly curved
SUB-OL-RB-10-241-1	5	3	1	0	8	1	9	Black	Curved
KAB-OL-RB-10-649-2	3	4	2	0	7	2	9	Black/Purple speckled	Straight
KAB-OL-RB-10-697-3	3	4	2	1	7	3	10	Black/Purple speckled	Curved
OL-OL-RB-10-39-2	5	2	0	0	7	0	7	White	Curved
OL-OL-RB-10-39-2	3	4	2	1	7	3	10	White	slightly curved
SUB-OL-RB-10-178-1	2	5	0	0	7	0	7	White	slightly curved
KAB-OL-RB-10-322-2	3	4	1	0	7	1	8	White	slightly curved
OL-OL-RB-10-64-2	2	5	0	0	7	0	7	White	Curved
OL-OL-RB-10-34-3	4	3	0	0	7	0	7	White	Curved
KAB-OL-RB-10-500-2	3	4	0	0	7	0	7	Purple/Black speckled	Curved
OL-OL-RB-10-11-1	2	5	0	0	7	0	7	White	slightly curved
OL-OL-RB-10-75-1	3	4	0	1	7	1	8	White	Curved
SUB-OL-RB-10-240-3	2	5	0	0	7	0	7	White	Straight
OL-OL-RB-10-67-1	2	5	2	2	7	4	11	White	Curved
SUB-OL-RB-10-178-2	5	2	1	1	7	2	9	White	slightly curved
KAB-OL-RB-10-446-1	2	4	0	0	6	0	6	White	Curved
KAB-OL-RB-10-660-3	2	4	3	1	6	4	10	Black	Curved
KAB-OL-RB-10-697-1	4	2	2	2	6	4	10	Black	slightly curved

Table 7.2 (continued)

Genotypes	Preferred by men	Preferred by women	Not preferred by men	Not Preferred by women	Total preferred votes	Total non-preferred votes	Total votes cast	Grain color	Pod shape
KAB-OL-RB-10-522-2	1	5	3	2	6	5	11	Black/Purple speckled	Curved
SUB-OL-RB-10-323-2	3	3	2	2	6	4	10	Black/Purple speckled	Curved
SUB-OL-RB-10-331-2	4	2	3	3	6	6	12	White	Curved
KAB-OL-RB-10-649-3	1	4	3	1	5	4	9	Black/Purple speckled	slightly curved
SUB-OL-RB-10-283/2-1	3	2	3	4	5	7	12	Purple/Black speckled	Curved
OL-OL-RB-10-39-3	3	1	4	3	4	7	11	Black/Purple speckled	slightly curved
SUB-OL-RB-10-94-2	3	1	3	2	4	5	9	Black	Straight
SUB-OL-RB-10-262-1	3	1	4	4	4	8	12	Black/Purple speckled	Curved
SUB-OL-RB-10-269-2	3	1	3	4	4	7	11	Black/Purple speckled	Straight
SUB-OL-RB-10-285-2	3	1	2	3	4	5	9	White	Straight
SUB-OL-RB-10-285-3	2	2	1	4	4	5	9	Black/Purple speckled	Straight
SUB-OL-RB-10-96-2	2	2	1	2	4	3	7	White	Curved
SUB-OL-RB-10-331-1	1	2	3	2	3	5	8	Black/Purple speckled	slightly curved
KAB-RB-09-81/1-3	0	3	3	2	3	5	8	Purple/Black speckled	Curved
OL-OL-RB-10-32-2	1	2	2	5	3	7	10	White	slightly curved
OL-OL-RB-10-37-1	1	1	2	3	2	5	7	White	Curved
SUB-OL-RB-10-124-1	2	0	4	2	2	6	8	White	slightly curved
SUB-OL-RB-10-190-1	0	2	3	3	2	6	8	White	Curved
SUB-OL-RB-10-238-3	1	1	3	3	2	6	8	White	Curved
SUB-OL-RB-10-275-2	2	0	5	4	2	9	11	White	slightly curved
SUB-OL-RB-10-308-2	0	2	2	3	2	5	7	White	slightly curved
SUB-OL-RB-10-327-2	1	1	4	4	2	8	10	White	Curved
SUB-OL-RB-10-271-2	2	0	4	3	2	7	9	White	Straight
KAB-OL-RB-10-500-3	1	0	5	2	1	7	8	Black/Purple speckled	slightly curved
KAB-RB-09-156/1-2	0	1	3	3	1	6	7	White	Curved
KAB-RB-09-156/1-3	0	1	4	2	1	6	7	White	Curved
OL-OL-RB-10-10-1	1	0	4	3	1	7	8	White	Curved

Table 7.2(continued)

Genotypes	Preferred by men	Preferred by women	Not preferred by men	Not Preferred by women	Total preferred votes	Total non-preferred votes	Total votes cast	Grain color	Pod shape
OL-OL-RB-10-32-3	1	0	3	3	1	6	7	White	Straight
SUB-OL-RB-10-114-2	0	1	4	2	1	6	7	Black/Purple speckled	Straight
SUB-OL-RB-10-177-1	0	1	2	3	1	5	6	Black/Purple speckled	Straight
SUB-OL-RB-10-177-2	0	1	5	1	1	6	7	White	Straight
SUB-OL-RB-10-177-4	0	1	3	4	1	7	8	White	slightly curved

Table 7.3: Positive and negative criteria used by farmers in selection of grain runner bean lines at Ol Joro-Orok in 2013.

Positive Criteria			Negative Criteria		
Male selectors	**Female selectors**	**Both Selectors**	**Male selectors**	**Female Selectors**	**Both selectors**
a) Early Maturity	**a)** Good climbing ability	**a)** many pods per plant	**a)** late maturity	**b)** other coloured grains	**a)** Few pods per plant
b) Some Foliage retained at Maturity	**b)** white grain colour	**b)** Good plant stand count		**c)**more foliage but poor yields	**b)** shorter pods with no grains
b) uniform distribution of pods/plant	**c)**No foliage at maturity	**c)** longer pods with filled seeds			

7.4 Discussions

Farmers used their own criteria to evaluate the tested genotypes which have also been reported in participatory research done in common bean by Fekadu (2013). It emerged that in this study farmers gave more priority to lines that had many pods per plant, good pod distribution within the plant, uniformity at pod maturity, stand count, earliness to maturity, longer pods with well filled seeds. Among the factors of priority good pod distribution and retainage of green foliage at maturity are factors that breeders have least interest on whereas farmers consider them as important. This implies that plant breeders should consider such important traits that farmers consider when setting objectives of improving runner bean lines. According to Odame et al. (2013), it's necessary to align the improved technology/varieties with the end users preference to enhance variety adoption.

About 70% of the lines evaluated were preferred by farmers which show that they possess traits of interest to farmers and can be further developed into varieties. All famers showed interest of growing improved grain and vegetable runner beans. In this study, women put more emphasis on white coloured grains which cook easily and lines with no foliage for easy harvesting whereas men considered high yield and other uses of the crop as fodder. From this we then understand that male and female farmers have particular preferences for certain traits because they have different roles along the food chain .Therefore, analysis of differentiated gender selection criterion can help breeders to develop varieties that compliment both farmers which makes the work effective and relevant ((Nkongolo et al., 2008). Asfaw et al., (2008) has shown that participatory variety selection is a cost-effective strategy that allows farmers participation in research work and therefore help scientists to develop varieties that are easily accepted by farmers. This study has

provided an understanding of farmers' situation, their preferences and their indigenous knowledge in setting criteria and prioritizing the criteria based on their needs.

Moreover, this approach has familiarized smallholder farmers who mainly grow runner bean for grain use with production of vegetable runner bean which they were not aware of. Based on the farmers selection criteria, the best identified lines were KAB-RB-09-83/1-2,OL-OL-RB-10-38-2,OL-OL-RB-10-22-2,OL-OL-RB-10-10-3,OL-OL-RB-10-21-2,OL-OL-RB-30-3,OL-OL-RB-10-21-1,OL-OL-RB-33-3,SUB-OL-RB-10-186-2,SUB-OL-RB-10-305-3 and KAB-OL-RB-10-446-2.

7.5 Conclusions

Farmers used their own criteria to evaluate the tested genotypes. From this study, farmers regarded runner bean that are mature early, have uniform pod distribution per plant, good climbing ability, white grain colour, many pods per plant, good plant stand count and pods with well filled grains. This shows that scientists should embrace farmer participation approaches in improvement of varieties so as to develop preferred runner bean varieties for easy adoption.

Selection criterion was also differentiated based on gender roles and such differences should be considered by scientists when developing improved runner bean varieties. Farmers appreciated the existence of vegetable runner bean production and showed interest of being involved in the enterprise.

Based on the farmers selection criteria, the best identified lines were KAB-RB-09-83/1-2, OL-OL-RB-10-38-2, OL-OL-RB-10-22-2, OL-OL-RB-10-10-3, OL-OL-RB-10-21-2, OL-OL-RB-30-3, OL-OL-RB-10-21-1, OL-OL-RB-33-3, SUB-OL-RB-10-186-2, SUB-OL-RB-10-305-3 and KAB-OL-RB-10-446-2.

CHAPTER EIGHT

GENERAL DISCUSSION, CONCLUSION, AND RECOMMENDATION

8.1 General Discussion

The results showed great potential of developing local snap bean and runner bean varieties from the evaluated advanced lines. In the genetic analysis of photoperiod inheritance, additive effects were found to majorly control inheritance of vegetative, inflorescence and pod yield traits in runner beans (Das et al., 2014; Alam and Newaz, 2005 and Arunga et al., 2010). This implies that improving runner bean will be achieved through selection procedures like backcross, pedigree and single seed descent method. However, breeders should also take advantage of some dominance effects revealed in studied crosses (Hinkossa et al., 2013). The local landraces used in this study showed greater variability which could be used as germplasm to improve runner bean.

From the results, runner bean lines evaluated for vegetable pods flowered easily under the short photoperiods had abundant number of flowers and promising high pod yield. Based on this performance at two locations and in two years nine lines were selected. These lines show promising ability of being developed into local vegetable runner bean and hence should be advanced to national trials. The results also showed that imported variety White Emergo could not form abundant racemes and pods compared to when produced in extended light which reveals its constrains when produced in shortday conditions (Hadjichristodoulou, 1990).

Evaluation of advanced grain runner beans, resulted in identification of eleven lines which had higher grain yield and resistant to diseases than the existing local landraces. These selected genotypes can be used in national trials for breeding improved grain runner beans. The development of improved grain runner beans will enhance food security through increased productivity and consumption of other legumes other than common beans (Wanjekeche et al., 1997).

The results on participatory variety selections appeals for agricultural scientists to embrace farmer involment in research to ensure efficiency and effective outcomes (Witcombe et al., 1996; Bellon, 2001).Distinct gender differences on preference of traits were also observed in this study with men preferring lines that retain foliage at Maturity while women preferring lines that had white seed. The farmer preferred attributes should be considered when improving this crop. The preferred lines by farmers can be used to develop runner bean alongside breeders' objectives.

The concept of multiple disease resistance was found to be achievable in this study as reported earlier by Fininsa and Tefera, (2006). The results showed that fifteen lines exhibited multiple disease resistance to rust, anthracnose and angular leaf spot. The lines also proved to have

marketable pod traits. Therefore, these lines can further be evaluated in nationalperformance trials under optimal conditions that enhance disease development and infection.

8.2 General Conclusion

This study revealed that photoperiod sensitivity in runner bean is influenced by additive and dominance effects. However, the major influence is controlled by additive than dominance effects. Therefore, improvement of such traits will be easily done by using backcross, pedigree and single seed descent selection methods and their modifications. Also, keen observation is needed during early population development due to high outcrossing nature of runner beans. The showed a high genetic variation between the local shortday landraces and the imported long-day variety. This confirmed the response of the two accessions to the day length.

The developed runner bean lines for vegetable and grain were found to flower easily and set adequate pods under the short-day conditions. The selected lines therefore can be utilized in development of shortday vegetable and grain runner bean under tropical conditions.

Farmers considered runner bean lines developed for short-day photoperiodism are high yielding, have longer pods and are uniformly distributed on the plant and are early maturing. Scientists should consider these traits alongside their breeding objectives when improving runner bean to enhance farmer adoption of improved varieties.

The selected snap bean lines in this study exhibited multiple disease resistance to rust, anthracnose and angular leaf spot. The lines also had high pod yield and market preferred traits; therefore can be used for development of snap bean varieties locally.

8.3 General Recommendations

1- This study provided information on gene action involved in inheritanceof photoperiod sensitivity in runner bean therefore this information should be considered in breeding strategies of runner bean improvement.

2- Further studies are recommended on the genes involved in control of traits influencing photoperiodism in runner beans.

3- This study utilized local landraces in Kenya; however genetic analysis of other runner bean collections especially in Africa is important. The studied local landraces show great variability in phenotypic traits and can be utilized in improvement of runner and common beans.

4- The selected vegetable and grain type runner bean lines should be evaluated in national performance trials and across different agro-ecological zones.

5-The selected snap bean lines used in this study should be further evaluated in national performance trials and also under artificial inoculation and molecular analysis where optimum conditions of disease development can be achieved.

References

Acquaah, G. 2007. Principles of Plant Genetics and Breeding. Blackwell Publishing, Malden (U.S.A). p. 121-140.

Aggarwal, V. D., M.A. Pastor-Corrales, R.M. Chirwa, and R.A. Buruchara. 2004. Andean bean (Phaseolus vulgaris L.) with resistance to the angular leaf spot pathogen (*Phaeoisariopsis griseola)* in southern and eastern Africa. Euphytica 136:201-210.

Alam, M. M., and M. M. Newaz . 2005. Combining ability of flower and pod character of lablab bean in two sowing environment. Asian Journal of Plant Science 4: 603-697.

Alzate-Marin, A., L. De Souza, V.A Ragagnin, M.A Moreira, and E.G De Barros. 2004. Allelism tests between the rust resistance genes present in common bean cultivar 3 Ouro Negro and genes ur-5 and ur-11. Journal of Phytopathology 152: 60-64.

Annapurna B, D.N. Bankar, R. M . Patil, V.M. Khade, V.D. Surve, A.M. Chavan, J.H. Bagwan, S. P. Taware, B.K. Honrao, and S.C. Misra. 2011. Genetic studies for improvement of spike characters in bread wheat J. Wheat Res. 3: 64.

Araya, C.M., A.T. Alleyne, J.R. Steadman, K.M. Elkridge, and D.P. Coyne. 2004. Phenotypic and genotypic characterization of Uromyces appendiculatus from *Phaseolus vulgaris* in the Americas. Plant Dis 88:830–836.

Arunga E. E., J. O. Ochuodho, M. G. Kinyua, and J. O. Owuoche. 2012. Characterization of Uromyces appendiculatus isolates collected from snap bean growing areas in Kenya. African Journal of Agricultural Research 7: 5685-5691.

Arunga, E.E., A.H.Van Rheenen and J.O. Owuche. 2010. Diallel analysis of snap bean (Phaseoulus vulgaris L.) varieties for important traits.African Journal of Agricultural Research 5: 1951-1957.

ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa) . 2012. Proceedings of regional stakeholders' workshop on snap bean commodity value chain held at Imperial resort beach Hotel as from 9th-10th December, 2009 in Entebbe, Uganda.

Asfaw, A., D. Dauro, G. Wolde and F. Alemayehu. 2008. Farmers participation in common beans breeding in South Ethiopia: The way forward. Report from Awassa Agricultural Research Center, Ethiopia.

Bankar, D. N., B. Annapurna, R.M. Patil, V.M. Khade, V.D. Surve, A.M. Charan, J.H. Bagwan, S.P.Taware, B.K. Hunrao, and S.P. Misra. 2011. Genetic studies for improvement of spike characters in bread wheat. J. Wheat Res. 3: 64-71.

Barelli, M. A., A.M.C. Gonçalves-Vidigal, A.T. Amaral Júnior, P.S.Vidigal Filho, and L. Silvério. 1999. Genetic control on number of days to flowering and yield components in common bean (*Phaseolus vulgaris* L.). Acta Scientiarum 21: 423-427.

Barnes, W. C. 1961. Multiple disease resistant cucumbers. Proc. Am. Soc. Hort. Sci. 77:417-23.

Bassanezi, R.B., L. Amorim, F.A. Bergamin, B. Hau. 1998. Effects of bean line pattern mosaic virus on the monocyclic components of rust and angular leaf spot of Phaseolus bean at different temperatures, Plant Pathology 47: 289-298.

Bassett, M. J. 2004. List of genes: Phaseolus vulgaris L. Annu. Rep. Bean Improv. Coop. 47:1–24.

Battey, N., S. D. Nicholls, F. Tooke, E. Coen. 1997. The induction and maintenance of flowering in Impatiens. Development 124: 3343–3351.

Battey, N.H., and R.F. Lyndon, 1990. Reversion of flowering .Bot. Rev. 56:162–189.

Bellon, M.R. 2001. Participatory research methods for technology evaluation. A manual for scientist working with farmers. Mexico, D. F. CIMMYT, p. 93.

Bicer, B.T., and D. Sakar . 2010. Heritability of yield and its components in lentil (Lens culinaris Medik.). J. Agri. Sci. 16: 30-35.

Bicer, B.T., and D.Sakar.2008. Heritability and gene effects for yield and yield components in chickpea. Heriditas 145:220-224.

Bliss, F.A.1980.Hybridization of crop plants: Common bean. American Society of Agronomy-Crop Science Society of America 677:273-284.

Brink, M. 2006. Cereals and pulses book. Plant Resources of Tropical Africa (PROTA), p. 138-148.

Buruchara, R., R. Chirwa, L. Sperling, C. Mukankusi, J.C. Rubyogo, R. Muthoni, and M.M. Abang. 2011. Development and delivery of bean varieties in Africa. The Pan-African Bean varieties Alliance (PABRA) model. African Crop Science Journal 19: 227-145.

Caiger, S.1995. Runner bean profile for Sri-Lanka.The agro-enterprise development project, Colombo, Sri-Lanka. Miscellaneous reports p.43.

Carvalho, G.A., T.J. Paula, A.L. Alzate-Marin, S. Nietsche, E.G. Barros, and M.A. Moreira. 1998. Inheritance of resistance to angular leaf spot of common bean in AND 277 to race 63–23 of *Phaeoisariopsisgriseola* and identification of a RAPD marker linked to the resistance gene. Fitopatol Bras 23: 482–485.

Ceballos, H., S. Pandey, L. Narro, and J. C. Perez-Velazquez. 1998. Additive, dominant and epistatic effects for maize grain yield in acid and non-acid soils. Theoretical and Applied Genetics 96:662-668.

Ceccarelli S., and S. Grando. 2002. Plant breeding with farmers requires testing the assumptions of conventional plant breeding: Lessons from the ICARDA barley program. In: Cleveland DA, Soleri D (eds) Farmers, scientists and plant breeding: integrating knowledge and practice. CABI Publishing International, Wallingford, Oxon, UK, p. 297-332.

CGIAR (Consultative Group on International Agricultural Research). 2012. Program research report on grain legumes: Leveraging legumes to combat poverty, hunger, malnutrition and environmental degradation.Available at www.worldagroforestry.org.

Checa, O., H. Ceballos, and M.W. Blair. 2006. Generation means analysis of climbing ability in common bean (*Phaseolus vulgaris* L.). Journal of Heredity 97:456-465.

Chemining'wa, G.N., P.M. Kimani, and J.H. Nderitu. 2012. Snap bean breeding activities in Kenya.In proceedings of ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa) regional stakeholders' workshop on snap bean commodity value chain held at Imperial Resort Beach Hotel as from 9^{th}-10^{th} Dec 2009 in Entebbe, Uganda, p.70-74.

CIAT (Centro Internacional de Agricultura Tropical) 1987. Bean Program Annual Report.Cali, Colombia.

CIAT .2006. Bean Program Annual Report 2006. Cali, Colombia.

CIAT .1984.A summary of major achievements during the period 1977-1983.Cali, Colombia.

CIAT .2006. Snap bean for income generation by small farmers in east Africa. CIAT Highlights Series No. 31. CIAT Cali, Colombia.

CIAT. 2013. A bean revolution in sub-saharan Africa.Available at www.ciat.cgiar.org.

CIAT2004. Bean research for development strategy in central and eastern Africa. CIAT Highlights Series No. 14. CIAT Cali, Colombia.

Cukadar-Olmedo, B., and J.F. Miller. 1997. Inheritance of the stay green trait in sunflower. Crop Science 37:150-153.

Das, I., T. Seth, S.V. Durwas, S. Duth, A.Chattopadhyay, and B. Singh. 2014. Gene action and combining ability for yield and yield coponents traits in dolichos bean (*Dolichos lablab var.*typicus). SABRAO Journal of Breeding and genetics, 46: 293-304.

De Jesus J, R., F.R. Do Vale, R.R. Coelho, B. Hau, L. Zambolim, L.C. Costa, and .A. Bergamin .2001. Effects of angular leaf spot and rust on yield loss of *Phaseolus vulgaris*. Phytopathology 91:1045-1053.

Deeksha, J., K.S. Hooda, J.C. Bhatt, B.L. Mina, and H.S. Gupta, 2009. Suppressive effects of composts on soil-borne and foliar diseases of French beanin the field in the western Indian Himalayas.Journal of Crop Protection 24: 608-615.

Delgado, S.A. 1988. Variation, taxonomy, domestication and germplasm potentialities in *Phaseolus coccineus*. In: P. Gepts (ed.), Genetic Resources of Phaseolus Beans, 2nd edition.p. 441—463. Kluwer Academic Publishers, Boston.

Doss, C. R. 2005.Analyzing technology adoption using micro-studies: Limitations, challenges, and opportunities for improvement.Agricultural economics 34:207–219.

Egli, D.B. 1998. Seed biology and yield of grain crops. Walling ford UK: CAB International. P. 178.

Emam Y., A. Shekoofa, F. Salehi, and A.H. Jalali. 2010. Water stress effects on two common 6 bean with constrating growth habits. American-Eurasian Journal of Agriculture and Enviromental Science 9 : 495-499.

EPZA (Export Processing zone of Africa), 2005. Horticultural report.www.epzakenya.com. Accessed on 24/10/2013.

Fekadu., G. 2013.Assesment of farmers criteria for common bean variety selection: the case of Umbullo watershed in sidama zone of the southern region of Ethiopia. Ethiopian e-Journal for Research and Innovation Foresight 5: 4-13.

Fernandez, M.T., M. Fernadez, A. Caseres, R. Rodriguez, and M. Fueyo. 2000. Bean germplasm evaluation for anthracnose resistance and characterisation of agronomic traits. A new physiological strain of *C. lindemuthianum* infecting *Phaseolus vulgaris* L. in Spain.Euphytica 114:143-149.

Ferreira, C.F, A. Borém, G.A. Carvalho, S. Nietsche , T.J. Paula , E.G. Barros, and M.A. Moreira. 2000. Inheritance of angular leaf spot resistance in common bean and identification of a RAPD marker linked to a resistance gene. Crop Sci 40:1130–1133.

Fininsa, C., and B. Tesso. 2006. Breeding food legumes for eastern Ethiopia. In: Ali K, Keneni G, editors. National workshop on food and forage legumes in Ethiopia. Addia Ababa, Ethiopia: Ethiopian Agricultural Research Organization (in press).

Fininsa, C., and T. Tefera. 2006. Multiple disease resistance in common bean genotypes and their agronomic performance in eastern Ethiopia. International Journal of Pest Management, 52: 291-296.

Freytag, G.F., and D.G. Debouck .2002.Taxonomy, distribution and ecology of the genus Phaseolus (Leguminosae-Papilionideae) in North America, Mexico and Central America.Sida, Botanical Miscellany, p. 23. Botanical Research Institute of Texas, Fort Worth.

Galloway, L. F., and K.S. Burgess. 2012. Artificial selection on flowering time: Influence on reproductive phenology across natural light environments. Journal of Ecology 100:852-861.

Ganesh, S. K., and M. Sakila. 1999. Generation mean analysis in sesame (*Sessamum indicum*L.) crosses. Sesame and Safflower Newsletter 14:8-14, Institute of Sustainable Agriculture (ISA).Cordoba, Spain.

Garner, W.W., and H.A Allard, 1920. Effect of relative day length of day and night and other factors of the environment on growth and reproduction in plants. Journal of Agricultural Science 18: 553-606.

Garner, W.W., and H.A. Allard.1923. Further studies on photoperiodism, the response of plants to relative length of day and night. Journal of Agricultural Science 23:871-920.

Gemechu, K., D. Asgelil, H. Hussein, and K. Fasil. 2004. The potential of participatory research in agriculture in the country. The case of Participatory Plant Breeding Project at Awassa Agricultural Research Center. In: Participatory Research in Action. Ethiopian Experience.Proceedings of participatory workshop.June 12-17. 2002. Ethiopian Agricultural Research Organization (EARO) and African Highland Initiative (AHI). Addis Ababa, Ethiopia, p. 89-99.

Giurca, D.M. 2009. Morphological and phenological differences between the two species of the phaseolus genus (*Phaseolus vulgaris* and *Phaseolus coccineus*). CercetăriAgronomiceîn Moldova XLII No. 2:138. Bank of Plant Genetic Resources, Suceava.

Gomez, O.2004. Evaluation of Nicaraguan common bean (*Phaseolus vulgaris* L.) 49 landraces.Doctoral thesis, Department of Ecology and Crop production Sciences Uppsala, Swedish University of Agricultural Sciences.

Grafton, K. F., and S.P. Singh. 2000. Twenty-first century dry bean cultivars. In S.P. Singh (ed.) Bean research, production, and utilization. P. 31-38.Univ. of Idaho, Moscow, Idaho.

Gressel, J., A.Hanafi and G.Head. 2004. Major heretofore intractable biotic constraints to African food security that may be amenable to novel biotechnological solutions.Crop Protection 23:661-689.

Gross, Y., and J. Kigel. 1994. Differential sensitivity to high temperature of stages in the reproductive development of common bean (*Phaseolus Vulgaris* L). Field Crops Res.36:201-212.

Gu, W., J. Zhu, D. H. Wallace, S. P. Singh, and N.F.Weeden.1998 .Analysis of genes controlling photoperiod sensitivity in common bean using DNA markers.Euphytica 7:102:125-132.

Hadjichristodoulou, A. 1990.Trials with scarlet runner bean (*Phaseolus coccineus*.L).Pub: Nicosia, Agricultural Research Institute 122: 95.

Hagedorn, D. J., and D.A Inglis .1986. Handbook of bean Diseases.Wisconsin press.Madison, p.6-10.

Hallauer, R. A., M. J. Carena and J. B. Miranda. 2010. Quantitative genetics in maize breeding.Springer Science and Buainess Media, p. 63-66.

Harveson, R.M., F.S. Horward, and J.R. Steadman. 2007. Rust of dry bean .University of Nebraska. Plant pathology department.

Hayman, B. I. 1958. The separation of epistatic from additive and dominance variation in generation means. Heredity 12: 371-390.

HCDA. 2004. Horticultural Crops Development Authority, Horticultural Export Statistics.www.hcda.org.

HCDA. 2009. Horticultural Crops Development Authority Horticultural Export Statistics.www.hcda.org.

Herklots, G.A. 1972. Vegetables in south East Asia.George Allen and unwin Ltd, London. P. 249.

Hinkossa, A., S. Gebeyehu and H. Seleke. 2013. Generation mean analysis and heritability of drought resistance in common bean (*Phaseoulus vulgaris* L.). African Journal of Agricultural research 8:1319-1329.

Horticultural Crops Development Authority (HCDA). 2013. Horticulture validated report. 2013. Available at: http://www.hcda.or.ke/.

Horticultural Crops Development Authority (HCDA). 2007. Export statistics volumes. Available at www.hcda.or.ke.Statistics

Huyghe, C. 1998.Genetics and genetic modifications of plant archtechture in grain legumes: a review. Agronomie 18: 383-411.

IBPGR (International Board for Plant Genetic Resources).1983. Crop descriptors.Rome, Italy.

Infonet Biovision. 2013. General information and agronomic aspects of snap beans .Available at www.infonet-biovision.org.

Iruria, P.W., H.A. Van Rheenen, A.O. Odindo. 2002. Anticipated promises and problems for snap bean seed production in Kenya.In: proceedings of the second horticulture seminar on sustainable horticultural production in the tropics held on 6th to 7th Aug, 2002.

Jaetzold, R., H. Schmidt, B. Hornetz, and B. Shisanya 2006.Farm management hand book of Kenya, Vol II.Nairobi, Kenya Ministry of Agriculture. Natural conditions and farm management information of Central Kenya.

Jinks, J. L., and R. M. Jones. 1958. Estimation of components of heterosis.Genetics, 43: 223-234.

Kahuro, J.G. 1990. The effect of plant population and phosphate fertilizer application on growth, yield, yield components and nutrient concentration of runner bean.Msc. thesis in the University of Nairobi Library.

Kamanu, J. K., G. N. Chemining'wa, J.H. Nderitu, and J. Ambuko. 2012. Growth , yield and quality response of snap bean (*Phaseolus vulgaris* L.) plants to different inorganic fertilizers applications in central Kenya. Journal of Applied Biosciences 55:3944-3952.

Kay, D. E. 1979. Runner bean, multiflora bean, scarlet runner bean. *In*: Food Legumes. Crop productions digest No.3 London: Tropical Products Institute. p. 355-365.

Kelly, J. D., and V.A. Vallejo. 2004. A comprehensive review of the major genes conditioning resistance to anthracnose in common bean. HortScience 39:1196–1207.

Kelly, J. F., and M. K. Scott. 1992. The nutritional value of snap beanversus other vegetables, p. 23-46. *In*: Henry, G. and W. Janssen (Tech. Eds.). CIAT Proceedings of an International Conference on Snap beanin the developing world held from 16th to 20th October 1989 in Cali, Colombia.

KEPHIS (Kenya Plant Health Inspectorate Services). 2010. Updated variety list-Kenya. KEPHIS, Nairobi, Kenya.

Khodambashi, M., N. Bitaraf, and S. Hoshmand. 2012. Generation Mean Analysis for Grain Yield and Its related traits in lentil. Journal of Agricultural Science and Technology 14:609-616.

Kimani P.M. 2008. Improved beans for the developing world. CIAT annual report 12:4.

Kimani, P. M. 2006. Snap bean breeding Programme in the East and Central African Region. In proceedings of snap bean ASARECA Project Stakeholders Workshop held on 11th - 12th October 2006. KARI, Thika (Kenya).

Kimani, P.M. 2010. Breeding for pod quality and multiple disease resistance in bush and climbing snap beans. A paper presented at the Snap bean Stakeholders Workshop, held 2nd March 2010, Agricultural Information Resource Centre, Nairobi, Kenya.

Kimani, P.M., H. Assefa, G. Rakotomalala, and A. Rabakoarihanta. 2002. Research on bean rust in east and central Africa: Status and future directions. Annual Report Bean Improvement Cooperative 45:134-135.

Kimani, P.M., R. Buruchara, K. Ampofo, M. Pyndji, R. M. Chirwa, and R. Kirkby. 2005a. Breeding beanfor smallholder farmers in Eastern, Central, and Southern Africa: constraints, achievements, and potential. In the Proccedings of PABRA millennium workshop (2005) held at Tanzania from 28th May-1st June, 2001.p.15-20.

Kimani, P.M., R. M. Chirwa, and R. Kirkby. 2005b. Bean breeding for Africa: Strategy and plan. In the Proccedings of PABRA millennium workshop (2005) held at Tanzania from 28th May-1st June, 2001.p. 21-24.

Koike, S.T., P. Gladders, and A.O. Paulus. 2007. Vegetable diseases. A color Hand book. P. 448-450. Manson publisher.

Koornneef, M., C. Alonso-Blanco, A. J. M. Peeters, and W. Soppe.1998. Genetic control of flowering time in Arabidopsis thaliana. Plant Mol. Biol. 49: 345–370.

Kornegay, J. L., and S.R. Temple. 1986. Inheritance and combining ability of leafhopper defense mechanisms in common bean. Crop Sci 26:1153–1158.

Kornegay, J., J.W. White, J.R. Dominguez, G.Tejada and G. Cajiao.1993.Inheritance of photoperiod response in Andean and Mesoamerican common bean. Crop Sci 33:977-984.

Kumar, R.,M. Singh, M.S.Narwal and S. Sharma. 2005. Gene effects for grain yield and its attributes in maize (Zea mays l.).National Journal of Plant Improvement 7:105-107.

Liebenberg, M. M., C.M.S. Mienie, and Z.A. Pretorius. 2006. The occurrence of rust resistance gene Ur-13 in common bean cultivars and lines. Euphytica 150:365–386.

Lindgren, D.T., K.M. Eskridge, J. R. Steadman, D.M. Schaaf .1995. A model for dry bean yield loss due to rust. Hort. Tech. 5:35-37.

López, C.E, I.F. Acosta , C. Jara , F. Pedraza , E. Gaitán-Solís, G. Gallego , S. Beebe , and J. Tohme. 2003. Identifying resistance gene analogs associated with resistances to different pathogens in common bean. Phytopathol 93:88–95.

Lumpkin, T. A., and D. C. McClary. 1994. Breeding and genetics. In: Lumpkin, T. A. and McClary, D. C. (eds), Azuki bean: botany, production and uses. CAB International, p. 119-155.

Magda, E.A.2013. Estimation of some genetic parameters through generation mean analysis in three bread wheat crosses.Alex.J.Agric.Res 58: 183-195.

Mahuku, G.S, M.A Henrıquez, C. Montoya, C. Jara, H. Teran, and S. Beebe. 2011. Inheritance and development of molecular markers linked to angular leaf spot resistance genes in the common bean accession G10909. Mol Breed 2011 28:57–71.

Mahuku, G.S., A.M. Iglesias, and C. Jara .2009. Genetics of angular leaf spot resistance in the Andean common bean accession G5686 and identification of markers linked to the resistance genes. Euphytica 167:381–396.

Martin, F.W 1984. Handbook of Tropical Food crops. CRC press, Australia. p. 48-49.

Mather, K. J. 1982. Biometrical Genetics.Chapman and Hall, 3rd edition, London. p. 65-81.

Mather, K., and L. Jinks. 1971. Biometrical Genetics. Cornell University Press, Ithaca, New York, USA.

Mendes, M. P., F.B. Botelho, M.A.Ramalho, A.B.Abreu and I.V. Furtini. 2008. Genetic control of number of days to flowering in common bean.Crop Breeding and Applied Biotech 8:279-282.

Mersha, Z., and B. Hau. 2008. Effects of bean rust (*U. appendiculatus*) on host dynamics of Phaseolus beans. Plant Pathology 57: 674-686.

Miklas, P.N, J. D. Kelly, S.E. Beebe, and M.W Blair. 2006. Common bean breeding for resistance against biotic and abiotic stresses: from classical to MAS breeding. Euphytica 147:106-131.

Miklas, P.N., M.A. Pastor-Corrales, G. Jung, D.P. Coyne, J.D. Kelly, P.E. McClean, and P. Gepts, 2002. Comprehensive linkage map of bean rust resistance genes. Annual Report Bean Improvement Cooperative 45:125-129.

Mohammed, Y., and S. Somsiri. 2007. Survival and transmission of 3 Colletotrichum lindemuthianum from naturally infected common bean seeds to the 4 seedlings. Tropical science 47: 96-103.

Monda, E.O., S. Munene, and A. Ndegwa. 2003. French bean production constraints in Kenya. Africa Crop Science Conference Proceedings 6:683-687.

Mooney, D. F. 2007. The Economic impact of disease resistant bean breeding research in Northern Ecuador. M.S. Thesis, Michigan State University, December 2007. P. 153.

Muchui, M. N., A. M. Ndegwa, S. M. Wachiuri, B. Muthama, and J. Kimamira. 2006. Post-harvest evaluation of introduced snap bean Phaseolus vulgaris Varieties. In Proceedings of 6th workshop on Sustainable Horticultural Production in the Tropics, 6th -9th December 2006, Mombasa, Kenya.

Muchui, M.N., A. M. Ndegwa, L.W. Njuguna . 2001. Postharvest Evaluation of Superior Snap (French) Bean and Snow/Snap pea varieties. In Annual Report, KARI, Thika. p. 111-112.

Muthomi, J.W., K.K. Muimui, and P.M.Kimani. 2011. Inheritance of resistance to Angular leafspot in yellow beans. African Crop science Journal 19: 267-275.

Mutuku, K.M., D. Tschirley, M. Ayieko, and M.T. Weber. 2004. Improving Kenya's domestic horticultural production, marketing and consumption systems: current competitiveness, forces of change and challenges for the future.

Mwangombe, A.W., I. N. Wagara, J.W. Kimenju and R.A. Buruchara, 2007.Occurrence and severity of angular leaf spot of common bean in Kenya as influenced by geographical location, altitude and agroecological zones. Plant Pathol. 6: 235-241.

Myers, J. R., and J.R. Baggett. 1999. Improvement of snap beans. In: S. P. Singh (ed.) Common Bean Improvement in the Twenty-First Century. Kluwer Academic Publishers, Dordrecht, the Netherlands. p. 289-330.

Ndegwa, A.M., M.N. Muchui, S.M. Wachuri, and J.N. Kimamira. 2009. Evaluation of introduced snap bean (Phaesolus vulgaris L.) varieties for adaptability and pod quality.In: Proceedings of the 10th KARI Biennial Conference. KARI, Nairobi, Kenya. 13th-17th Nov. 2009.

Ndegwa, A.M., N.M.Muthoka, C.W.Gathambiri, M.N.Muchui, M.W.Kamau and S.M. Waciuri. 2012. Snap bean production to post-harvest practices and constraints.Acase study in Kirinyaga and Machakos districts,Kenya. In proceedings of ASARECA (Association for Strengthening Agricultural Research in Eastern and Central Africa) regional stakeholders' workshop on snap bean commodity value chain held at Imperial Resort Beach Hotel as from 9th-10th Dec 2009 in Entebbe, Uganda, p.70-74.

Nderitu, J. H., E.M. Wambua, F. Olubayo, M. J. Kasina, and C.N. Waturu. 2007. Management of thrips (Thysanoptera: Thripidae) infestation on French bean (*Phaseolus vulgaris* L.) in Kenya by effect of intercrops on thrips combination of insecticides and varietal resistance. Journal of Entomology 4: 469–473.

Nderitu.J .H, M. A. Ugen, A. Ndegwa, A. Musoni and F.S.Ngulu.2009. In Proceedings of ASARECA regional stake holders workshop on snap bean commodity value chain held at imperial Resort Beach hotel from 9th -10th Dec.

Nene, Y.L. 1988.Multiple Disease Resistance in grain legumes.Ann.Rev.Phytopathol.26:203-17. Legumes Program, International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502: 324, Andhra Pradesh, India.

Nietsche, S., A. Borém , G. A. Carvalho, R.C. Rocha, J.R. Paula, E.G Barroso, and M.A Moreira. 2000. RAPD and SCAR markers linked to a gene conferring resistance to angular leaf spot in common bean. J Phytopathol 148:117–121.

Nkongolo , K., K.K. Cninthu, M. Malusi, and Z.Vokhiwa. 2008 .Participatory variety selection and characterization of sorghum (*Sorghum bicolor* (L). Moench) elite accessions from Malawian gene pool using farmer and breeder knowledge .African Journal of Agricultural Research 3: 273-283.

Nyabyenda, P. 1991. Le haricot: Fiches descriptives des variétés diffusées. Institut des Sciences Agronomiques du Rwanda (ISAR), Butare, Rwanda.

Oblessuc, P. R., R. M. Baroni, A. A. Garcia, A. F. Chioratto, S. A. Carbonell, L. E. Camargo and L. L. Benchimol. 2012 . Mapping of angular leaf spot resistance QTL in common bean (Phaseolus vulgaris L.) under different environments. BMC Genetics 13:50.

Odame, H., L. Kimenye , C. Kabutha, D. Alemu, and L.H. Oduori . 2013. Why the low adoption of agricultural technologies in Eastern and Central Africa? ASARECA , Entebbe, p.21-23.

Oliveira, L.K., L.C. Melo, C. Brondani, M.J. Peloso, and R. P. Brondani. Backcross assisted by microsatellite markers in common bean. Genetics and Molecular Re- search, 7: 1000-1010.

Onkoba, .M. 2002.Studies on Control of Uromyces appendiculatus (Prs.) unger var. appendiculatus using fungal and bacterial metabolites.MSc Thesis, University of Nairobi, Kenya.

Orton, W. A. 1902. The wilt disease of the cowpea and its control. US Dep. Agric. Bur. Plant Industries Bull. 17:9-20

Park, S.J., P.R. Timming, D.T. Quiring, P.Y. Jui . 1994. Inheritance of leaf area and hooked trichome density of the first trifoliolate leaf in common bean (Phaseolus vulgaris L.). Can J. Plant Sci 74:235–240.

Pastor Corrales, M.A., J. Osorno, S. Markell, and R.Goswani. 2011. Identifying Plants of Stampede Pinto Bean with Resistance to New races of Rust Pathogen. Bean Improvement Cooperative Annual Report. p. 126-127.

Pastor-Corrales M. A , J.R. Steadman, and J.S. Beaver. 2001. An overview of the 3rd bean rust and 2nd bean common bacterial blight international workshops, Mar. 4–8, 2002, Pietermaritzburg, South Africa. Annu. Rep. Bean Improv. Coop. 45:120–124.

Pastor-Corrales, M.A. 2002. Apparent vulnerability of certain rust resistant gene combinations in common bean for the management of Uromyces appendiculatus. Annu. Rep. Bean Improv. Coop 45:42-43.

Pastor-Corrales, M. A., C. Jara, and S. Singh. 1998. Pathogenic variation in, source of, and breeding for resistance to *Phaeoisariopsis griseola*causing angular leaf spot in common bean. Euphytica 103: 161-171.

Pastor-Corrales, M.A, O.A. Erazo, E.I. Estrada, and S.P. Singh. 1994. Inheritance of anthracnose resistance in common bean accession G2333.Plant Dis 78:959-962

Pastor-Corrales, M.A., E.M. Wright, S.G. Markel, H.E. Awale, J.D. Kelly, J.G. Jordahl, R.S. Lamppa, F.M. Mathew, J.M. Osorno, and R.S. Goswami. 2010. Comparing the 24 155 virulence of new races of the common bean rust pathogen from Michigan and North 1 Dakota. Annual Report Bean Improvement Cooperative 53:128–129.

Plant Varieties and Seeds Gazette. 2002. Department for Environment, Food and Rural Affairs and the Plant Variety Rights Office.Special Edition. No. 450. Cambridge, United Kingdom.

Purseglove, J.W.1987. Tropical crops book (Dicotyledons). Cambridge University Press.Wiley, New york.

Raemarkers, H.R.2001. Crop production in Tropical Africa.Brussels, Belgium. Geokint graphic . P 300-320.

Rainey, K.M., and P. D. Griffiths. 2005. Inheritance of heat tolerance during reproductive development in snap bean (Phaseolus vulgaris L.). HortSci 130:700–706.

Rodino, A.P., M. Lema, M. Paerez-Barbeito, M. Santalla, and A. De Ron. 2007. Assesment of runner bean (*Phaseoulus coccineus* L.) germplasm for tolerance to low temperature during early seedling growth. Euphyitica 155: 63-70.

Rodriguez, M., D. Rau, S.A Angioi, E. Bellucci, and E. Bitocchi. 2013. European Phaseolus coccineus L. landraces: Population Structure and Adaptation, as revealed by cpSSRs and Phenotypic Analyses. PLoS ONE 8:2.

Rotem, J., and J.Palti. 1969. Irrigation and plant diseases. Annu. Rev.Phytopatholo.7:267-288.

Sabolou, S., B.K. Keshubhai, R.M. Chintan, and S. Kumar. 2014. Generation mean analysis of fruit quality traits in eggplant (*Solanum melongena*L.). Australian Journal of crop science 8:243-250.

Saettler, A.W. 1991. Angular leaf spot. In: Compendium of Bean Diseases (Hall R. (ed.). APS Press, St. Paul, U.S.A: p.15–16.

Salisbury and Ross. 1992. Plant physiology.Wadsworth Publishing Company.Belmont,California.

Santalla, M., A.B. Monteagudo, A.M. Gonza'lez and A.M. De Ron. 2004. Agronomical and quality traits of runner bean germplasm and implications for breeding. Euphytica 135: 205-215.

Sartorato, A., S. Nietsche, E.G. Barros, M.A.Moreira. 2000. RAPD and SCAR markers linked to resistance gene to angular leaf spot in common beans.Fitopatol Bras. 25:637–642.

Scheffe, H. 1959. The analysis of variance. John Wiley and Sons, New York. p. 45-85.

Sharmila, V., K.S. Ganesh, and M. Gunasekaran. 2007. Generation mean analysis for quantitative traits in sesame (*Sesamum indicum* L.) crosses. Gen. Mol. Biol. 30:80-84.

Sher, H., I. Muhammad, K. Kiramat, Y. Muhammad, and Hameed-ur-Rahman. 2012. Genetic analysis of maturity and flowering characteristics in maize (*Zea mays*L.). Asian Pacific Journal of Tropical Biomedicine 4:621-626.

Silva, K., J.D, E. A. Souza, A. Sartorato, and C.N.S. Freire.2008. Pathogenic variability of Isolates of *Phaeoisariopsis griseola*, the cause of common bean angular leaf spot, and its implications for resistance breeding. Journal of Phytopathology 156: 602-606.

Singh, P. K., and A.K. Roy. 2007. Diallel analysis of inbred lines in maize (*Zea mays* L.).Int J Agri Sci 3: 213-216.

Singh, S. P., P. Gepts and D.G. Debouck. 1991. Races of common bean *Phaseolus vulgaris* L., Fabaceae. Econ Bot, 45: 379–396.

Singh, S.P. 2001. Broadening the genetic base of common bean cultivars: a review. Crop Science 41: 1659–1675.

Singh, S.P., (2001). Broadening the genetic base of common bean cultivars.Crop Science. 41: 1659-1675.

Singh, S.P., P. Gepts and D.G. Debouck.1991. Races of common bean (Phaseolus vulgaris, Fabaceae).Economic Botany 45:379–396.

Snape, J.W., S.A. Quarrie, and D.A. Laurie.1996. Comparative mapping and its use for the genetic analysis of agronomic characters in wheat. Euphytica 89: 27–31.

Spataro,G., B. Tiranti, P. Arcaleni, E. Belluci, G. Attene, R. Papa, P. Spagnoletti Zeuli, and V. Negri. 2011. Genetic diversity and structure of a worldwide collection of Phaseolus coccineus. Theor Appl Genet 122:1281-1291.

Stenglein S., L. D. Ploper, O. Vizgarra, and P. Balatti. 2003. Angular leaf spot: A disease caused by the fungus Phaeiosariopsis griseola (Sacc.) Ferraris on Phaseolus vulgaris L. Advanced Application Microbiology 52:209-243.

Sumin,L., S. Kihye, S. Hae-Ryong, N. Yoo-Sun, L. Rin-A, L. Seugjun, K. Soo-Young, P. Soon-Ki, L. Sunghoon, and S. Moon-Soo. 2013. Genetic identification of novel locus, accelerated flowering 1 that controls chromatin modification associated with histone H3 lysine 27 trimethylationArabidopsis thaliana. Plant Sci 208:20-27.

Sunripe Company manual. 2013. Unpublished data. Production and Raw material product specifications of Runner bean for export.

Suttie, J.M. 1969. The butter bean (*Phaseolus coccineus* L.) in Kenya. East African Agric.J. 35:211-212.

Thomas, B., D. Vince –Prue. 2007. Photoperiodism in plants, second edition. 1997. Academic Press. London.

Tindall, H. D. 1983. Vegetables in the Tropics . Macmillan International College edition, UK.p.303-533.

Tumwesigye, M.R.1988. Heterosis and combining ability in common bean in Kenya. MSc. thesis University of Nairobi, Kenya.

Turi, N.L., S.Raziuddin, S. Shar and A.Sardar.2006.Estimation of heterossi for some importatnt traits in mustard (*Brassica juncea* L.).Journal of Agricultural and Biological Science 1:687-698.

Van Schoonhoven, A., and M.A. Pastor-Corrales. 1987. Standard system for the evaluation of bean germplasm. Cali, Colombia, 54: 8.

Vanda, M., M. Khodambashi, S. Houshmand, B. Shiran and R.Fahlian.2013.Determination of gene action and heritability in some biometraical traits in lentils (*lens culinaris* L.) using F2.3 families. International Journal of Agricultural and Crop Science 5: 1427-1431.

VSN International. 2011. GenStat for Windows 13th Edition. VSN International, Hemel Hempstead, UK. Web page: GenStat.co.uk

Wahome, S.W, P.M. Kimani, J.W. Muthomi, R.D. Narla, and R. Buruchara. 2013. Pod quality and yield of snap bean lines locally developed in Kenya.International Journal of Agronomy and Agrcultural Research, 3:1-10.

Wahome, S.W. 2011.Selection of snap bean genotypes for multiple disease resistance pod quality and yield in Kenya. MSc. Thesis, available in the Library of University of Nairobi, Kenya.

Wahome, S.W., P.M. Kimani, J.W. Muthomi, R.D. Narla, and R. Buruchara .2011.Multiple disease resistance in Snap bean genotypes in Kenya.African Crop Science Journal, 19: 289 – 302.

Wallace, D.H. 1985. Physiological genetics of plant maturity, adaptation and yield. Plant Breeding Rev 3: 21-167.

Wallace, D.H., A.G. Paula and R.W. Zobel. 1991. Photoperiod, temperature and genotype interaction effects on days and nodes required for flowering of bean. J. Amer.Soc.Hort. Sci 116:534-543.

Wanjekeche, E., T. S. Mwangi, M. Kamidi, P. Powum and J. Khaemba. 2007. Farmer participation in the evaluation of grain legumes in North Western Kenya. KALRO project report. Available at www.kalro. org

Wasonga, J., C. Marcial, A. Pastor-Corrales, G. Timothy, P. Porch, and D. Griffiths. 2010. Targeting gene combinations for broad spectrum rust resistance in heat-tolerant snap beandeveloped for tropical environments.Journal of American Society of Horticulture Science 135:521-532.

Webber, H. J., Orton, W. A. 1902. A cowpea resistant to root-knot (Heterodera radicicola). US Dep. Agric. Bur. Plant Industries Bull 17:23-26

Weerapun, K., S. Julsrigaval, C. Senthong and D.Karlade. 2010. Generation mean analysis on seed yield and pod per plant in Azuki bean growing on highland areas. Journal of National Science 9: 125.

Weller, J. L., J. B. Reid, S.A. Taylor, and I. C. Murfet. 1997. The genetic control of flowering in pea. Trends Plant Sci. 2: 412–418.

Weltzien, E., M. E. Smith, L. S. Meitzner and L.S. Sperling. 2003.Technical and institutional issues in participartory plant breeding-from the perspective of formal plant breeding.CGIAR system wide program research and genede analysis for technology development and institutional innovation. PPB Monograph NO.1 PRGA program coordination office,Cali,Coloumbia.

Westphal, E. 1974. Pulses in Ethiopia: Their taxonomy and agricultural significance.Agricultural publishing, Wageningen. p. 135-140.

White, J. W., J. Kornegay, and C. Cjiao. 1996. Inheritance of temperature sensitivity of the photoperiod response in common bean (Phaseolus vulgaris). Euphytica 91:5-8.

Witcombe, J.R, A. Joshi, K.D. Joshi and B.R. Sthapit. 1996. Farmers participatory crop improvement. Varietal selection and breeding methods and their impacts on biodiversity.Expl Agric 32:445-460.

Wolfgang, E., R. Mladen and C. B. Heiko.2008.Heterosis for yield and yield components in rapeseed(*Brassica napus* L.) by Quantitantive Trait Loci mapping 2008.Genetics 179:1547-1558.

Wong, S.P., and T. Wai-Yuan.1978. On the probabilities of obtaining negative estimates of genetic varaiace components. Available at www.researchgate.net.

Yadaw.R.B., S.P. Kahtiwada, B. Chandhary, N.P. Adhikari, B. Baniya, A. Mudwari and P. Tripathi. 2006. Partcipartory Varietal Selection of rice varieties for rain fed conditions. Rice fact sheet, International Rice Research Institute (IRRI) , Ethiopia.

Zdravkovic, J., N. Pavlovic, Z. Girek, M. Bradar-Jokanovic, D. Savic, M. Zdravkovic and D. Cvikic.2011.Generation mean analysis of yield and yield components in tomato (*Lycopersicon esculentum* Mill). Pak .J. Bot 43:1575-1580.

Zeven, A. C., H.H. Mohamed, J. Waninge, and H. Veirunk. 1993. Phenotypic variation within a Hungarian landrace of runner bean. Euphytica 68:155-166.

APPENDICES

Appendix 1a : Anova table of traits in seven runner bean crosses evaluated at two locations

Cross	Days to 50% flowering											
	Kabete						Ol Joro-orok					
W X KIN 1	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	Population	5	540.69	108.1	9.08	<.001	Population	5	523.79	104.8	9.94	<.001
	Residual	33	393.05	11.91			Residual	40	421.43	10.54		
	Total	38	933.74				Total	45	945.22			
W X KIN 2	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	population	5	738.66	147.7	10.66	<.001	population	5	391.89	78.38	10.5	<.001
	Residual	45	623.85	13.86			Residual	60	449.28	7.488		
	Total	50	1362.5				Total	65	841.17			
W X KIN 3	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	Populations	5	676.88	135.4	9.26	<.001	population	5	687.57	137.5	10.1	<.001
	Residual	44	643.12	14.62			Residual	44	601.25	13.66		
	Total	49	1320				Total	49	1288.8			
W X NYERI	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	Populations	5	1422.1	284.4	31.56	<.001	Populations	5	1338.4	267.7	36	<.001
	Residual	69	621.73	9.011			Residual	84	624.69	7.437		
	Total	74	2043.8				Total	89	1963.1			

W X DWARF 1	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	population	5	1822	364.4	45.58	<.001	population	5	620.05	124	15.9	<.001
	Residual	47	375.78	7.995			Residual	69	538.62	7.806		
	Total	52	2197.8				Total	74	1158.7			
W X DWARF 2	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	population	5	1176.7	235.3	24.47	<.001	population	5	532.6	106.5	15.7	<.001
	Residual	58	557.8	9.617			Residual	57	386.01	6.772		
	Total	63	1734.5				Total	62	918.6			
WX DWARF 3	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	population	5	1242	248.4	35.93	<.001	population	5	1000.4	200.1	30.1	<.001
	Residual	49	338.75	6.913			Residual	60	399.09	6.652		
	Total	54	1580.7				Total	65	1399.5			

Number of racemes at first flowering

Cross	**Kabete**						**Ol Joro-orok**					
W X KIN 1	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
					12.3	<.00						0.03
	population	5	560.343	112.069	2	1	population	5	293.11	58.62	2.77	1
	Residual	34	309.257	9.096			Residual	38	803.61	21.15		

	Total	39	869.6				Total	43	1096.73			
W X KIN 2	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
						0.00						<.00
	population	5	361.09	72.22	4.26	3	population	5	405.55	81.11	5.96	1
	Residual	46	779.58	16.95			Residual	60	816.77	13.61		
	Total	51	1140.67				Total	65	1222.32			
W X KIN 3	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
						0.06						
	population	5	285.34	57.07	2.26	8	population	5	257.98	51.6	2.14	0.08
	Residual	39	986.44	25.29			Residual	42	1014.02	24.14		
	Total	44	1271.78				Total	47	1272			
W X NYERI	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
					18.7	<.00				368.5	28.6	<.00
	population	5	1617.81	323.56	2	1	population	5	1842.62	2	2	1
	Residual	73	1261.53	17.28			Residual	87	1120.18	12.88		
	Total	78	2879.34				Total	92	2962.8			
W X DWARF 1	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.

						0.00					149.2	11.4	<.00
	population	5	224.99	45	3.83	5	population	5	746.03	1	9	1
	Residual	47	552.18	11.75			Residual	69	896.29	12.99		
	Total	52	777.17				Total	74	1642.32			
W X												
DWARF 2	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
						<.00				137.6	11.7	<.00
	population	5	364.02	72.8	5.73	1	population	5	688.33	7	7	1
	Residual	57	724.58	12.71			Residual	68	795.31	11.7		
	Total	62	1088.6				Total	73	1483.64			
WX		d.f						d.f				
DWARF 3	Source of variation	.	s.s.	m.s.	v.r.	F pr.	Source of variation	.	s.s.	m.s.	v.r.	F pr.
						<.00						<.00
	population	5	272.5	54.5	5.33	1	population	5	434.07	86.81	7.53	1
	Residual	49	500.7	10.22			Residual	62	714.8	11.53		
	Total	54	773.2				Total	67	1148.87			

Number of racemes at second flowering											
Cross	Kabete					Ol Joro-orok					
W X KIN 1	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	population	5	662.5	132.5	6.73	<.001	population	5	371.4	74.3	5.2	<.001
	Residual	34	669.9	19.7			Residual	38	542.3	14.3		
	Total	39	1332				Total	43	913.6			
W X KIN 2	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	population	5	501.4	100.3	6.33	<.001	population	5	783.7	157	13	<.001
	Residual	45	712.7	15.84			Residual	60	712.4	11.9		
	Total	50	1214				Total	65	1496			
W X KIN 3	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	population	5	477	95.41	3.74	0.007	population	5	909.6	182	16	<.001
	Residual	43	1098	25.54			Residual	44	505.7	11.5		
	Total	48	1575				Total	49	1415			
W X NYERI	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	population	5	1584	316.9	25	<.001	population	5	1414	283	16	<.001
	Residual	68	861.1	12.66			Residual	87	1575	18.1		
	Total	73	2445				Total	92	2989			
W X DWARF 1	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	population	5	805.1	161	10.1	<.001	population	5	566.5	113	10	<.001

	Residual	47	748	15.92			Residual	69	776.1	11.3		
	Total	52	1553				Total	74	1343			
W X DWARF 2	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	GEN	5	388.2	77.63	4.22	0.002	population	5	609.6	122	15	<.001
	Residual	58	1066	18.38			Residual	68	562.8	8.28		
	Total	63	1454				Total	73	1172			
WX DWARF 3	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	population	5	288.5	57.69	2.87	0.024	population	5	221.8	44.4	5.4	<.001
	Residual	48	963.7	20.08			Residual	59	489.1	8.29		
	Total	53	1252				Total	64	710.9			

						Number of pods						
Cross			**Kabete**						**Ol Joro-orok**			
W X KIN		d.						d.				
1	Source of variation	f	s.s.	m.s.	v.r.	F pr.	Source of variation	f	s.s.	m.s.	v.r.	F pr.
						<.00						<.00
	population	5	2638.39	527.68	12.38	1	population	5	2078.96	415.79	19.85	1
	Residual	33	1407.05	42.64			Residual	38	795.83	20.94		
	Total	38	4045.44				Total	43	2874.8			
W X KIN	Source of variation	d.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.	s.s.	m.s.	v.r.	F pr.

2		f						f				
						<.00						<.00
	population	5	1094.78	218.96	3.58	0.008	population	5	5544.43	1108.89	17.46	1
	Residual	47	2874.54	61.16			Residual	60	3811.1	63.52		
	Total	52	3969.32				Total	65	9355.53			
W X KIN		d.						d.				
3	Source of variation	f	s.s.	m.s.	v.r.	F pr.	Source of variation	f	s.s.	m.s.	v.r.	F pr.
						<.00						<.00
	population	5	3522.02	704.4	13.61	1	population	5	6585.67	1317.13	43.45	1
	Residual	43	2225.98	51.77			Residual	45	1364.01	30.31		
	Total	48	5748				Total	50	7949.69			
W X		d.						d.				
NYERI	Source of variation	f	s.s.	m.s.	v.r.	F pr.	Source of variation	f	s.s.	m.s.	v.r.	F pr.
						<.00						<.00
	population	5	7409.26	1481.85	32.78	1	population	5	6159.37	1231.87	28.88	1
	Residual	68	3074.14	45.21			Residual	87	3711.21	42.66		
	Total	73	10483.41				Total	92	9870.58			
W X		d.						d.				
DWARF 1	Source of variation	f	s.s.	m.s.	v.r.	F pr.	Source of variation	f	s.s.	m.s.	v.r.	F pr.
						<.00						<.00
	population	5	2148.81	429.76	10.3	1	population	5	4331.48	866.3	10.34	1

	Residual	47	1960.32	41.71			Residual	69	5778.2	83.74		
	Total	52	4109.13				Total	74	10109.68			
W X		d.						d.				
DWARF 2	Source of variation	f	s.s.	m.s.	v.r.	F pr.	Source of variation	f	s.s.	m.s.	v.r.	F pr.
						<.00						<.00
	population	5	3208.21	641.64	24.17	1	GEN	5	6336.61	1267.32	34.46	1
	Residual	58	1539.53	26.54			Residual	69	2537.71	36.78		
	Total	63	4747.73				Total	74	8874.32			
WX		d.						d.				
DWARF 3	Source of variation	f	s.s.	m.s.	v.r.	F pr.	Source of variation	f	s.s.	m.s.	v.r.	F pr.
						<.00						<.00
	population	5	4478.12	895.62	18.67	1	population	5	2980.93	596.19	14.77	1
	Residual	49	2350.32	47.97			Residual	59	2380.85	40.35		
	Total	54	6828.44				Total	64	5361.78			

Appendix 1b: Variances of populations for studied traits in each cross and location

Population variances for studied traits in each cross and location

Number of racemes during the second flowering

	P1		P2		F1		F2		BC1P1		BC2P2	
	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ
W XKIN 1	9.11	6.61	14.70	5.69	11.62	8.95	42.98	35.25	22.92	19.58	18.25	12.67
W X KIN 2	4.70	2.81	4.27	5.11	6.95	5.40	33.00	33.96	10.86	9.30	17.30	16.92
W X KIN 3	16.08	5.17	11.27	7.27	12.69	6.80	54.67	30.98	18.25	12.25	34.80	15.47
W X NYERI	5.58	2.31	3.33	4.17	6.27	3.89	28.03	52.47	13.93	14.98	13.95	27.11
W X DWARF 1	7.03	3.93	10.69	5.12	10.86	5.66	31.47	24.72	11.33	8.20	16.30	13.24
W X DWARF 2	5.49	4.11	7.72	4.40	7.50	5.89	35.10	16.20	13.33	7.00	18.20	8.67
W X DWARF 3	10.67	4.44	12.25	3.49	10.77	5.34	41.77	19.19	22.92	9.67	17.70	7.98

Number of pods

	P1		P2		F1		F2		BC1P1		BC2P2	
	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ
W XKIN 1	25.11	11.25	30.84	9.41	36.57	12.24	90.14	49.78	34.67	24.67	42.00	22.00
W X KIN 2	30.10	36.02	30.57	45.28	31.64	34.73	131.30	148.10	35.27	52.30	46.92	34.92
W X KIN 3	20.45	18.33	31.93	17.61	34.11	21.55	118.70	75.84	44.25	34.25	46.30	30.17
W X NYERI	8.60	19.26	34.10	26.13	25.79	22.70	107.50	99.38	21.27	38.41	41.48	37.17
W X DWARF 1	24.69	28.03	20.37	39.70	25.84	41.15	89.60	198.60	39.00	69.70	31.20	78.00
W X DWARF 2	11.27	11.08	15.48	25.53	17.67	17.25	48.66	79.61	20.67	40.00	18.22	38.27
W X DWARF 3	25.86	20.71	24.28	24.07	30.85	19.88	100.50	90.23	43.58	47.33	50.20	40.12

Number of racemes during first flowering

	P1		P2		F1		F2		BC1P1		BC2P2	
	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ
W XKIN 1	6.32	10.36	6.57	12.05	4.57	7.24	20.90	51.50	9.58	22.00	8.25	26.25
W X KIN 2	9.34	4.18	7.47	6.13	9.27	5.76	32.83	32.92	10.12	16.30	15.70	17.67
W X NYERI	4.52	2.18	10.05	8.57	11.63	4.76	43.71	30.79	8.11	13.14	13.12	15.82
W X DWARF 1	6.50	6.44	7.80	4.98	6.27	6.99	23.26	29.03	11.67	14.30	10.20	11.14
W X DWARF 2	5.87	3.36	5.07	6.52	3.24	8.09	23.82	24.78	9.58	11.58	12.71	11.47
W X DWARF 3	3.89	7.15	4.44	7.89	2.86	6.44	33.59	24.44	10.92	11.67	14.50	10.98

Number of days to 50% flowering

	P1		P2		F1		F2		BC1P1		BC2P2	
	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ	KAB	OLJ
W XKIN 1	5.50	4.00	7.98	6.22	4.67	5.36	31.24	24.22	9.67	12.20	16.25	11.67
W X KIN 2	6.50	1.54	5.90	1.52	5.71	4.62	27.78	21.61	10.29	9.30	11.30	10.00
W X KIN 3	6.15	7.55	4.84	8.86	9.36	13.90	32.61	33.12	15.33	13.33	16.70	14.67
W X NYERI	1.00	1.37	13.80	1.84	8.82	2.39	22.80	22.24	7.14	5.55	10.14	5.42
W X DWARF 1	5.78	3.14	2.99	2.98	2.79	6.09	17.83	16.71	6.67	7.30	9.30	8.29
W X DWARF 2	3.16	4.15	6.00	2.85	3.62	3.22	18.13	15.96	7.00	8.80	8.10	6.67
W X DWARF 3	3.92	3.72	2.50	6.54	7.49	4.46	27.27	15.96	10.92	8.67	13.30	6.13

Appendix 2: Weather data at Kabete and Ol Joro-orok during 2013-2014 for vegetable and grain runner beans.

KABETE 2013-2014 WEATHER DATA

	YEAR	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	MEAN
MEAN MAX TEMP(0C)	2013	25.1	24.1	22.8	39.2	22.6	20.8	24.5	25.6	23.6	22.9	25.1
	2014	24.3	23.0	23.5	22.3	21.6	_	22.3	_	_	_	22.8
MEAN MIN TEMP(0C)	2013	15.1	14.9	13.8	18.5	10.9	11.9	12.2	13.3	14.5	14.1	13.9
	2014	14.2	14.2	14.8	14.1	12.5	12.4	12.2	14.5	14.4	13.8	13.7
TOTAL RAINFALL/MONTH (mm)	2013	175.2	508.8	53.4	20.3	5.4	51.7	25.9	7.6	128.4	163.2	114.0
	2014	154.7	81.7	72.8	101.5	10.0	28.9	23.9	136.2	95.5	88.6	79.4
TOTAL EVAPORATION/MONTH (KG/M2)	2013	152.5	89.8	95.4	67.9	93.9	75.5	117.9	168.1	123.9	163.5	114.8
	2014	157.1	136.7	107.3	73.4	75.0	99.9	29.5	_	_	_	97.0
MEAN R/H 0600Z	2013	82.2	86.6	83.0	88.0	76.3	88.3	77.9	68.9	84.8	83.6	82.0
	2014	78.0	84.5	81.5	87.6	85.7	81.1	81.5	79.9	84.8	79.6	82.4
MEAN R/H 1200Z	2013	53.5	64.9	60.1	70.0	57.4	63.4	51.3	39.6	58.7	65.0	58.4
	2014	51.6	58.2	55.1	64.4	61.0	54.3	52.0	51.7	58.6	55.2	56.2

		OL JORO-OROK WEATHER DATA										
	YEAR	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEPT**	**OCT**	**NOV**	**DEC**	**MEAN**
MEAN MAX TEMP(^{0}C)	2013	24.2	22.0	21.7	21.0	20.6	19.9	21.9	22.0	20.3	20.2	21.4
	2014	23.1	22.8	22.8	23.4	22.3	21.2	20.6	22.0	22.1	20.6	22.1
MEAN MIN TEMP(^{0}C)	2013	8.3	10.3	6.9	8.0	8.1	7.3	7.4	6.9	9.7	9.6	8.3
	2014	8.4	7.3	7.3	8.0	8.5	8.0	7.6	5.9	7.8	9.0	7.8
TOTAL RAINFALL/MONTH(mm)	2013	124.6	295.1	106.7	98.5	214.1	229.4	66.8	91.0	130.3	159.5	151.6
	2014	76.5	41.3	41.3	69.0	109.2	109.4	183.1	36.8	94.0	62.8	82.3
TOTAL EVAPORATION/MONTH(KG/M^2)	2013	173.6	117.6	121.6	91.5	105.3	88.9	112.2	130.9	107.8	116.0	116.5
	2014	181.0	155.3	155.3	125.4	112.2	105.4	104.1	125.6	122.8	111.8	129.9
MEAN R/H 0600Z	2013	70.7	85.0	84.7	85.5	84.8	85.9	77.1	68.5	81.2	80.2	80.4
	2014	71.8	70.6	70.6	77.5	82.7	85.3	85.1	73.3	71.4	75.6	76.4
MEAN R/H 1200Z	2013	42.5	64.0	57.6	59.2	59.7	68.9	57.4	53.1	66.2	58.5	58.7
	2014	44.6	45.7	45.7	51.5	53.5	59.3	65.5	50.2	54.9	62.8	53.4

Appendix 3: Vegetable Runner beans' number of racemes and plant vigor at two sites in 2013

Genotypes	Number of racemes plant^{-1} during second flowering		Number of racemes plant^{-1} during first flowering		Plant vigor	
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	ol Joro-orok
KAB13-1-105	2.0	4.9	8.7	6.4	3.0	1.0
KAB13-120-17	3.0	0.1	5.2	5.1	1.0	1.0
KAB13-129-121	1.2	4.0	5.5	7.2	2.0	3.0
KAB13-240-119	1.4	1.3	9.0	5.5	2.0	3.0
KAB13-294-24	5.4	2.0	1.1	6.2	1.0	3.0
KAB13-296-111	0.8	7.4	2.1	15.0	3.0	1.0
KAB13-299-43	0.6	2.5	4.1	8.9	2.0	1.0
KAB13-30-87	1.2	7.6	0.4	8.9	2.0	3.0
KAB13-301-39	3.2	3.3	16.5	4.9	7.0	3.0
KAB13-301-40	2.0	2.8	5.2	5.0	3.0	3.0
KAB13-301-45	1.3	1.8	1.6	4.1	5.0	3.0
KAB13-301-46	1.6	4.0	1.1	10.3	4.0	1.0
KAB13-302-100	1.1	10.2	2.4	8.3	2.0	1.0
KAB13-302-90	0.7	4.9	2.6	8.4	1.0	2.0
KAB13-303-32	1.0	5.7	3.9	12.6	2.0	3.0
KAB13-305-130	2.3	1.0	1.5	4.1	3.0	6.0
KAB13-308-114	2.1	10.3	2.5	21.1	2.0	4.0
KAB13-308-57	2.8	4.4	5.3	7.6	1.0	3.0
KAB13-309-60	3.5	3.0	0.5	2.3	5.0	3.0
KAB13-309-61	1.9	5.3	5.9	11.2	2.0	2.5
KAB13-309-64	2.6	1.8	2.3	2.9	2.0	1.5
KAB13-310-86	2.2	4.6	4.3	11.2	1.0	2.0
KAB13-311-102	1.3	4.4	4.8	6.9	1.0	2.0
KAB13-311-103	1.8	8.3	3.9	5.3	2.0	2.0
KAB13-312-135	1.7	5.2	4.0	5.7	2.0	3.0
KAB13-312-35	0.9	3.3	2.1	10.4	1.0	2.0
KAB13-312-36	0.2	3.1	7.0	10.5	1.0	2.0
KAB13-312-37	0.2	5.4	2.8	5.7	1.0	3.0
KAB13-313-26	1.8	4.4	4.1	6.2	1.0	1.0
KAB13-318-34	1.4	6.0	3.8	13.0	5.0	1.0
KAB13-320-104	0.7	8.8	4.9	8.4	2.0	1.0
KAB13-322-6	0.9	7.2	0.8	8.9	4.0	1.0
KAB13-325-51	1.0	2.2	1.0	5.4	4.0	1.0
KAB13-326-58	4.3	1.8	2.9	2.3	4.0	3.0
KAB13-326-59	1.3	2.0	0.8	4.8	4.0	1.0
KAB13-326-98	1.1	4.0	7.3	7.4	1.0	1.0
KAB13-327-48	2.9	3.6	7.8	4.3	2.0	1.0
KAB13-327-92	0.2	6.5	8.6	10.4	1.0	1.0

Genotypes	Number of racemes plant^{-1} during second flowering		Number of racemes plant^{-1} during first flowering		Plant vigor	
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	ol Joro-orok
KAB13-329-108	0.7	12.4	3.2	11.7	2.0	1.0
KAB13-330-27	2.2	6.6	5.9	15.8	1.0	1.0
KAB13-330-93	0.6	4.1	7.2	11.4	1.0	1.0
KAB13-331-113	1.9	5.7	2.8	7.7	1.0	3.0
KAB13-331-66	3.3	4.4	3.0	6.7	3.0	3.0
KAB13-334-29	3.6	1.3	1.3	3.0	2.0	4.0
KAB13-336-28	2.1	2.8	2.0	6.8	1.0	3.0
KAB13-336-63	0.8	3.3	0.6	10.1	4.0	1.0
KAB13-337-101	0.7	4.5	5.6	4.2	1.0	2.0
KAB13-338-38	0.4	1.4	6.1	4.9	1.0	1.0
KAB13-338-41	2.0	3.6	3.0	4.6	1.0	1.0
KAB13-339-89	0.3	7.4	1.4	11.2	2.0	2.0
KAB13-339-95	2.0	2.7	2.3	9.7	2.0	1.0
KAB13-341-94	0.1	10.4	13.6	12.9	1.0	1.0
KAB13-363-131	1.0	6.4	1.3	6.9	3.0	2.0
KAB13-363-54	1.8	4.0	1.5	9.8	4.0	1.0
KAB13-369-136	0.2	2.6	0.0	5.0	5.0	2.0
KAB13-37-16	0.7	5.1	2.4	8.5	1.0	1.0
KAB13-379-33	1.1	4.5	2.0	6.6	1.0	3.0
KAB13-380-109	1.4	10.3	3.7	15.4	1.0	3.0
KAB13-380-55	1.6	9.5	3.9	7.0	3.0	1.0
KAB13-380-56	13.3	5.1	0.0	6.2	7.0	1.0
KAB13-396-53	4.6	3.8	0.8	4.3	1.0	2.0
KAB13-399-99	1.0	3.6	0.7	4.8	3.0	3.0
KAB13-426-84A	3.0	5.1	3.3	6.5	1.0	3.0
KAB13-440-74	1.8	0.5	2.2	4.2	2.0	3.0
KAB13-446-4	2.9	1.5	4.8	6.0	4.0	2.0
KAB13-446-5	0.6	3.0	2.0	6.9	4.0	1.0
KAB13-46-22	4.8	1.2	7.8	4.4	4.0	1.0
KAB13-46-23	0.3	2.9	3.5	8.4	2.0	3.0
KAB13-470-72	2.6	3.7	4.0	8.8	2.0	1.0
KAB13-470-8	2.0	3.5	0.8	12.1	2.0	2.0
KAB13-471-117	1.9	1.4	1.2	5.0	3.0	3.0
KAB13-471-118	1.5	2.8	0.0	3.0	2.0	4.0
KAB13-50-15	1.2	2.6	3.6	10.2	1.0	4.0
KAB13-522-7	3.5	1.9	3.7	2.8	3.0	5.0
KAB13-522-73	0.7	4.4	2.1	2.9	1.0	4.0
KAB13-57-106	1.0	8.3	2.4	10.0	2.0	3.0
KAB13-64-107	1.5	8.3	2.7	6.7	2.0	3.0
KAB13-649-70	0.2	5.6	1.4	7.4	1.0	3.0
KAB13-660-71	1.5	3.6	2.5	10.1	1.0	2.0
KAB13-697-132	1.7	4.6	1.6	6.4	3.0	3.0

Genotypes	Number of racemes plant^{-1} during second flowering		Number of racemes plant^{-1} during first flowering		Plant vigor	
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	ol Joro-orok
KAB13-697-133	1.9	2.0	2.1	6.4	2.0	3.0
KAB13-85-18	0.9	2.1	2.1	3.7	1.0	3.0
KAB13-97-14	3.1	3.9	1.0	7.2	1.0	2.0
OL13-21-1	1.2	4.4	0.4	3.6	4.0	3.0
OL13-21-1A	0.6	4.6	0.3	7.5	3.0	3.0
OL13-21-2	2.4	3.9	4.1	8.5	3.0	3.0
SUB13-106-12	0.9	8.4	10.3	11.3	2.0	3.0
SUB13-114-77	1.4	3.2	5.5	4.2	2.0	3.0
SUB13-117-68	1.9	2.6	3.8	5.8	1.0	3.0
SUB13-129-120	2.1	5.9	2.7	3.2	3.0	4.0
SUB13-133-10	5.9	4.6	2.9	13.2	2.0	3.0
SUB13-133-11	1.9	5.3	4.7	5.3	2.0	2.0
SUB13-133-80	0.3	3.8	1.5	11.1	3.0	2.0
SUB13-178-123	2.4	7.4	0.3	3.8	4.0	1.0
SUB13-221-128	0.5	4.3	2.4	4.4	1.0	1.0
SUB13-238-127	4.3	4.8	4.0	8.3	5.0	1.5
SUB13-240-125	1.0	4.6	2.0	5.9	4.0	1.0
SUB13-240-126	0.6	6.5	1.6	10.0	2.0	1.5
SUB13-240-9	0.7	2.7	1.9	5.3	3.0	1.0
SUB13-269-129	1.4	7.1	2.2	10.4	1.0	2.0
SUB13-271-78	1.0	9.0	1.9	6.4	1.0	2.0
SUB13-271-79	0.9	2.5	2.0	7.5	1.0	2.0
SUB13-283-122	4.4	2.9	1.5	3.8	3.0	3.0
SUB13-285-82	0.5	3.9	1.8	7.2	1.0	2.0
SUB13-305-76	0.3	5.8	1.7	6.7	2.0	1.0
SUB13-308-75	0.8	7.0	3.6	9.5	3.0	2.0
SUB13-325-134	0.7	5.6	2.8	7.2	3.0	2.0
SUB13-82-69	2.2	1.4	3.2	3.6	2.0	4.0
White Emergo	0.8	1.8	1.0	5.1	3.0	5.0
Trial Mean	1.77	4.51	3.25	7.4	2.3	2.2
% CV	95.8	55.8	85.3	48.6	57.5	43.8
L.s.d	3.36	5.0	5.5	7.1	2.6	1.9

Appendix 4: Vegetable runner bean days to flowering and reaction to diseases at two sites in 2013

Genotypes	Days to flowering		Rust scores		Common Bacterial Blight		Powdery mildew scores	Bean Common Mosaic virus scores
	Kabete	ol Joro-orok	Kabete	ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok
KAB13-1-105	51.5	51.5	1.0	1.0	2.0	3.0	1.0	2.0
KAB13-120-17	50.5	51.0	1.0	1.0	3.0	4.0	2.0	2.5
KAB13-129-121	51.0	50.0	1.0	1.5	1.0	2.5	1.0	2.5
KAB13-240-119	50.5	49.5	1.0	1.0	3.0	2.0	3.5	3.5
KAB13-294-24	50.5	50.5	1.0	1.0	2.0	1.0	2.0	4.0
KAB13-296-111	50.5	52.0	1.0	1.0	2.0	1.0	2.0	3.0
KAB13-299-43	50.5	51.0	1.0	1.0	1.0	2.0	2.0	3.0
KAB13-30-87	51.5	50.5	1.0	1.0	1.5	1.0	1.0	3.0
KAB13-301-39	52.5	52.0	1.0	1.0	3.0	4.0	2.0	3.0
KAB13-301-40	50.5	50.5	1.0	1.0	1.0	4.0	2.0	2.0
KAB13-301-45	52.0	52.0	1.0	1.0	2.0	3.0	1.0	2.0
KAB13-301-46	50.0	53.0	1.0	1.0	2.0	3.5	1.0	1.5
KAB13-302-100	52.5	51.5	1.0	1.5	1.0	2.0	6.0	1.0
KAB13-302-90	50.0	50.0	1.0	1.0	3.0	2.0	1.0	1.0
KAB13-303-32	50.5	50.0	1.0	1.0	2.0	2.0	1.0	3.0
KAB13-305-130	49.0	50.0	1.0	1.0	1.5	4.0	1.0	5.0
KAB13-308-114	50.0	52.0	1.0	1.0	1.5	1.0	6.0	3.0
KAB13-308-57	50.5	51.0	1.0	1.0	1.0	2.0	1.0	3.0
KAB13-309-60	51.5	51.5	1.0	1.0	2.0	6.0	1.0	5.0
KAB13-309-61	50.5	50.0	1.0	2.0	1.0	3.0	3.0	3.0
KAB13-309-64	51.0	53.0	1.5	1.0	1.5	4.0	4.0	3.0
KAB13-310-86	51.0	52.0	1.0	1.0	2.0	3.0	3.0	2.5
KAB13-311-102	50.5	52.0	1.0	1.0	1.5	3.0	1.0	3.0
KAB13-311-103	50.0	52.0	1.0	1.0	1.5	2.0	1.0	2.0
KAB13-312-135	50.0	50.0	1.0	2.0	1.0	3.5	1.0	3.0
KAB13-312-35	50.5	50.5	1.0	2.0	1.0	2.0	5.0	2.0
KAB13-312-36	47.5	52.5	1.0	1.5	3.0	4.5	1.0	2.0
KAB13-312-37	48.5	48.5	1.0	1.0	1.0	4.5	1.0	4.0
KAB13-313-26	49.0	50.5	1.0	1.0	2.0	4.5	1.0	3.0
KAB13-318-34	50.0	50.0	1.0	1.0	1.0	2.5	1.0	4.0
KAB13-320-104	49.0	50.5	1.0	1.0	1.0	1.0	3.0	2.0
KAB13-322-6	51.5	51.0	1.0	1.0	1.5	2.0	1.0	3.0
KAB13-325-51	51.0	49.0	1.0	1.0	1.5	2.0	1.0	3.0
KAB13-326-58	50.0	49.0	1.0	1.0	2.0	2.0	1.0	5.0
KAB13-326-59	49.5	51.0	1.0	1.0	1.0	2.0	2.0	4.0
KAB13-326-98	51.0	50.5	1.0	1.0	2.0	2.0	2.0	3.0
KAB13-327-48	46.0	50.0	1.0	1.0	2.0	2.0	1.0	5.0
KAB13-327-92	50.0	51.0	1.0	1.0	2.0	2.0	4.0	4.0

Genotypes	Days to flowering		Rust scores		Common Bacterial Blight		Powdery mildew scores	Bean Common Mosaic virus scores
	Kabete	ol Joro-orok	Kabete	ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok
KAB13-329-108	49.5	50.0	1.0	1.0	1.0	2.0	1.0	1.0
KAB13-330-27	49.5	50.5	1.0	1.0	1.5	2.0	1.0	1.0
KAB13-330-93	48.5	50.0	1.0	1.0	1.5	2.0	3.0	5.0
KAB13-331-113	51.5	50.0	1.0	1.0	2.0	1.0	6.0	2.0
KAB13-331-66	50.5	50.5	1.0	1.0	2.0	1.0	1.0	6.0
KAB13-334-29	51.0	51.0	1.0	3.0	1.5	1.5	3.0	4.0
KAB13-336-28	48.5	51.0	1.5	2.0	2.0	2.0	4.0	3.0
KAB13-336-63	50.0	51.0	1.0	1.0	1.5	2.0	3.0	4.0
KAB13-337-101	51.5	47.5	1.0	1.0	2.5	2.0	4.0	3.0
KAB13-338-38	48.5	51.5	1.0	1.0	1.0	2.0	1.0	3.0
KAB13-338-41	50.5	52.0	1.0	1.0	1.5	2.5	1.0	3.0
KAB13-339-89	51.5	50.0	1.0	1.0	1.0	3.0	4.0	3.0
KAB13-339-95	50.5	50.0	1.0	1.0	1.5	2.0	1.0	3.0
KAB13-341-94	49.0	50.0	1.0	1.0	2.5	2.0	5.0	3.0
KAB13-363-131	51.0	50.5	1.0	1.0	2.0	2.0	1.0	3.0
KAB13-363-54	50.0	50.0	1.0	1.0	1.0	2.0	1.0	3.0
KAB13-369-136	51.0	50.5	1.0	1.5	1.0	2.0	1.0	3.0
KAB13-37-16	48.5	50.0	1.5	1.0	2.0	2.0	2.0	3.0
KAB13-379-33	50.0	51.5	1.0	1.0	1.0	2.0	2.0	3.0
KAB13-380-109	50.5	50.0	1.0	1.0	1.5	2.0	1.0	3.0
KAB13-380-55	48.5	49.5	1.0	1.5	2.0	2.0	3.0	3.0
KAB13-380-56	51.0	50.0	1.0	1.0	3.0	2.0	2.0	3.0
KAB13-396-53	51.0	49.0	1.0	1.0	2.0	1.0	1.0	3.0
KAB13-399-99	51.0	50.0	1.0	1.0	1.0	1.0	1.5	3.0
KAB13-426-84A	51.0	49.0	1.0	1.0	2.0	5.0	2.0	3.0
KAB13-440-74	50.0	50.5	1.0	1.0	1.5	4.0	1.0	3.0
KAB13-446-4	25.0	51.5	1.0	1.0	3.0	5.0	1.5	2.0
KAB13-446-5	50.0	52.0	1.0	1.0	1.5	2.0	3.0	1.5
KAB13-46-22	51.0	52.0	1.0	1.0	2.0	2.0	1.0	3.0
KAB13-46-23	50.0	50.0	1.0	1.0	3.0	2.0	3.0	3.0
KAB13-470-72	50.0	50.0	1.0	1.0	1.0	2.0	2.5	1.0
KAB13-470-8	50.0	50.5	1.0	1.0	1.5	2.0	3.0	1.0
KAB13-471-117	50.0	50.5	1.0	1.0	1.0	2.0	3.0	4.0
KAB13-471-118	52.5	50.0	1.0	1.0	1.0	1.0	1.0	4.0
KAB13-50-15	50.0	52.5	1.0	1.5	1.5	1.0	3.0	3.0
KAB13-522-7	50.5	53.5	1.0	1.0	1.5	1.0	1.0	4.0
KAB13-522-73	50.0	50.5	1.0	1.0	1.5	1.0	1.5	4.0
KAB13-57-106	49.5	52.0	1.0	1.0	1.0	2.0	1.0	3.0
KAB13-64-107	50.5	52.5	1.0	1.0	1.0	2.0	1.0	2.0
KAB13-649-70	49.0	53.0	1.0	1.0	1.0	2.0	1.0	2.0
KAB13-660-71	52.0	51.5	1.0	1.0	2.5	2.0	2.0	1.0

Genotypes	Days to flowering		Rust scores		Common Bacterial Blight		Powdery mildew scores	Bean Common Mosaic virus scores
	Kabete	ol Joro-orok	Kabete	ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok
KAB13-697-132	51.0	51.0	1.0	1.0	1.5	3.5	1.0	3.0
KAB13-697-133	51.0	51.0	1.0	1.0	1.0	2.0	2.0	3.0
KAB13-85-18	51.0	52.0	1.0	1.0	1.0	2.0	2.0	3.0
KAB13-97-14	51.5	50.5	1.0	1.0	1.0	2.5	3.0	3.0
OL13-21-1	50.5	52.0	1.0	1.0	1.0	2.0	3.0	3.0
OL13-21-1A	25.0	52.0	1.5	1.0	1.5	2.0	2.0	3.0
OL13-21-2	52.0	51.5	1.0	2.0	2.0	2.0	1.0	2.0
SUB13-106-12	26.5	50.5	1.5	1.0	2.0	2.0	1.5	2.0
SUB13-114-77	51.5	51.0	1.0	1.0	1.0	2.0	1.0	3.0
SUB13-117-68	50.0	51.5	1.0	1.0	2.0	2.0	1.0	3.0
SUB13-129-120	52.0	50.5	1.0	1.0	2.0	2.0	1.0	3.0
SUB13-133-10	47.5	52.0	1.5	1.0	2.0	2.0	2.0	1.0
SUB13-133-11	51.5	51.0	1.0	1.0	1.5	2.0	2.0	2.0
SUB13-133-80	48.0	49.5	1.0	1.0	2.5	2.0	1.0	2.0
SUB13-178-123	49.0	50.0	1.0	2.0	2.5	2.0	2.5	3.0
SUB13-221-128	46.0	51.0	1.0	1.0	1.0	2.0	1.5	4.0
SUB13-238-127	49.5	50.0	1.0	1.0	3.0	3.5	2.5	4.0
SUB13-240-125	49.0	49.5	1.0	2.0	3.5	2.5	2.5	3.0
SUB13-240-126	49.5	50.0	1.0	1.0	3.5	3.0	2.5	3.0
SUB13-240-9	52.5	50.5	1.0	1.0	3.5	4.5	2.0	4.0
SUB13-269-129	49.5	51.0	1.0	1.0	2.0	3.0	2.0	3.0
SUB13-271-78	47.5	50.0	1.0	1.0	2.0	1.0	2.5	3.0
SUB13-271-79	50.0	50.0	1.0	1.0	2.5	1.0	3.0	3.0
SUB13-283-122	47.5	53.0	1.0	1.0	2.0	3.0	2.5	3.0
SUB13-285-82	50.0	50.5	1.0	1.0	1.0	2.0	2.0	3.0
SUB13-305-76	51.0	50.5	1.0	1.0	1.5	2.0	2.0	3.0
SUB13-308-75	49.0	50.0	1.0	1.5	1.0	2.0	2.5	2.0
SUB13-325-134	52.0	49.5	1.0	1.0	1.5	2.5	1.0	2.0
SUB13-82-69	49.5	50.0	1.0	1.0	3.5	3.0	2.0	3.0
White Emergo	54.5	58.5	2.5	1.0	3.0	3.0	3.5	3.0
Trial Mean	49.6	50.8	1.0	1.1	1.8	2.3	2.0	2.9
CV (%)	12.4	2.1	17.0	31.7	47.2	47.1	69.0	34.1
$LSD_{0.05}$	NS	2.2	0.4	0.7	1.6	2.2	2.8	2.0

Apppendix 5. Anova results of pod yield of vegetable runner beanfor 2013 and 2014

Pod Yield (Kgha^{-1})										
	2013					2014				
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	1.28E+08	1.28E+08	49.85		2	1.21E+07	6.06E+06	0.4	
REP.*Units* stratum										
Genotype	35	1.79E+08	5120432	2	0.022	83	2.88E+09	3.47E+07	2.3	<.001
Residual	35	89811196	2566034			166	2.50E+09	1.51E+07		
Total	71	3.97E+08				251	5.40E+09			

Appendix 6: Grain Runner beans' Plant vigor, days to flowering and number of racemes during 2013

Genotypes	Plant Vigor		Days to 50% flowering		Number of Racemes plant -1 at first flowering		Number of racemes plant -1 at second flowering	
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	ol Joro-orok
KAB-OL-RB13-36-230	3.0	1.7	47.3	50.7	0.5	7.1	0.0	3.4
KAB-OL-RB13-426-228	3.0	2.3	50.0	51.7	1.1	8.8	0.5	6.3
KAB-OL-RB13-426-229	2.3	1.7	50.7	50.7	2.0	7.8	1.3	6.6
KAB-OL-RB13-440-232	2.3	2.3	49.0	50.0	1.7	5.9	0.0	1.5
KAB-RB13-108-125	2.3	1.7	48.3	51.0	1.3	8.4	0.4	5.5
KAB-RB13-120-123	1.0	1.7	48.3	50.7	0.6	9.3	0.1	7.8
KAB-RB13-13-128	3.0	3.0	49.0	50.3	1.1	5.6	0.0	5.8
KAB-RB13-132-4	2.3	1.7	50.7	50.7	3.5	5.9	0.2	3.6
KAB-RB13-155-122	2.3	2.3	49.0	50.7	1.7	6.3	0.0	5.9
KAB-RB13-293-218	1.0	2.3	51.3	50.0	5.8	7.3	0.7	6.7
KAB-RB13-294-201	2.3	2.3	50.3	50.3	1.3	3.4	0.4	2.5
KAB-RB13-294-204	3.7	1.7	50.3	51.0	1.0	5.9	0.6	4.8
KAB-RB13-294-205	4.3	2.3	51.0	50.3	2.0	4.5	1.1	4.3
KAB-RB13-297-142	2.3	1.7	49.7	50.7	1.6	8.9	0.7	7.9
KAB-RB13-297-144	1.0	3.0	51.7	50.7	0.6	3.9	0.7	4.1
KAB-RB13-299-168	2.3	1.7	48.7	50.7	0.1	4.4	0.1	3.1
KAB-RB13-299-169	2.3	1.7	49.3	51.0	2.1	6.6	0.5	7.4
KAB-RB13-299-176	3.0	2.3	51.0	50.3	4.0	5.8	0.5	2.3
KAB-RB13-301-171	1.7	3.0	50.0	50.0	2.0	9.1	0.0	6.5
KAB-RB13-303-146	3.0	2.3	50.7	50.7	3.2	8.7	0.8	5.3
KAB-RB13-303-151	2.3	2.3	48.7	51.0	2.0	8.1	0.0	4.8
KAB-RB13-306-181	3.0	3.0	50.7	51.0	4.4	10.1	0.0	6.1
KAB-RB13-308-217	2.3	1.7	47.3	49.0	0.6	8.0	0.0	4.8
KAB-RB13-308-222	1.7	3.0	51.7	50.0	3.0	5.4	0.0	9.0

Appendix 6 (continued)

Genotypes	Plant Vigor		Days to 50% flowering		Number of Racemes plant -1 at first flowering		Number of racemes plant -1 at second flowering	
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	ol Joro-orok
KAB-RB13-309-224	1.7	1.7	49.7	50.3	0.8	5.0	0.3	3.5
KAB-RB13-310-159	1.7	3.0	49.0	50.0	2.2	8.3	0.9	6.0
KAB-RB13-310-161	1.3	2.3	50.7	50.7	2.1	7.3	0.2	5.2
KAB-RB13-310-162	3.3	2.3	49.0	50.7	3.0	9.2	3.3	3.2
KAB-RB13-312-156	3.0	1.7	51.0	50.0	2.0	6.2	0.3	4.2
KAB-RB13-312-158	1.0	1.0	48.3	50.3	1.4	9.4	0.0	8.5
KAB-RB13-312-160	2.3	1.7	47.0	50.0	5.0	10.1	2.3	4.8
KAB-RB13-313-127	1.0	2.3	47.0	50.7	1.0	6.4	0.0	5.8
KAB-RB13-314-191	1.0	2.3	51.3	51.0	3.4	9.8	0.4	6.6
KAB-RB13-314-192	2.3	2.3	49.3	50.0	3.5	6.9	0.6	7.8
KAB-RB13-315-197	4.3	1.7	49.7	50.7	2.5	4.5	0.2	5.1
KAB-RB13-318-157	3.0	3.7	49.7	50.0	1.2	5.9	0.0	4.0
KAB-RB13-319-182	3.7	2.3	50.3	50.7	1.7	8.9	0.0	4.9
KAB-RB13-319-193	3.0	2.3	51.3	50.0	0.9	4.8	1.8	5.1
KAB-RB13-319-194	1.0	3.0	50.0	51.0	1.5	7.1	0.4	5.7
KAB-RB13-321-185	1.0	3.0	52.0	50.7	1.4	12.0	1.0	5.1
KAB-RB13-321-187	1.0	2.3	49.7	52.7	1.3	9.3	0.8	4.5
KAB-RB13-321-190	2.3	1.7	49.0	50.0	1.2	5.4	0.0	5.3
KAB-RB13-325-198	3.0	1.7	47.7	50.3	3.8	7.6	0.4	9.3
KAB-RB13-325-200	3.7	2.3	49.7	50.0	2.4	5.9	0.2	4.1
KAB-RB13-325-202	1.0	1.0	50.3	49.7	1.1	8.9	0.7	6.5
KAB-RB13-326-207	3.7	1.7	50.7	51.0	3.6	10.8	0.7	11.3
KAB-RB13-327-48	2.3	1.7	51.7	49.0	9.7	4.5	1.4	4.3
KAB-RB13-327-92	1.7	1.7	49.7	48.7	7.0	7.0	1.5	7.0
KAB-RB13-329-163	3.7	2.3	51.0	51.0	1.7	6.3	1.3	3.9
KAB-RB13-329-164	3.0	2.3	50.3	51.3	1.8	5.9	0.5	3.2
KAB-RB13-329-165	2.3	1.7	49.7	50.0	1.6	3.1	0.0	2.5
KAB-RB13-329-166	1.0	1.7	50.0	50.0	4.1	5.1	1.7	4.5
KAB-RB13-329-167	3.0	2.3	50.7	51.0	2.1	5.6	0.0	7.2
KAB-RB13-329-172	3.7	1.0	50.3	50.0	2.6	7.5	0.9	10.0
KAB-RB13-330-126	1.7	2.3	48.7	50.3	2.4	8.7	0.0	4.1
KAB-RB13-330-140	2.3	1.7	52.7	50.0	2.7	6.7	1.1	4.9
KAB-RB13-331-113	1.0	3.0	50.7	48.3	6.3	6.1	2.1	6.3
KAB-RB13-331-225	3.7	2.3	50.7	50.7	4.9	6.7	1.0	3.3
KAB-RB13-333-223	2.0	2.3	52.0	50.7	3.0	6.2	0.6	4.5
KAB-RB13-334-130	1.7	1.0	49.7	49.7	3.7	6.5	1.2	5.6
KAB-RB13-334-136	3.0	2.3	50.3	50.0	0.4	7.2	0.5	2.9
KAB-RB13-334-137	3.7	1.7	50.3	51.0	1.1	6.2	0.7	2.4
KAB-RB13-334-139	2.3	1.7	49.3	51.0	0.3	6.7	0.2	2.2
KAB-RB13-334-29	2.3	3.7	50.3	50.0	10.3	4.3	2.2	4.3
KAB-RB13-335-199	1.0	1.7	51.0	50.0	5.9	5.7	0.3	8.6
KAB-RB13-335-203	1.7	3.0	50.7	51.0	0.6	4.2	0.4	1.6

Appendix 6 (continued)

Genotypes	Plant Vigor		Days to 50% flowering		Number of Racemes plant -1 at first flowering		Number of racemes plant -1 at second flowering	
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	ol Joro-orok
KAB-RB13-336-132	3.0	1.0	47.0	49.0	0.4	6.1	0.0	5.8
KAB-RB13-336-133	3.7	2.3	51.0	50.0	3.1	6.6	1.0	6.1
KAB-RB13-336-63	3.3	1.7	49.3	49.3	6.3	6.8	2.5	3.7
KAB-RB13-338-175	3.7	1.7	47.7	50.3	1.1	7.5	0.6	2.7
KAB-RB13-338-178	1.7	2.3	50.3	35.3	1.6	8.8	0.9	8.0
KAB-RB13-338-179	2.3	3.0	51.0	50.3	1.5	8.9	2.3	9.4
KAB-RB13-338-41	1.7	1.7	50.0	50.3	4.1	5.7	2.6	4.7
KAB-RB13-340-180	1.0	2.3	51.3	50.3	1.6	5.6	0.2	9.7
KAB-RB13-341-129	3.7	2.3	50.3	51.3	3.3	10.3	0.3	6.6
KAB-RB13-341-134	3.7	1.7	51.0	50.0	0.7	5.4	1.5	4.6
KAB-RB13-341-143	3.0	2.3	50.0	50.7	2.7	9.1	0.4	7.4
KAB-RB13-342-145	1.7	1.0	47.7	50.0	1.0	9.4	0.0	7.2
KAB-RB13-343-183	1.7	1.7	49.3	51.0	4.6	7.2	0.4	8.1
KAB-RB13-343-184	3.0	2.3	49.3	36.3	3.3	8.9	0.3	10.3
KAB-RB13-343-188	1.7	1.7	52.3	50.0	2.7	8.0	1.3	5.2
KAB-RB13-343-189	3.0	1.7	49.3	50.0	1.7	8.8	0.3	7.4
KAB-RB13-364-211	1.7	3.0	50.0	51.0	1.5	5.4	0.6	4.9
KAB-RB13-364-212	1.7	3.7	50.3	50.7	3.5	8.4	0.4	6.0
KAB-RB13-37-16	1.7	1.7	49.0	49.0	5.0	9.7	2.1	5.7
KAB-RB13-378-131	1.7	2.3	51.3	51.7	2.8	8.7	1.7	9.5
KAB-RB13-378-141	3.0	2.3	48.7	52.0	1.3	7.7	0.3	3.9
KAB-RB13-379-147	1.7	1.7	50.7	51.7	1.6	11.0	0.9	6.5
KAB-RB13-379-148	1.7	1.7	49.7	51.7	1.5	10.3	2.4	6.1
KAB-RB13-379-154	2.3	2.3	49.7	50.7	1.2	6.4	0.0	9.7
KAB-RB13-396-210	3.0	1.7	50.0	50.7	3.4	6.1	0.0	4.9
KAB-RB13-399-219	2.3	2.3	50.7	50.3	2.0	6.3	1.7	6.8
KAB-RB13-399-221	3.0	3.7	49.0	50.3	1.0	5.4	0.0	3.3
KAB-RB13-403-149	2.3	2.3	49.7	50.3	2.3	5.5	0.2	3.3
KAB-RB13-403-150	2.3	1.7	51.0	50.7	3.0	7.7	0.8	4.0
KAB-RB13-403-152	3.0	3.0	51.3	50.0	2.8	5.4	0.0	8.3
KAB-RB13-403-153	3.0	2.3	50.7	50.3	4.4	10.8	0.3	10.8
KAB-RB13-405-195	1.0	1.7	48.7	50.3	1.8	6.1	0.3	4.4
KAB-RB13-405-196	3.0	2.3	49.7	50.3	2.0	10.1	0.3	4.4
KAB-RB13-408-220	3.0	1.0	49.3	50.0	2.5	8.9	0.2	7.3
KAB-RB13-410-216	2.3	1.7	48.7	50.7	3.5	10.2	0.5	7.5
KAB-RB13-426-84	1.7	3.0	50.0	48.0	7.3	6.3	2.4	6.0
KAB-RB13-46-124	1.7	1.7	49.7	51.0	2.8	8.2	0.4	5.2
KAB-RB13-46-19	1.7	1.7	49.3	50.3	0.5	11.7	0.7	4.3
KAB-RB13-471-117	3.0	3.0	49.0	49.3	8.3	6.0	2.4	4.0
KAB-RB13-48-16	3.0	3.0	47.3	50.0	0.8	9.5	0.0	4.7
KAB-RB13-48-17	2.3	1.7	50.3	50.3	1.6	4.1	0.1	3.2
KAB-RB13-522-73	1.7	3.7	50.7	49.7	5.5	3.9	2.4	5.7

Appendix 6(continued)

Genotypes	Plant Vigor		Days to 50% flowering		Number of Racemes plant -1 at first flowering		Number of racemes plant -1 at second flowering	
	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	Ol Joro-orok	Kabete	ol Joro-orok
KAB-RB13-62-8	2.3	3.0	52.3	51.0	2.4	5.8	0.0	3.3
KAB-RB13-62-9	2.3	2.3	52.0	50.0	4.4	9.0	0.4	2.5
KAB-RB13-75-6	3.7	1.0	50.7	51.3	5.1	11.8	0.2	7.5
KAB-RB13-80-14	1.0	3.0	52.0	50.0	2.7	10.0	0.6	11.3
KAB-RB13-84-11	4.3	1.7	49.0	50.0	1.7	6.1	0.1	4.0
KAB-RB13-85-18	3.7	1.7	50.0	50.0	1.4	6.0	0.8	1.8
KAB-RB13-97-12	1.7	2.3	50.0	51.7	3.9	4.2	1.2	4.0
KAB-RB13-97-13	2.3	1.7	48.7	50.0	0.9	4.6	0.5	1.6
KIN 2	3.0	2.3	49.7	51.0	0.8	5.0	0.3	3.3
KIN 3	2.3	5.7	48.7	52.3	1.2	5.3	1.0	2.4
NYERI	2.3	3.0	50.7	52.0	1.1	8.7	0.0	1.3
OLJ DWF 1	4.3	3.7	50.3	50.7	2.9	7.4	0.2	0.0
OLJ DWF 3	3.7	2.7	51.3	51.0	1.0	3.9	0.0	0.0
OL-OL-RB13-10-242	4.3	2.3	49.7	51.0	3.2	6.0	0.3	4.5
OL-OL-RB13-21-240	3.0	2.3	50.3	49.3	0.8	3.2	1.1	2.7
OL-OL-RB13-23-1	2.3	4.3	49.3	50.3	1.9	4.7	0.7	2.3
OL-OL-RB13-27-250	1.7	2.3	50.0	50.0	3.3	5.7	0.9	5.8
OL-OL-RB13-37-234	1.7	2.3	49.0	50.0	1.7	4.8	0.7	2.6
OL-OL-RB13-67-231	2.3	1.7	49.3	51.0	0.4	4.3	0.0	2.7
OL-OL-RB13-96-236	1.0	1.7	49.3	50.7	0.0	6.7	0.2	5.7
SUB-OL-RB13-129-235	1.7	1.7	50.0	51.0	0.5	3.9	0.0	3.5
SUB-OL-RB13-133-243	3.0	3.7	51.3	50.3	2.3	11.3	0.2	5.7
SUB-OL-RB13-177-3	1.7	1.7	49.0	50.0	1.6	5.0	0.8	7.0
SUB-OL-RB13-178-239	3.0	2.3	45.7	52.0	1.8	10.7	0.1	2.8
SUB-OL-RB13-220-245	2.3	1.7	50.7	50.7	2.3	3.1	0.3	6.3
SUB-OL-RB13-226-251	3.0	2.3	50.0	50.7	2.4	6.1	0.4	3.9
SUB-OL-RB13-228-247	1.7	2.3	49.7	50.3	1.1	5.0	0.8	5.1
SUB-OL-RB13-231-226	3.0	1.7	50.7	50.3	0.7	6.0	0.6	2.9
SUB-OL-RB13-238-238	1.7	2.3	50.0	51.3	1.0	5.5	0.1	3.3
SUB-OL-RB13-275-248	1.0	3.0	50.3	51.3	4.1	7.7	0.7	5.3
SUB-OL-RB13-275-249	1.7	1.7	50.0	51.0	0.8	7.5	0.5	3.0
SUB-OL-RB13-312-252	6.3	3.0	49.0	50.3	1.1	9.8	0.4	8.7
SUB-OL-RB13-323-2	2.3	1.7	49.7	50.0	0.9	7.9	0.2	6.8
SUB-OL-RB13-96-237	2.3	2.3	49.3	50.7	2.9	10.8	0.1	7.2
SUB-RB13-221-128	1.7	1.7	49.0	49.3	6.6	4.3	1.6	6.3
SUB-RB13-269-129	1.7	2.3	49.0	49.7	6.5	7.0	1.1	7.7
SUB-RB13-308-75	3.0	2.3	49.7	49.0	5.2	7.6	2.2	7.3
SUB-RB13-325-134	2.3	2.3	50.7	48.7	7.6	7.5	2.4	8.0
Mean	2.9	2.2	50.9	50.2	2.5	7.0	1	5.0
CV (%)	57.2	55.4	41.9	6.5	87.9	47.0	172	65.0
$LSD_{0.05}$	2.2	NS	NS	NS	3.6	5.3	NS	6

Appendix 7: Reaction of grain runner beanto diseases and grain yield (kgha^{-1}) in 2013

Genotypes	Rust Scores		Common bacterial blight scores		Powdery mildew scores	Bean common Mosaic virus	Grain Yield (kgha^{-1})
	Ol Joro-orok	Kabete	Ol Joro--orok	Kabete	Kabete	ol Joro-orok	ol Joro-orok
KAB-OL-RB13-36-230	1.0	1.0	1.7	1.0	2.3	3.0	6111
KAB-OL-RB13-426-228	1.7	1.0	2.0	1.0	1.0	3.0	5803
KAB-OL-RB13-426-229	1.0	1.0	2.0	1.0	2.3	3.0	7450
KAB-OL-RB13-440-232	1.0	1.0	2.0	1.0	1.7	3.0	6404
KAB-RB13-108-125	1.0	1.0	3.0	1.0	2.3	3.0	7138
KAB-RB13-120-123	1.0	1.0	2.0	1.0	1.0	2.7	7253
KAB-RB13-13-128	1.3	1.0	1.7	1.0	1.0	3.0	5889
KAB-RB13-132-4	1.0	1.0	1.7	1.0	1.3	2.7	2772
KAB-RB13-155-122	1.0	1.0	1.7	1.0	1.0	4.3	7213
KAB-RB13-293-218	1.0	1.0	2.0	1.0	2.3	2.3	4706
KAB-RB13-294-201	1.0	1.0	2.0	1.0	1.0	3.0	5474
KAB-RB13-294-204	1.0	1.0	1.3	1.0	1.0	3.0	7141
KAB-RB13-294-205	1.0	1.0	2.0	1.3	1.0	2.3	4433
KAB-RB13-297-142	1.0	1.0	2.0	1.0	5.0	3.7	0.0
KAB-RB13-297-144	1.0	1.0	2.0	1.0	1.0	3.0	9199
KAB-RB13-299-168	1.0	1.0	2.0	1.0	5.0	3.0	4519
KAB-RB13-299-169	1.0	1.0	1.3	1.0	1.7	3.0	5719
KAB-RB13-299-176	1.0	1.3	2.3	1.0	2.7	3.0	4733
KAB-RB13-301-171	1.3	1.0	1.7	1.0	1.7	3.0	9374
KAB-RB13-303-146	1.0	1.0	2.0	1.7	1.0	3.0	9019
KAB-RB13-303-151	1.0	1.0	2.0	1.0	3.7	3.0	6942
KAB-RB13-306-181	1.0	1.0	1.7	1.0	1.0	3.0	8519
KAB-RB13-308-217	1.0	1.0	3.3	1.0	2.3	2.3	4183
KAB-RB13-308-222	1.0	1.0	3.7	1.0	2.3	2.7	6721
KAB-RB13-309-224	1.3	1.0	2.0	1.0	1.0	3.0	0.0
KAB-RB13-310-159	1.0	1.0	1.3	1.3	1.0	3.0	0.0
KAB-RB13-310-161	1.0	1.0	1.3	1.0	1.0	2.7	5201
KAB-RB13-310-162	1.0	3.0	3.0	3.0	3.0	3.0	9575
KAB-RB13-312-156	1.0	1.3	2.3	1.0	2.3	3.0	7244
KAB-RB13-312-158	1.0	1.0	2.0	1.0	3.0	3.0	10114
KAB-RB13-312-160	1.0	2.0	2.0	2.7	2.7	3.0	8936
KAB-RB13-313-127	1.0	1.0	1.7	1.0	1.0	3.0	7481
KAB-RB13-314-191	1.0	1.3	2.0	1.7	2.3	3.0	7651
KAB-RB13-314-192	1.0	1.0	1.7	1.0	1.7	3.0	4590
KAB-RB13-315-197	1.0	1.0	1.7	1.0	1.0	2.7	6024
KAB-RB13-318-157	1.0	1.0	1.3	1.0	1.0	3.0	3241
KAB-RB13-319-182	1.3	1.0	2.0	1.0	1.0	3.0	7292
KAB-RB13-319-193	1.3	1.0	3.0	1.0	2.3	2.3	4772
KAB-RB13-319-194	2.3	1.0	2.7	1.0	1.0	3.3	5483
KAB-RB13-321-185	1.0	1.0	1.3	1.0	1.0	2.7	8150

Appendix 7 (continued)

Genotypes	Rust Scores		Common bacterial blight scores		Powdery mildew scores	Bean common Mosaic virus	Grain Yield (kgha^{-1})
	Ol Joro-orok	Kabete	Ol Joro--orok	Kabete	Kabete	ol Joro-orok	ol Joro-orok
KAB-RB13-321-187	2.0	1.0	2.0	1.0	2.3	3.0	6613
KAB-RB13-321-190	1.0	1.0	2.0	1.0	1.0	3.0	0.0
KAB-RB13-325-198	1.0	1.0	2.3	1.0	1.0	3.0	4595
KAB-RB13-325-200	1.0	1.0	3.0	1.7	1.0	3.0	10422
KAB-RB13-325-202	1.0	1.0	1.7	1.0	1.0	3.0	4658
KAB-RB13-326-207	1.0	1.7	2.3	1.0	1.0	3.0	7450
KAB-RB13-327-48	1.7	1.7	2.7	1.7	1.7	4.3	9449
KAB-RB13-327-92	1.7	1.7	2.3	1.3	3.7	3.7	12934
KAB-RB13-329-163	1.0	1.0	1.7	1.0	2.3	4.3	11964
KAB-RB13-329-164	1.0	1.7	2.0	1.0	1.0	3.0	8773
KAB-RB13-329-165	1.0	1.0	1.7	1.0	1.0	2.7	6063
KAB-RB13-329-166	1.0	1.0	1.3	1.0	3.0	3.0	0.0
KAB-RB13-329-167	1.7	1.0	2.3	1.0	1.0	2.3	8671
KAB-RB13-329-172	1.0	1.0	2.3	1.0	1.0	2.3	6184
KAB-RB13-330-126	1.0	1.0	2.0	1.0	1.0	2.7	3362
KAB-RB13-330-140	1.0	1.0	2.0	1.0	1.7	2.7	5767
KAB-RB13-331-113	1.7	1.7	1.7	1.3	4.7	2.3	9188
KAB-RB13-331-225	1.7	1.0	3.0	1.0	1.0	2.3	4167
KAB-RB13-333-223	1.0	1.3	2.7	1.7	3.7	3.0	4967
KAB-RB13-334-130	1.0	1.0	2.0	1.0	1.0	3.0	6983
KAB-RB13-334-136	1.0	1.0	2.0	1.0	1.0	3.0	7167
KAB-RB13-334-137	1.0	1.0	2.0	1.0	1.0	3.0	6667
KAB-RB13-334-139	1.0	1.3	2.0	1.0	1.0	3.0	5499
KAB-RB13-334-29	3.0	1.3	2.0	1.7	3.0	3.7	13128
KAB-RB13-335-199	1.3	1.0	2.0	1.7	1.0	3.0	4359
KAB-RB13-335-203	1.0	1.0	2.3	1.0	1.0	3.0	3269
KAB-RB13-336-132	1.0	1.0	1.7	1.0	1.0	3.0	4773
KAB-RB13-336-133	1.7	1.0	1.7	1.0	2.3	2.7	6491
KAB-RB13-336-63	1.7	2.0	2.3	2.3	3.0	3.7	11231
KAB-RB13-338-175	1.0	1.0	1.7	1.0	1.0	3.0	6122
KAB-RB13-338-178	1.7	1.0	2.0	1.0	1.3	3.0	2709
KAB-RB13-338-179	1.3	1.0	1.3	1.0	1.0	2.3	5760
KAB-RB13-338-41	1.7	1.7	2.7	1.7	1.0	3.0	13285
KAB-RB13-340-180	1.0	1.3	2.0	1.3	1.0	3.0	6448
KAB-RB13-341-129	1.0	1.0	2.0	1.0	1.0	3.0	10802
KAB-RB13-341-134	1.0	1.0	2.0	1.0	1.0	3.0	7821
KAB-RB13-341-143	1.0	1.0	1.3	1.3	1.0	3.0	7625
KAB-RB13-342-145	1.0	1.0	2.3	1.0	1.0	3.0	5735

Genotypes	Rust Scores		Common bacterial blight scores		Powdery mildew scores	Bean common Mosaic virus	Grain Yield (kgha^{-1})
	Ol Joro-orok	Kabete	Ol Joro--orok	Kabete	Kabete	ol Joro-orok	ol Joro-orok
KAB-RB13-343-183	1.0	1.0	2.0	1.0	1.0	3.0	6438
KAB-RB13-343-184	1.0	1.0	1.7	1.0	1.0	3.0	8696
KAB-RB13-343-188	1.0	1.0	1.7	1.0	2.3	3.0	5719
KAB-RB13-343-189	1.0	1.0	2.3	1.0	1.0	3.0	5828
KAB-RB13-364-211	1.0	1.0	2.0	1.0	1.0	3.0	5052
KAB-RB13-364-212	1.3	1.0	1.7	1.7	1.0	3.0	10311
KAB-RB13-37-16	1.7	2.7	2.3	1.7	2.3	3.0	14999
KAB-RB13-378-131	1.0	1.0	2.7	1.0	3.0	3.0	6867
KAB-RB13-378-141	1.3	1.0	2.3	1.0	3.0	2.7	3139
KAB-RB13-379-147	1.0	1.3	2.3	1.0	3.0	2.3	8457
KAB-RB13-379-148	1.0	1.7	1.3	1.0	4.3	3.0	6162
KAB-RB13-379-154	1.0	1.0	1.7	1.0	1.0	3.0	4086
KAB-RB13-396-210	1.0	1.7	2.3	1.0	1.0	3.0	7778
KAB-RB13-399-219	1.0	1.3	2.0	1.0	1.3	3.0	6393
KAB-RB13-399-221	1.0	1.0	1.7	1.0	1.0	3.0	5691
KAB-RB13-403-149	1.0	1.3	3.3	1.0	1.0	3.0	5971
KAB-RB13-403-150	1.0	1.0	1.3	1.0	1.0	3.0	7183
KAB-RB13-403-152	1.7	1.0	3.3	1.0	1.0	3.0	6339
KAB-RB13-403-153	1.7	1.0	1.7	1.0	1.0	3.7	7370
KAB-RB13-405-195	1.0	1.0	2.0	1.0	1.0	3.0	3774
KAB-RB13-405-196	1.0	1.0	3.3	1.0	1.0	3.0	7822
KAB-RB13-408-220	1.0	1.0	3.0	1.0	1.0	2.7	5761
KAB-RB13-410-216	1.0	1.0	1.7	1.0	1.7	3.0	8201
KAB-RB13-426-84	1.7	1.7	4.7	2.3	1.0	3.3	11576
KAB-RB13-46-124	1.0	1.0	2.3	1.0	1.0	3.0	10270
KAB-RB13-46-19	1.0	1.0	2.7	1.0	1.0	2.7	6591
KAB-RB13-471-117	1.7	1.7	2.3	1.3	1.7	3.7	11563
KAB-RB13-48-16	1.0	1.0	2.3	1.0	2.3	3.0	6306
KAB-RB13-48-17	1.3	1.0	2.0	1.3	1.0	2.7	6096
KAB-RB13-522-73	1.7	1.7	1.7	1.7	1.7	3.7	7440
KAB-RB13-62-8	1.0	1.0	3.3	1.0	1.0	3.0	4337
KAB-RB13-62-9	1.0	1.0	2.0	1.0	1.0	3.0	6859
KAB-RB13-75-6	1.0	1.0	1.7	1.3	2.3	2.3	6658
KAB-RB13-80-14	1.0	1.0	1.7	1.0	1.0	3.0	6880
KAB-RB13-84-11	1.0	1.0	2.0	1.0	2.3	3.0	7910
KAB-RB13-85-18	1.7	1.0	2.3	1.7	1.0	3.0	7995
KAB-RB13-97-12	1.0	1.0	2.0	1.0	1.7	2.3	3016
KAB-RB13-97-13	1.0	1.3	1.3	1.0	1.0	3.0	
KIN 2	1.7	1.0	2.3	1.0	2.3	3.7	2343
KIN 3	1.0	1.0	3.0	1.0	1.3	3.7	3820

Genotypes	Rust Scores		Common bacterial blight scores		Powdery mildew scores	Bean common Mosaic virus	Grain Yield (kgha^{-1})
	Ol Joro-orok	Kabete	Ol Joro--orok	Kabete	Kabete	ol Joro-orok	ol Joro-orok
NYERI	1.0	1.3	2.3	1.0	3.3	3.0	0.0
OLJ DWF 1	1.7	1.3	3.3	1.0	2.7	3.0	0.0
OLJ DWF 3	1.0	1.0	3.3	1.0	1.0	3.0	0.0
OL-OL-RB13-10-242	1.0	1.0	1.3	1.0	1.0	3.0	3039
OL-OL-RB13-21-240	1.0	1.0	2.0	1.0	1.0	2.3	6082
OL-OL-RB13-23-1	1.3	1.0	1.7	1.0	1.0	2.3	3247
OL-OL-RB13-27-250	1.0	1.0	1.7	1.0	1.3	3.0	14382
OL-OL-RB13-37-234	1.3	1.0	1.7	1.0	1.0	3.0	3948
OL-OL-RB13-67-231	1.7	1.0	2.3	1.0	3.7	3.0	3585
OL-OL-RB13-96-236	1.7	1.0	2.7	1.0	1.0	3.0	8591
SUB-OL-RB13-129-235	1.0	1.0	2.0	1.0	2.7	3.0	5243
SUB-OL-RB13-133-243	1.0	1.7	1.7	1.0	1.0	2.7	6243
SUB-OL-RB13-177-3	1.0	1.0	1.7	1.0	4.3	2.3	9254
SUB-OL-RB13-178-239	1.0	1.0	2.0	1.0	2.3	3.0	6237
SUB-OL-RB13-220-245	1.3	1.0	2.3	1.0	1.0	3.0	10052
SUB-OL-RB13-226-251	1.0	1.0	1.7	1.0	1.0	3.0	6233
SUB-OL-RB13-228-247	1.0	1.0	2.0	1.0	2.3	3.0	4632
SUB-OL-RB13-231-226	1.0	1.0	1.7	1.0	3.7	3.0	3504
SUB-OL-RB13-238-238	1.0	1.0	2.0	1.0	1.0	3.0	7394
SUB-OL-RB13-275-248	1.0	1.0	1.7	1.0	1.3	3.0	6846
SUB-OL-RB13-275-249	1.0	1.0	2.0	1.0	1.0	3.0	2870
SUB-OL-RB13-312-252	1.0	1.0	1.7	1.0	1.0	3.0	5791
SUB-OL-RB13-323-2	1.0	1.0	1.7	1.0	1.3	3.0	10483
SUB-OL-RB13-96-237	1.0	1.0	2.3	1.0	1.0	3.0	6394
SUB-RB13-221-128	2.0	1.7	2.3	1.7	1.3	3.7	5825
SUB-RB13-269-129	1.7	1.7	3.3	1.7	1.3	3.0	11452
SUB-RB13-308-75	2.3	1.7	2.3	1.3	1.7	2.3	8309
SUB-RB13-325-134	1.7	1.3	3.0	2.0	1.7	2.3	10260
Mean	1.2	1.4	1.1	2.3	1.6	3	6753
CV (%)	14.9	52.5	27.6	42.3	83.4	34	55.6
LSD $_{0.05}$	NS	1.2	NS	1.6	2.2	NS	6034

Appendix 8: Performance of advanced snap bean lines in the preliminary trial during long rains at Mwea

Genotypes	Vigor	Rust	ALS	Anthracnose	No of pods/Plant	seed yield(kgha-1)	pod curvature	pod shape
GCI-SNAP13-350-199	5.0	1.0	2.5	1.5	6.2	702.2	straight	flat
GCI-SNAP13-351-200	2.5	1.0	2.5	1.5	4.0	441.3	straight	flat
GCI-SNAP13-353-201	4.5	1.0	2.5	2.0	7.6	976.8	straight	flat
GCI-SNAP13-357-202	4.0	0.5	1.5	1.0	1.8	201.5	straight	flat
GCI-SNAP13-382-203	3.0	1.5	1.5	2.0	10.1	1346.0	straight	flat
KNSB13-01-221	5.0	1.0	1.5	0.5	6.0	518.4	curved	Round
KNSB13-04-222	2.5	1.5	3.0	2.0	0.3	37.2	curved	Round
KNSB13-08-191	3.5	1.0	3.0	2.0	7.4	955.1	slightly curved	Round
KNSB13-22-194	4.0	1.0	2.5	1.5	5.5	539.4	slightly curved	Round
KNSB13-36-195	5.0	1.5	2.5	1.5	8.2	625.0	slightly curved	Round
KNSB13-53-219*	3.0	1.0	2.0	1.5	7.7	1221.2	slightly curved	Round
KNSB13-77-190	3.5	0.5	1.5	1.5	1.5	167.4	curved	Round
KNSB13-77-228	5.0	0.5	1.5	1.5	1.8	366.1	slightly curved	Round
KNSB13-78-196	6.0	1.0	3.0	2.0	4.5	410.9	curved	Round
KNSB13-78-227*****	4.0	1.5	2.5	2.5	6.8	838.4	curved	Round
KNSB13-79-189	4.5	1.0	2.5	1.5	8.4	759.2	curved	Round
KNSB13-79-226	2.5	0.5	1.0	0.5	2.5	244.9	slightly curved	flat
KNSB13-88-197	5.0	1.5	2.0	2.0	4.0	185.0	curved	Round
KNSB13-88-198	6.0	1.0	2.5	1.5	5.5	437.1	slightly curved	Round
KNSB13-88-223	4.0	0.5	3.0	2.0	8.8	1000.8	slightly curved	Round
KNSB13-88-224	6.0	0.5	1.0	1.0	3.3	248.8	slightly curved	Round
KNSB13-88-225	3.5	1.0	3.0	2.0	6.3	484.8	slightly curved	Round
KNSB13-88-229*****	4.0	1.5	1.5	1.5	13.4	838.8	slightly curved	Round
KNSB13-90-188*****	4.0	1.0	2.0	2.0	7.3	354.6	slightly curved	Round
KNSB13-90-192	7.0	0.5	1.0	1.0	4.0	108.4	curved	Round
KNSB13-90-193	3.5	1.0	2.5	1.5	5.1	406.9	curved	Round
KNSB13-90-220	2.0	2.0	2.5	1.5	4.7	509.0	straight	flat
KSB13-06-186	0.0	0.5	1.0	0.5	0.0	0.0	curved	Round
KSB13-06-211	4.0	1.0	2.0	2.0	8.4	1175.2	curved	Round
KSB13-06-212	4.0	1.0	2.0	1.5	7.4	1755.5	straight	Round
KSB13-06-214	5.0	1.0	1.5	1.0	6.9	1069.0	straight	Round
KSB13-06-230	5.0	1.0	2.5	2.0	6.5	696.2	slightly curved	Round
KSB13-06-236	5.0	1.0	2.5	1.5	9.5	804.0	slightly curved	Round
KSB13-06-25	2.5	1.0	2.0	1.5	2.0	223.9	slightly curved	Round
KSB13-06-83	5.0	1.0	2.0	2.0	6.0	427.1	curved	Round
KSB13-08-125	1.5	0.5	1.5	1.5	1.0	137.7	curved	Round
KSB13-08-14	4.5	0.0	0.0	0.0	0.0	0.0	curved	Round
KSB13-08-246	1.0	1.0	2.0	1.5	5.3	837.1	straight	Round
KSB13-10-11	3.0	1.0	2.5	2.0	6.4	754.2	curved	Round
KSB13-10-12	6.0	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-13-24	3.0	1.0	3.0	2.0	6.4	1078.3	slightly curved	Round
KSB13-14-139	5.0	1.0	1.5	1.0	10.8	2045.3	slightly curved	Round

Appendix 8 (continued)

Genotypes	Vigor	Rust	ALS	Anthracnose	No of pods/Plant	seed yield(kgha-1)	pod curvature	pod shape
KSB13-14-172	5.0	1.0	2.0	1.0	5.5	407.7	curved	Round
KSB13-14-173	5.0	1.5	3.0	2.5	1.5	450.0	straight	Round
KSB13-14-205	5.0	1.0	2.5	2.0	9.4	775.6	curved	Round
KSB13-14-218*****	4.0	1.0	2.5	1.5	5.0	881.6	slightly curved	Round
KSB13-154-242	4.0	1.0	3.0	2.5	13.4	2004.0	straight	Round
KSB13-17-181	2.5	0.5	1.5	1.0	6.5	615.0	curved	Round
KSB13-17-182*	4.0	2.0	1.0	0.5	3.8	625.0	straight	Round
KSB13-17-183	3.5	1.0	2.5	2.0	2.5	609.7	straight	Round
KSB13-17-4	6.0	1.0	2.0	1.5	0.5	84.0	curved	Round
KSB13-17-5	6.0	0.5	1.0	0.5	2.0	110.8	slightly curved	Round
KSB13-17-6	0.5	0.5	0.5	0.5	3.3	412.2	straight	Round
KSB13-17-7	0.0	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-17-8	2.0	1.0	2.5	2.0	3.8	0.0	straight	Round
KSB13-17-82	3.0	1.5	2.0	1.5	9.8	1083.8	straight	Round
KSB13-17-85	0.0	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-17-87	0.0	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-17-88	0.5	0.5	1.5	1.0	3.5	590.3	straight	Round
KSB13-18-170	1.5	1.0	1.5	1.0	4.3	688.0	curved	Round
KSB13-18-171	2.5	0.5	1.0	0.5	2.5	0.0	curved	Round
KSB13-18-52	5.0	1.0	2.5	2.0	1.0	182.0	curved	Round
KSB13-18-53	2.5	1.0	1.5	1.5	0.0	0.0	curved	Round
KSB13-19-92	1.5	0.5	1.0	0.5	8.4	1964.2	slightly curved	Round
KSB13-19-93	4.0	1.5	2.0	1.5	5.6	1200.3	slightly curved	Round
KSB13-19-94	4.5	1.0	3.0	2.0	1.3	228.0	slightly curved	Round
KSB13-19-95	4.0	2.0	2.5	2.5	8.0	570.2	curved	Round
KSB13-20-16	1.5	1.0	2.0	2.0	6.2	730.2	curved	Round
KSB13-20-17	4.0	1.0	2.0	2.0	4.2	472.5	curved	Round
KSB13-20-178	3.5	1.0	1.0	1.0	1.5	249.0	curved	Round
KSB13-20-18	5.0	1.0	3.0	2.5	1.4	135.3	curved	Round
KSB13-20-180*	3.0	1.0	3.0	1.5	5.3	850.8	curved	Round
KSB13-20-19	4.0	1.0	2.0	1.5	3.7	399.2	slightly curved	Round
KSB13-20-205	5.0	1.0	2.5	2.0	3.6	266.7	straight	Round
KSB13-20-208*	5.0	2.0	2.5	1.5	7.7	1177.7	slightly curved	Round
KSB13-20-215	4.0	1.0	2.5	2.0	7.0	824.4	slightly curved	Round
KSB13-20-217	2.5	0.5	2.0	1.0	6.0	167.3	curved	Round
KSB13-20-22	3.5	0.5	1.5	1.0	1.0	176.0	curved	Round
KSB13-20-23	5.0	1.0	2.0	1.5	4.9	987.1	straight	Round
KSB13-20-232	4.0	1.0	3.0	2.5	7.6	723.7	slightly curved	Round
KSB13-20-234	2.5	1.0	1.5	1.0	0.0	0.0	_	_
KSB13-20-89	5.0	1.5	3.0	2.0	5.9	1033.2	slightly curved	Round
KSB13-21-207	2.5	1.0	2.0	2.0	13.0	475.0	curved	Round
KSB13-21-231	5.0	1.0	3.0	2.5	7.4	2635.5	slightly curved	Round
KSB13-21-235	3.5	0.5	1.5	0.5	2.5	57.7	curved	Round
KSB13-21-51	1.5	0.5	1.0	0.5	3.0	121.5	curved	Round

Appendix 8 (continued)

Genotypes	Vigor	Rust	ALS	Anthracnose	No of pods/Plant	seed yield(kgha-1)	pod curvature	pod shape
KSB13-22-243	4.0	1.0	3.0	2.5	4.5	660.4	curved	Round
KSB13-22-247*	5.0	1.0	2.0	1.5	6.4	394.5	straight	Round
KSB13-23-176	2.0	1.0	1.0	1.5	3.0	526.0	straight	Round
KSB13-23-177	6.0	1.0	2.5	3.5	1.3	166.2	slightly curved	Round
KSB13-23-185	6.0	1.5	3.0	1.5	4.8	250.6	straight	flat
KSB13-23-20	3.5	0.0	0.0	0.0	0.0	0.0	curved	Round
KSB13-23-239*****	2.0	2.0	3.0	2.0	5.6	545.3	straight	Round
KSB13-23-240*	3.0	1.0	2.0	2.5	7.4	887.8	straight	Round
KSB13-23-241*	2.0	1.0	2.5	2.5	7.8	1004.5	slightly curved	Round
KSB13-23-245	5.0	1.0	2.5	2.5	5.0	194.2	slightly curved	Round
KSB13-23-248*	3.0	1.0	2.5	1.0	5.6	1084.8	straight	Round
KSB13-23-76	4.0	0.5	0.5	0.5	3.2	438.3	straight	Round
KSB13-23-78*	2.5	0.5	1.0	1.0	5.0	271.0	straight	Round
KSB13-23-79	2.5	0.5	1.0	0.5	0.0	0.0	curved	Round
KSB13-23-80	0.0	0.0	0.0	0.0	0.0	0.0	curved	Round
KSB13-23-81	3.0	0.5	1.0	0.5	0.5	154.3	curved	Round
KSB13-23-84	3.5	0.5	1.0	0.5	0.0	0.0	curved	Round
KSB13-24-106	0.0	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-24-107	2.0	0.5	1.5	1.0	2.7	345.3	curved	Round
KSB13-24-108	1.5	0.5	1.0	0.5	3.3	408.3	slightly curved	Round
KSB13-25-91	5.0	0.5	1.0	0.5	2.0	150.7	curved	Round
KSB13-26-209	7.0	1.5	2.5	1.5	4.9	349.1	curved	Round
KSB13-26-210	4.0	1.5	2.5	2.0	11.4	842.7	curved	Round
KSB13-26-213	5.0	1.0	3.0	2.0	8.3	572.4	slightly curved	Round
KSB13-27-10	0.0	0.0	0.0	0.0	0.0	0.0	_	Round
KSB13-27-13	5.0	0.0	0.0	0.0	0.0	0.0	_	Round
KSB13-27-21	2.0	1.0	2.5	0.5	6.1	918.5	slightly curved	Round
KSB13-27-238	4.0	1.5	2.5	2.0	7.7	807.3	slightly curved	Round
KSB13-27-244	3.0	1.5	2.5	1.0	8.2	926.6	straight	Round
KSB13-27-249	3.0	1.0	2.0	1.5	9.5	1496.0	slightly curved	Round
KSB13-27-9	1.5	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-29-122	2.0	1.5	2.5	1.5	4.6	804.0	straight	Round
KSB13-29-123	4.0	1.0	2.5	1.5	3.2	560.9	straight	Round
KSB13-29-124	6.0	0.5	1.0	1.5	3.1	361.0	straight	Round
KSB13-29-150	5.0	0.5	1.0	1.0	1.0	93.3	slightly curved	Round
KSB13-30-1	2.0	1.5	1.5	1.0	6.9	1321.8	slightly curved	Round
KSB13-30-144	5.0	1.5	2.5	2.5	5.3	861.0	curved	Round
KSB13-30-145	4.0	1.0	3.0	2.5	1.2	434.3	slightly curved	Round
KSB13-30-146	2.5	0.5	1.5	1.0	3.5	179.7	slightly curved	Round
KSB13-30-174	3.0	1.5	1.5	1.0	6.3	772.9	slightly curved	Round
KSB13-30-175	5.0	1.0	2.5	2.0	5.3	245.7	curved	Round
KSB13-30-206	4.0	0.5	1.5	1.0	4.5	116.3	slightly curved	Round
KSB13-30-216	6.0	0.5	1.5	1.0	7.5	361.5	curved	Round

Appendix 8(continued)

Genotypes	Vigor	Rust	ALS	Anthracnose	No of pods/Plant	seed yield(kgha-1)	pod curvature	pod shape
KSB13-30-233	4.0	1.0	2.5	2.0	9.5	822.6	slightly curved	Round
KSB13-30-26	4.0	1.5	2.0	1.0	3.3	446.0	slightly curved	Round
KSB13-30-27	0.5	0.5	1.5	1.0	3.5	119.9	slightly curved	Round
KSB13-30-28	2.0	1.0	2.5	2.0	9.0	752.0	curved	Round
KSB13-32-15	2.5	0.5	1.0	0.5	0.0	0.0	curved	Round
KSB13-32-74	5.0	0.5	0.5	1.0	2.8	188.0	curved	Round
KSB13-35-127	3.5	0.5	0.5	0.5	0.0	0.0	curved	Round
KSB13-35-128	0.0	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-35-129	2.0	1.0	2.0	1.0	8.2	1022.8	straight	Round
KSB13-35-130	3.0	1.0	2.5	2.5	4.0	949.2	slightly curved	Round
KSB13-35-132	3.0	1.5	2.0	2.0	4.7	868.7	slightly curved	Round
KSB13-35-133	4.0	1.5	1.5	2.0	8.5	1078.2	slightly curved	Round
KSB13-38-136	4.0	1.0	2.5	1.5	6.5	839.9	curved	Round
KSB13-38-137	1.5	1.0	2.0	1.5	8.5	1664.8	slightly curved	Round
KSB13-38-138	5.0	1.0	2.5	1.5	1.8	230.5	curved	Round
KSB13-39-118	3.0	1.0	3.0	2.0	5.3	879.1	straight	Round
KSB13-39-119	2.5	0.5	1.0	0.5	2.8	285.5	straight	Round
KSB13-39-120	2.0	0.5	1.0	0.5	2.9	547.3	straight	Round
KSB13-39-121	1.5	1.0	1.5	1.5	6.7	565.5	curved	Round
KSB13-39-135	1.5	0.0	0.0	0.0	2.0	475.0	curved	Round
KSB13-39-140	5.0	1.0	2.0	2.0	3.3	326.2	curved	Round
KSB13-39-152	3.5	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-39-153	2.0	2.0	2.0	1.5	7.0	1711.2	slightly curved	Round
KSB13-39-154	1.5	0.5	1.0	0.5	1.6	115.4	slightly curved	Round
KSB13-39-155	4.5	1.0	2.5	1.5	0.0	0.0	slightly curved	Round
KSB13-39-156	5.5	1.0	2.0	2.0	4.6	713.0	straight	Round
KSB13-39-164	4.5	1.5	2.5	1.5	2.7	294.5	curved	Round
KSB13-39-165	1.0	0.5	1.0	0.5	2.5	374.5	curved	Round
KSB13-39-166	1.5	0.5	1.0	1.0	1.1	262.0	straight	Round
KSB13-39-167	0.0	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-39-169	2.5	1.0	1.5	0.5	0.8	427.7	curved	Round
KSB13-39-29	3.5	0.5	1.0	0.5	8.0	762.0	slightly curved	Round
KSB13-39-30	2.5	0.5	1.0	0.5	1.0	159.0	slightly curved	Round
KSB13-39-31	5.0	1.0	2.0	1.0	2.5	1000.2	straight	Round
KSB13-39-33	3.5	0.5	1.5	1.0	0.0	0.0	slightly curved	Round
KSB13-39-34	5.0	1.0	3.0	2.5	4.0	804.5	straight	Round
KSB13-39-35	6.0	1.0	3.0	2.5	0.0	0.0	slightly curved	Round
KSB13-39-36	6.0	1.0	2.0	1.5	2.0	166.4	curved	Round
KSB13-39-37	0.0	0.5	1.5	1.0	1.8	0.0	curved	Round
KSB13-39-38	1.5	0.5	1.5	1.0	1.2	540.0	curved	Round
KSB13-39-39	4.0	1.0	2.5	1.5	4.0	562.2	slightly curved	Round
KSB13-39-40	3.0	1.0	2.5	1.5	3.3	722.4	slightly curved	Round
KSB13-39-41	3.0	0.5	1.5	1.5	1.7	427.7	straight	Round
KSB13-39-42	2.5	0.5	1.0	0.5	1.5	47.0	slightly curved	Round

Appendix 8 (continued)

Genotypes	Vigor	Rust	ALS	Anthracnose	No of pods/Plant	seed yield(kgha-1)	pod curvature	pod shape
KSB13-39-43	2.0	0.5	1.5	1.0	3.0	482.6	slightly curved	Round
KSB13-39-44	1.5	0.5	1.5	1.0	2.6	293.9	slightly curved	Round
KSB13-39-45	2.5	0.5	1.5	1.5	4.3	419.5	curved	Round
KSB13-39-46	5.0	1.0	3.0	2.0	2.3	101.6	slightly curved	Round
KSB13-39-47	5.0	1.0	3.0	2.0	3.3	290.0	slightly curved	Round
KSB13-39-57	2.5	0.5	2.5	1.5	0.5	85.0	slightly curved	Round
KSB13-39-65	1.5	1.0	2.5	2.0	3.7	937.0	curved	Round
KSB13-39-66	0.0	0.0	0.0	0.0	0.0	0.0	curved	Round
KSB13-39-67	3.5	0.0	0.0	0.0	0.0	0.0	curved	Round
KSB13-39-68	1.5	0.5	1.5	1.5	2.5	446.0	slightly curved	Round
KSB13-39-69	5.0	1.0	2.5	1.5	2.8	363.0	straight	Round
KSB13-39-70	2.5	0.5	1.5	1.0	1.3	153.6	straight	Round
KSB13-39-72	3.0	1.0	1.5	1.5	5.3	929.7	slightly curved	Round
KSB13-39-73	2.5	1.5	1.0	2.0	3.0	384.0	slightly curved	Round
KSB13-39-75	5.0	1.0	0.5	1.0	5.3	388.6	slightly curved	Round
KSB13-42-104	2.0	1.0	3.0	2.0	9.9	1933.1	slightly curved	Round
KSB13-42-105	3.5	0.0	0.0	0.0	0.0	0.0	slightly curved	Round
KSB13-42-32	4.0	0.5	1.5	1.5	3.9	772.2	slightly curved	Round
KSB13-42-96	4.0	1.0	2.0	1.5	3.4	113.0	slightly curved	Round
KSB13-44-112	2.5	0.5	0.5	1.0	4.0	703.0	straight	Round
KSB13-44-113	0.0	0.0	0.0	0.0	0.0	0.0	curved	Round
KSB13-44-114	4.0	0.5	0.5	0.5	4.5	358.0	curved	Round
KSB13-44-116	3.5	0.5	0.5	1.0	0.5	66.5	curved	Round
KSB13-44-117	3.0	1.0	2.0	1.0	3.8	316.0	slightly curved	Round
KSB13-45-100	3.5	1.0	3.0	3.0	0.0	0.0	curved	Round
KSB13-45-101	1.5	1.0	0.5	1.0	2.1	523.2	straight	Round
KSB13-45-102	4.0	1.0	2.0	1.0	6.9	592.1	straight	flat
KSB13-45-103	1.5	1.0	0.5	1.0	3.8	941.2	curved	Round
KSB13-45-151	2.5	0.5	1.0	0.5	1.5	253.0	curved	Round
KSB13-47-109	4.0	1.5	2.0	2.0	5.2	927.1	slightly curved	Round
KSB13-47-110	2.5	0.5	1.0	0.5	2.5	490.0	slightly curved	Round
KSB13-47-141	0.0	0.0	0.0	0.0	0.0	0.0	slightly curved	Round
KSB13-47-142	1.5	0.5	1.5	1.0	3.0	224.8	straight	Round
KSB13-47-143	5.0	1.0	1.5	1.5	1.0	30.7	curved	Round
KSB13-47-147	3.0	1.5	2.5	2.5	1.6	312.5	straight	Round
KSB13-47-148	2.5	0.5	1.0	0.5	2.5	308.0	curved	Round
KSB13-47-158	3.5	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-47-160	3.5	1.0	1.0	0.5	0.0	0.0	curved	Round
KSB13-47-161	4.0	1.5	1.5	2.0	4.1	778.0	curved	Round
KSB13-47-162	5.0	1.5	2.5	1.5	11.0	185.9	curved	Round
KSB13-47-163	0.5	1.0	0.5	1.0	3.5	400.0	straight	Round
KSB13-47-48	2.5	0.5	1.0	1.0	2.5	363.0	curved	Round
KSB13-47-49	4.0	0.5	1.0	1.0	2.0	64.0	straight	Round
KSB13-47-50	2.0	1.0	3.0	2.5	9.8	1930.8	slightly curved	Round

Appendix 8 (continued)

Genotypes	Vigor	Rust	ALS	Anthracnose	No of pods/Plant	seed yield(kgha-1)	pod curvature	pod shape
KSB13-47-54	4.0	1.0	2.5	2.5	1.0	217.0	slightly curved	Round
KSB13-47-55	4.0	1.0	2.5	2.5	1.3	734.0	curved	Round
KSB13-47-56	3.5	0.0	0.0	0.0	0.0	0.0	curved	Round
KSB13-47-58	2.5	0.5	1.0	0.5	4.0	346.0	curved	Round
KSB13-47-60	3.0	1.0	2.0	1.5	7.8	1874.8	curved	Round
KSB13-47-61	1.5	0.5	1.5	1.0	2.5	182.0	slightly curved	Round
KSB13-47-62	2.5	0.5	1.0	1.0	1.5	169.0	curved	Round
KSB13-47-63	3.5	0.0	0.0	0.0	0.0	0.0	_	_
KSB13-47-64	1.5	0.5	1.5	1.0	2.5	156.2	straight	Round
KSB13-47-97	6.5	1.0	2.0	1.0	1.6	289.2	straight	Round
KSB13-47-98	4.0	1.0	2.0	1.5	4.0	439.0	straight	Round
KSB13-52-157	6.0	0.5	1.0	1.0	3.0	307.0	straight	Round
KSB13-67-184	5.0	0.5	1.0	0.5	5.2	283.2	slightly curved	Round
KSB13-67-3	3.0	1.0	2.5	2.5	8.6	1167.4	curved	Round
Checks								
Morelli	1.5	0.5	1.0	0.5	2.8	0.0	straight	Round
Samantha	7.0	0.5	1.0	1.0	4.5	627.5	slightly curved	Round
Star 2053	1.5	0.5	1.5	0.5	5.7	1896.3	curved	Round
Julia	1.5	0.5	1.0	1.0	0.0	0.0	_	_
Trial mean	3.3	0.8	1.7	1.3	4.0	511.0		
CV (%)	69.7	69.7	66.7	71.5	91.4	113.1		
$LSD_{0.05}$	NS	NS	2.2	1.8	7.2	1139.9		

Appendix 9: Weather data for Wangu'ru site in Mwea division, Kirinyaga South district during the experimental period.

Month	Average total rainfall (mm)	Temperature ^{0}c(Maximum)	Temperature ^{0}c(Minimum)
January 2013	13	32	11
February 2013	24	34	12
March 2013	72	37	12
April 2013	294	34	12
May 2013	139	34	11
June 2013	23	32	10
July 2013	7	31	10
August 2013	11	31	10
September 2013	12	34	11
October 2013	108	36	11
November 2013	158	33	11
December 2013	59	32	10

Appendix 10: Weather data for Kawanjara site in Runyenjes division, Embu East district during the experimental period.

Month	Average total rainfall (mm)	Temperature (Maximum)	Temperature (Minimum)
January 2013	27	29	10
February 2013	26	30	10
March 2013	113	32	11
April 2013	278	31	10
May 2013	164	29	10
June 2013	32	27	9
July 2013	29	26	9
August 2013	38	26	9
September 2013	41	29	10
October 2013	171	30	10
November 2013	234	29	10
December 2013	53	28	9
January 2014	16	29	10

Appendix 11.Anova results of pod yield and disease resistance in the second season at Mwea and Embu

Trait	**Anova analysis**					
Pod yield	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	1	9.13E+06	9.13E+06	0.75	
	REP.*Units* stratum					
	Genotype	33	6.07E+08	1.84E+07	1.51	0.078
	location	1	2.60E+08	2.60E+08	21.3	<.001
	Genotype.location	33	8.81E+08	2.67E+07	2.19	0.003
	Residual	67	8.18E+08	1.22E+07		
	Total	135	2.58E+09			
ALS	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	1	10.618	10.618	6.27	
	REP.*Units* stratum					
	Genotype	33	47.471	1.439	0.85	0.691
	location	1	79.529	79.529	47	<.001
	Genotype.location	33	47.471	1.439	0.85	0.691
	Residual	67	113.382	1.692		
	Total	135	298.471			
Rust	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	1	11.765	11.765	8.19	
	REP.*Units* stratum					
	Genotype	33	61.029	1.849	1.29	0.189
	location	1	15.559	15.559	10.83	0.002
	Genotype.location	33	30.941	0.938	0.65	0.91
	Residual	67	96.235	1.436		
	Total	135	215.529			
Anthracnose	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	1	5.7647	5.7647	6.99	
	REP.*Units* stratum					

Genotype	33	18.4412	0.5588	0.68	0.889
location	1	113.0588	113.0588	137.14	<.001
Genotype.location	33	18.4412	0.5588	0.68	0.889
Residual	67	55.2353	0.8244		
Total	135	210.9412			

Appendix 12. Anova table of preliminary evaluation of snap beans at Mwea.

Anova table of preliminary evaluation of snap beans at Mwea					
Angular leaf spot					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	0.306	0.306	0.24	
REP.*Units* stratum					
GENOTYPE	234	373.65	1.597	1.26	0.039
Residual	234	296.69	1.268		
Total	469	670.65			
Anthracnose					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	1.1649	1.1649	1.36	
REP.*Units* stratum					
GENOTYPE	234	259.05	1.107	1.29	0.027
Residual	230	197.36	0.8581		
Total	465	456.31			
Rust					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	0.2202	0.2202	0.65	
REP.*Units* stratum					
GENOTYPE	234	95.202	0.4068	1.2	0.08
Residual	230	77.784	0.3382		
Total	465	171.61			
Vigor					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	2.546	2.546	0.47	
REP.*Units* stratum					
GENOTYPE	234	1200.2	5.129	0.95	0.645
Residual	230	1238.5	5.385		
Total	465	2424.1			
Pods per plant					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	139.93	139.93	10.4	
REP.*Units* stratum					
GENOTYPE	234	4493.9	19.2	1.43	0.004
Residual	230	3094.9	13.46		

Total	465	7679.5			
Seed yield					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	329719	329719	0.99	
REP.*Units* stratum					
GENOTYPE	234	1E+08	474807	1.42	0.004
Residual	230	8E+07	334704		
Total	465	2E+08			

Appendix 13: Anova table of traits of grain runner bean lines in 2013

Trait	Anova of traits of grain runner bean lines evaluated at two locations in 2013										
	Kabete					Ol Joro-orok					
Days to 50% flowering	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	38.841	19.42	3.4		REP stratum	2	8.005	4.002	2.16	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	133	582.736	4.381	0.77	0.958	GENOTYPE	138	279.472	2.025	1.09	0.27
	Residual	266	1521.159	5.719			Residual	276	511.995	1.855		
	Total	401	2142.736				Total	416	799.472			
BCMV	No disease						Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
							REP stratum	2	4.763	2.381	2.29	
							REP.*Units* stratum					
							GENOTYPE	138	151.645	1.099	1.06	0.344
							Residual	276	286.571	1.038		
							Total	416	442.978			
CBB	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	0.85075	0.42537	5.03		REP stratum	2	5.2134	2.6067	2.8	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	133	10.56965	0.07947	0.94	0.652	GENOTYPE	138	166.6091	1.2073	1.3	0.036
	Residual	266	22.48259	0.08452			Residual	276	256.7866	0.9304		
	Total	401	33.90299				Total	416	428.6091			
Rust	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	0.49751	0.24876	10.73		REP stratum	2	38	19	34.65	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	133	3.08458	0.02319	1	0.493	GENOTYPE	138	81.5444	0.5909	1.08	0.3
	Residual	266	6.16915	0.02319			Residual	276	151.3333	0.5483		
	Total	401	9.75124				Total	416	270.8777			

PM	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	No Disease was observed					
	REP stratum	2	14.14	7.07	3.9							
	REP.*Units* stratum											
	Genotype	132	389.895	2.954	1.63	<.001						
	Residual	264	478.526	1.813								
	Total	398	882.561									
Vigor	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	14.811	7.405	2.84		REP stratum	2	12.36	6.18	4.06	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	133	227.575	1.711	0.66	0.997	GENOTYPE	138	204.887	1.485	0.97	0.562
	Residual	266	692.522	2.603			Residual	276	420.307	1.523		
	Total	401	934.908				Total	416	637.554			
Racemes at first flowering	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	31.577	15.789	3.26		REP stratum	2	1358.32	679.16	63.81	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	133	829.523	6.237	1.29	0.042	GENOTYPE	138	2343.83	16.98	1.6	<.001
	Residual	266	1287.664	4.841			Residual	276	2937.62	10.64		
	Total	401	2148.764				Total	416	6639.77			
Racemes at second flowering	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	1.0736	0.5368	0.93		REP stratum	2	315.65	157.83	13.86	
	REP.*Units* stratum						REP.*Units* stratum					
	Genotype	132	104.4762	0.7915	1.36	0.017	GENOTYPE	138	2325.5	16.85	1.48	0.003
	Residual	264	153.0954	0.5799			Residual	276	3142.54	11.39		

	Total	398	258.6453	Total	416	5783.69			
Grain yield	NO grain yield was evaluated			Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
				Rep stratum	2	1.69E+07	8.45E+06	1.39	
				Rep.*Units* stratum					
				Genotype	125	1.01E+09	8.04E+06	1.32	0.034
				Residual	250	1.53E+09	6.10E+06		
				Total	377	2.55E+09			

Appendix 14: Anova table of traits of grain runner bean lines in 2014

Trait	Anova of traits of grain runner bean lines evaluated at two locations in 2014										
	Kabete					Ol Joro-orok					
Days to 50% flowering	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	43.51	21.75	0.72		REP stratum	2	402.292	201.146	29.02	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	72	5585.65	77.58	2.56	<.001	GENOTYPE	56	805.906	14.391	2.08	<.001
	Residual	144	4369.83	30.35			Residual	112	776.374	6.932		
	Total	218	9998.99				Total	170	1984.573			
Vigor	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	2.667	1.333	0.52		REP stratum	2	34.105	17.053	8.5	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	72	169.826	2.359	0.92	0.656	GENOTYPE	56	72.281	1.291	0.64	0.966
	Residual	144	370.667	2.574			Residual	112	224.561	2.005		
	Total	218	543.16				Total	170	330.947			
PM	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	No disease					
	REP stratum	2	7.7534	3.8767	6.9							
	REP.*Units* stratum											
	GENOTYPE	72	40.5936	0.5638	1	0.484						
	Residual	144	80.9132	0.5619								
	Total	218	129.2603									
Rust	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	1.8356	0.9178	2.71		REP stratum	2	8.573	4.287	2.11	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	72	65.5525	0.9105	2.68	<.001	GENOTYPE	56	57.836	1.033	0.51	0.997
	Residual	144	48.8311	0.3391			Residual	112	227.427	2.031		
	Total	218	116.2192				Total	170	293.836			

CBB	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	6.7671	3.3836	17.46		REP.*Units* stratum					
	REP.*Units* stratum						GENOTYPE	56	45.754	0.817	0.61	0.978
	GENOTYPE	72	21.2785	0.2955	1.53	0.017	Residual	112	148.842	1.329		
	Residual	144	27.8995	0.1937			Total	170	196.421			
	Total	218	55.9452									
Racemes at first flowering	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	201.906	100.953	10.8		REP.*Units* stratum					
	REP.*Units* stratum						GENOTYPE	56	481.73	8.602	2.02	<.001
	GENOTYPE	72	1012.021	14.056	1.5	0.02	Residual	112	477.736	4.265		
	Residual	144	1345.635	9.345			Total	170	1117.823			
	Total	218	2559.562									
Racemes at second flowering	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	152.62	76.31	5.89		REP stratum	2	245.42	122.71	10.56	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	72	1922.32	26.7	2.06	<.001	GENOTYPE	56	984.98	17.59	1.51	0.032
	Residual	144	1865.68	12.96			Residual	112	1301.65	11.62		
	Total	218	3940.62				Total	170	2532.06			
Grain Yield	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Grain yield was not evaluated					
	REP stratum	2	39364150	19682075	6.62							
	REP.*Units* stratum											
	GENOTYPE	72	300710552	4176535	1.41	0.044						
	Residual	143	424984206	2971918								
	Total	217	763134570									
BCMV	No disease was observed						Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

REP stratum	2	1.205	0.602	0.24	
REP.*Units* stratum					
GENOTYPE	56	101.52	1.813	0.74	0.899
Residual	112	276.129	2.465		
Total	170	378.854			

Appendix 15: Anova table of traits of vegetable runner bean lines at two locations in 2013

Trait	2013									
	Kabete					Ol Joro-orok				
Racemes at first flowering	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	1	72.142	72.142	9.37		REP stratum	1	0.015	0.015	0.01	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	108	1564.318	14.484	1.88	<.001	GENOTYPE	108	573.494	5.31	1.85	<.00
	Residual	108	800.943	7.701			Residual	108	309.966	2.87		
	Total	213	2371.593				Total	217	883.475			
Racemes at second flowering	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.						
	REP stratum	1	0.2145	0.2145	0.7							
	REP.*Units* stratum											
	GENOTYPE	108	164.68	1.3956	4.57	<.001						
	Residual	108	36.017	0.3052								
	Total	217	200.91									

CBB

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	6.28	6.28	4.61	
REP.*Units* stratum					
GENOTYPE	108	291.22	2.696	1.98	<.001
Residual	108	147.22	1.363		
Total	217	444.72			

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	0.225	0.225	0.13	
REP.*Units* stratum					
GENOTYPE	108	451.532	4.181	2.44	<.00
Residual	108	185.275	1.716		
Total	217	637.032			

PM

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	0.115	0.115	0.05	
REP.*Units* stratum					
GENOTYPE	108	359.367	3.327	1.37	0.05
Residual	108	261.385	2.42		
Total	217	620.867			

NO disease

Rust

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	0.225	0.225	0.09	
REP.*Units* stratum					
GENOTYPE	108	360.844	3.341	1.41	0.038
Residual	108	256.275	2.373		
Total	217	617.344			

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	3.344	3.344	1.9	
REP.*Units* stratum					
GENOTYPE	108	363.495	3.366	1.91	<.00
Residual	108	190.156	1.761		
Total	217	556.995			

BCMV

No disease

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	1	0.073	0.073	0.04	
REP.*Units* stratum					
GENOTYPE	108	365.358	3.383	2.03	<.00
Residual	108	179.927	1.666		
Total	217	545.358			

Pod yield

Not determined

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.

		REP stratum	1		1.28E+08	1.28E+08	49.85	
		REP.*Units* stratum						
		Genotype	35		1.79E+08	5120432	2	0.0
		Residual	35		89811196	2566034		
		Total	71		3.97E+08			
Pod diameter	Not determined	Source of variation	d.f.	s.s.		m.s.	v.r.	F pr.
		REP stratum	1		0.00019	0.00019	0	
		REP.*Units* stratum						
		Market_grades	2		1.92694	0.96347	10.09	<.00
		Genotypes	35		24.93833	0.71252	7.46	<.00
		Market_grades.Genotypes	70		4.97306	0.07104	0.74	0.9
		Residual	107		10.21981	0.09551		
		Total	215		42.05833			
Pod length	Not determined	Source of variation	d.f.	s.s.		m.s.	v.r.	F pr.
		REP stratum	1		1.185	1.185	0.53	
		REP.*Units* stratum						
		Market_grades	2		4.431	2.216	0.99	0.3
		Genotypes	35		298.193	8.52	3.82	<.00
		Market_grades.Genotypes	70		536.426	7.663	3.44	<.00
		Residual	107		238.625	2.23		
		Total	215		1078.86			

Appendix 16: Anova table of traits of vegetable runner bean lines evaluated at two locations in 2014

Anova of traits of vegetable runner bean lines at two locations

Trait	2014										
	Kabete					**Ol Joro-Orok**					
1st racemes	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	94.795	47.397	10.02		REP stratum	2	142.024	71.012	11.26	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	48	368.827	7.684	1.62	0.023	GENOTYPE	48	812.468	16.926	2.68	<.001
	Residual	96	454.227	4.732			Residual	96	605.194	6.304		
	Total	146	917.849				Total	146	1559.687			
2nd Racemes	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	196.23	98.12	4.71		REP stratum	2	18.95	9.48	0.24	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	48	1538.59	32.05	1.54	0.037	GENOTYPE	48	3913.7	81.54	2.03	0.002
	Residual	96	1998.38	20.82			Residual	96	3863.2	40.24		
	Total	146	3733.19				Total	146	7795.8			
Vigor	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	2.122	1.061	0.97		REP stratum	2	7.238	3.619	1.66	
	REP.*Units* stratum						REP.*Units* stratum					
	GENOTYPE	48	56.925	1.186	1.09	0.356	GENOTYPE	48	82.667	1.722	0.79	0.813
	Residual	96	104.544	1.089			Residual	96	208.76	2.175		
	Total	146	163.592				Total	146	298.67			
DF	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.	Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
	REP stratum	2	22.82	11.41	0.81		REP stratum	2	328.75	164.37	6.52	
	REP.*Units* stratum						REP.*Units* stratum					

	GENOTYPE	48	1940.64	40.43	2.86	<.001
	Residual	96	1355.85	14.12		
	Total	146	3319.31			

GENOTYPE	48	1622.67	33.81	1.34	0.112
Residual	96	2419.25	25.2		
Total	146	4370.67			

CBB

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.5102	0.7551	1.79	
REP.*Units* stratum					
GENOTYPE	48	31.3061	0.6522	1.55	0.036
Residual	96	40.4898	0.4218		
Total	146	73.3061			

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.4218	0.2109	1.15	
REP.*Units* stratum					
GENOTYPE	48	13.6871	0.2851	1.56	0.034
Residual	96	17.5782	0.1831		
Total	146	31.6871			

PM

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.8299	0.415	1	
REP.*Units* stratum					
GENOTYPE	48	28.3265	0.5901	1.42	0.073
Residual	96	39.8367	0.415		
Total	146	68.9932			

No disease

Rust

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	3.2245	1.6122	4.13	
REP.*Units* stratum					
GENOTYPE	48	32.517	0.6774	1.74	0.011
Residual	96	37.4422	0.39		
Total	146	73.1837			

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	0.5034	0.2517	3.92	
REP.*Units* stratum					
GENOTYPE	48	2.65306	0.05527	0.86	0.714
Residual	96	6.16327	0.0642		
Total	146	9.31973			

Pod yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	2	1.21E+07	6.06E+06	0.4	
REP.*Units* stratum					
GENOTYPE	83	2.88E+09	3.47E+07	2.3	<.001

Residual	166	2.50E+09	1.51E+07	
Total	251	5.40E+09		

Appendix 17: Regression analysis based on the 3-parameter model of seven runner bean crosses for traits studied at two locations

Cross	Days to flowering										
	Kabete					Ol Joro-Orok					
W x Kin 1	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	122.25	61.127	21.71	<.001	Regression	2	128.23	64.116	39.44	<.001
	Residual	9	25.34	2.816			Residual	9	14.63	1.625		
	Total	11	147.6	13.418			Total	11	142.86	12.987		
W x Kin 2	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	170.14	85.07	28.13	<.001	Regression	2	73.8	36.899	13.72	0.002
	Residual	9	27.22	3.024			Residual	9	24.21	2.69		
	Total	11	197.36	17.942			Total	11	98.01	8.91		
W x Kin 3	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	152.9	76.449	17.9	<.001	Regression	2	153.15	76.575	17.06	<.001
	Residual	9	38.43	4.271			Residual	9	40.4	4.489		
	Total	11	191.33	17.394			Total	11	193.55	17.595		
W x Nyeri	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	209.42	104.708	30.94	<.001	Regression	2	166.02	83.008	58.14	<.001
	Residual	9	30.46	3.384			Residual	9	12.85	1.428		
	Total	11	239.88	21.807			Total	11	178.86	16.26		
W xDwarf 1	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	314.12	157.062	28.48	<.001	Regression	2	91.987	45.9937	50.3	<.001
	Residual	9	49.63	5.514			Residual	9	8.229	0.9144		
	Total	11	363.75	33.069			Total	11	100.217	9.1106		
W x Dwarf 2	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.

	Regression	2	243.39	121.693	46.91	<.001	Regression	2	85.93	42.963	18.91	<.001
	Residual	9	23.35	2.594			Residual	9	20.45	2.272		
	Total	11	266.73	24.248			Total	11	106.37	9.67		
W xDwarf 3	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	247.21	123.604	85.99	<.001	Regression	2	151.05	75.525	52.56	<.001
	Residual	9	12.94	1.437			Residual	9	12.93	1.437		
	Total	11	260.15	23.65			Total	11	163.98	14.908		

Number of Racemes during the first flush of flowering

	Kabete						**Ol Joro-Orok**					
W x Kin 1	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	133.81	66.906	33.4	<.001	Regression	2	61.46	30.731	4.7	0.04
	Residual	9	18.03	2.003			Residual	9	58.86	6.54		
	Total	11	151.84	13.804			Total	11	120.32	10.938		
W x Kin 2	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	108.02	54.012	14.3	0.002	Regression	2	62.8	31.401	16.58	<.001
	Residual	9	33.98	3.776			Residual	9	17.04	1.894		
	Total	11	142.01	12.91			Total	11	79.85	7.259		
W x Nyeri	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	254.06	127.028	39.8	<.001	Regression	2	152.91	76.455	21.81	<.001
	Residual	9	28.73	3.192			Residual	9	31.55	3.505		
	Total	11	282.78	25.708			Total	11	184.46	16.769		
W x Dwarf 1	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	39.55	19.777	5.56	0.027	Regression	2	94.01	47.004	15.12	0.001
	Residual	9	32.01	3.557			Residual	9	27.99	3.11		
	Total	11	71.56	6.506			Total	11	121.99	11.09		
W xDwarf 2	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	63.65	31.823	15.81	0.001	Regression	2	77.4	38.699	12.02	0.003
	Residual	9	18.12	2.013			Residual	9	28.97	3.218		
	Total	11	81.77	7.433			Total	11	106.36	9.669		

W xDwarf 3	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	43.98	21.99	14.32	0.002	Regression	2	62.51	31.254	7.28	0.013
	Residual	9	13.83	1.536			Residual	9	38.66	4.296		
	Total	11	57.81	5.255			Total	11	101.17	9.197		

Number of racemes during second flush of flowering

	Kabete						**Ol Joro-Orok**					
W x Kin 1	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	132.1	66.03	5.17	0.032	Regression	2	79.95	39.975	8.5	0.008
	Residual	9	114.9	12.77			Residual	9	42.31	4.701		
	Total	11	247	22.45			Total	11	122.26	11.114		
W x Kin 2	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	105.05	52.525	24.06	<.001	Regression	2	125.43	62.715	8.39	0.009
	Residual	9	19.65	2.183			Residual	9	67.24	7.471		
	Total	11	124.7	11.336			Total	11	192.67	17.516		
W x Kin 3	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	104.44	52.221	19.49	<.001	Regression	2	159.33	79.667	8.45	0.009
	Residual	9	24.12	2.68			Residual	9	84.86	9.429		
	Total	11	128.56	11.687			Total	11	244.2	22.2		
W x Nyeri	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	279.54	139.772	86.86	<.001	Regression	2	158.12	79.06	19.13	<.001
	Residual	9	14.48	1.609			Residual	9	37.2	4.133		
	Total	11	294.03	26.73			Total	11	195.32	17.756		
W x Dwarf 1	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	89.6	44.8	7.68	0.046	Regression	2	36	18.001	5.61	0.026
	Residual	9	52.5	5.83			Residual	9	28.89	3.209		
	Total	11	142.1	12.92			Total	11	64.89	5.899		
W x Dwarf 2	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	74.94	37.47	10.98	0.004	Regression	2	57.4	28.699	5.87	0.023

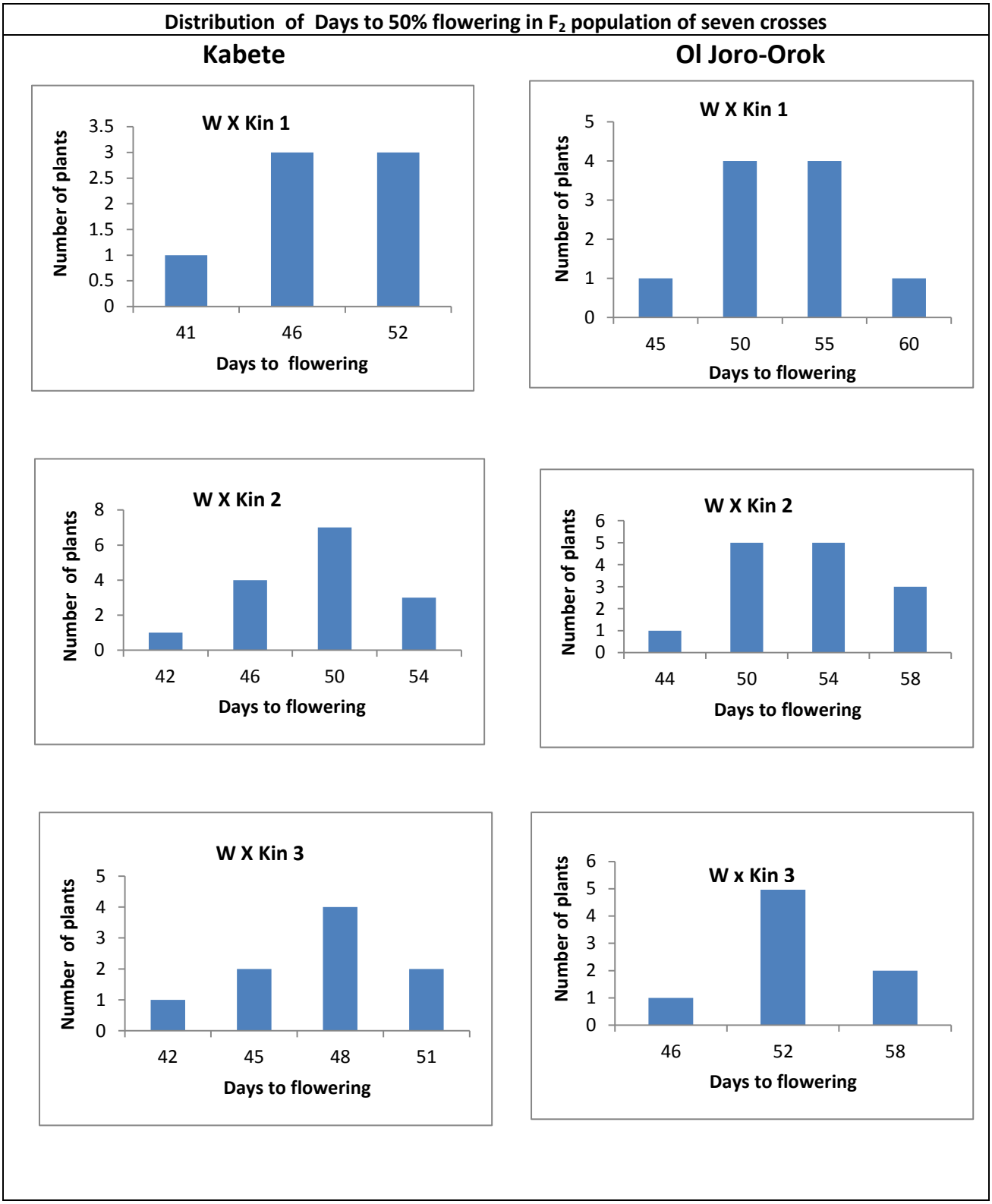
	Residual	9	30.7	3.411			Residual	9	44.02	4.891		
	Total	11	105.64	9.603			Total	11	101.42	9.22		
W x Dwarf 3	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	30.98	15.489	2.25	0.161	Regression	2	46.2	23.1	13.75	0.004
	Residual	9	61.84	6.871			Residual	9	15.12	1.68		
	Total	11	92.81	8.438			Total	11	61.32	5.58		

Number of pods

	Kabete						**Ol Joro-Orok**					
W x Kin 1	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	691.6	345.79	11.82	0.003	Regression	2	452.1	226.03	16.96	<.001
	Residual	9	263.3	29.25			Residual	9	120	13.33		
	Total	11	954.8	86.8			Total	11	572	52		
W x Kin 2	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	232.19	116.095	16.74	<.001	Regression	2	892	445.99	12.99	0.002
	Residual	9	62.43	6.936			Residual	9	309.1	34.35		
	Total	11	294.62	26.783			Total	11	1201.1	109.19		
W x Kin 3	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	401.1	200.54	3.74	0.066	Regression	2	1127.3	563.63	10.74	0.004
	Residual	9	482.6	53.63			Residual	9	472.5	52.5		
	Total	11	883.7	80.34			Total	11	1599.8	145.44		
W x Nyeri	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	1194.3	597.16	28.1	<.001	Regression	2	658.2	329.08	14.64	0.001
	Residual	9	191.2	21.25			Residual	9	202.3	22.48		
	Total	11	1385.6	125.96			Total	11	860.4	78.22		
W x Dwarf 1	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	401.45	200.723	29.04	<.001	Regression	2	488.6	244.31	8.1	0.01
	Residual	9	62.2	6.911			Residual	9	271.5	30.17		
	Total	11	463.64	42.149			Total	11	760.1	69.1		

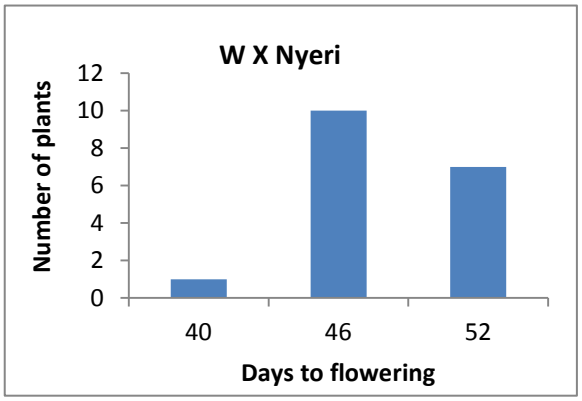
W x Dwarf 2	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	590.74	295.372	33.53	<.001	Regression	2	906.6	453.299	78.53	<.001
	Residual	9	79.27	8.808			Residual	9	51.95	5.772		
	Total	11	670.02	60.911			Total	11	958.55	87.141		
W x Dwarf 3	Source	d.f.	s.s.	m.s.	v.r.	F pr.	Source	d.f.	s.s.	m.s.	v.r.	F pr.
	Regression	2	787.6	393.78	33.21	<.001	Regression	2	391.4	195.7	15.45	0.001
	Residual	9	106.7	11.86			Residual	9	114	12.67		
	Total	11	894.3	81.3			Total	11	505.4	45.95		

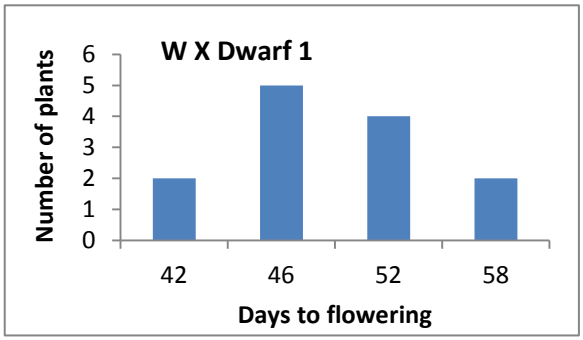
Appendix 18: Histograms showing distribution of F_2 population for days to 50% flowering, number of racemes and pods in seven crosses evaluated at two locations

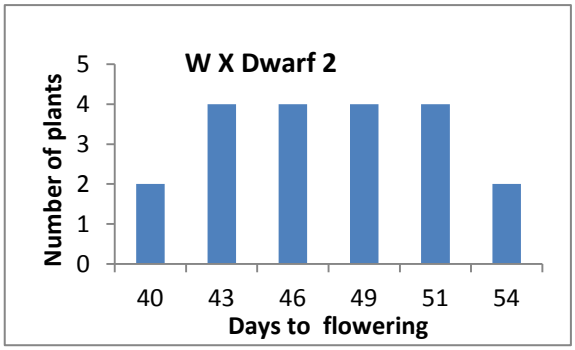


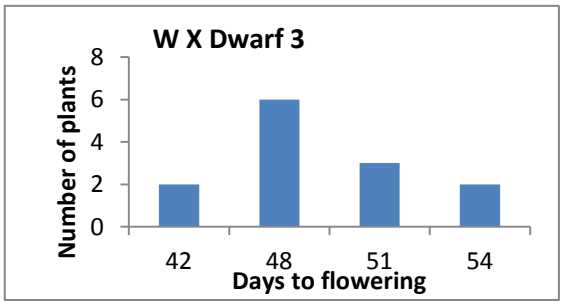
Distribution of days to flowering in F_2 population of seven crosses

Kabete

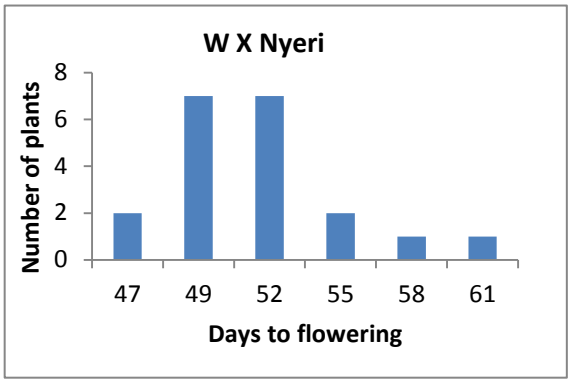


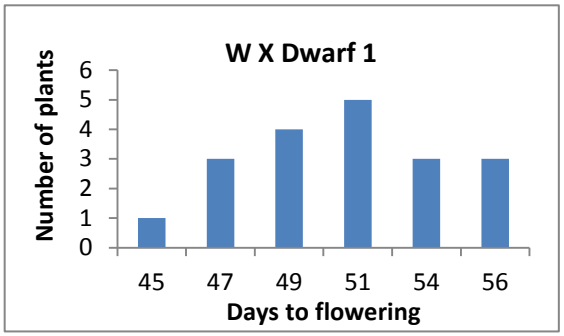


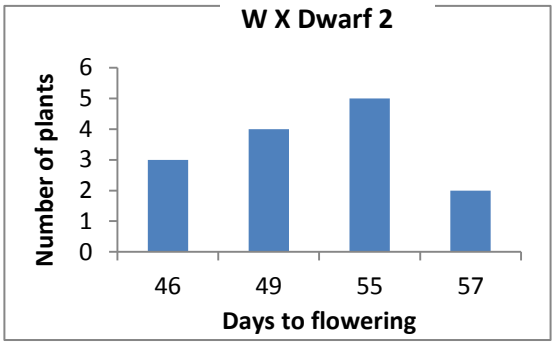


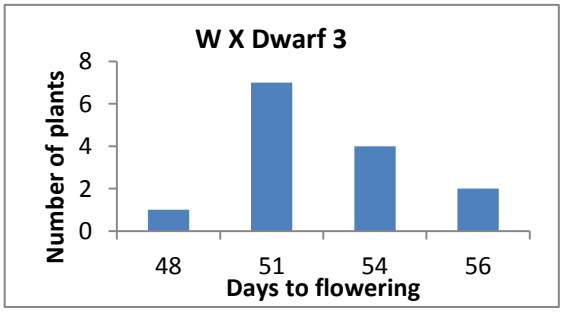


Ol Joro-Orok



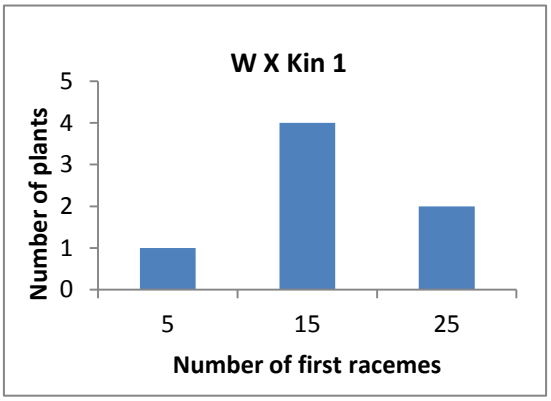


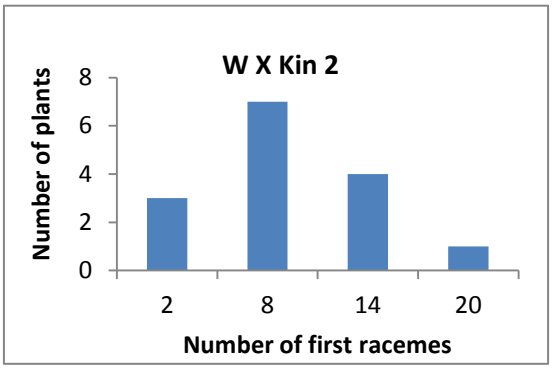


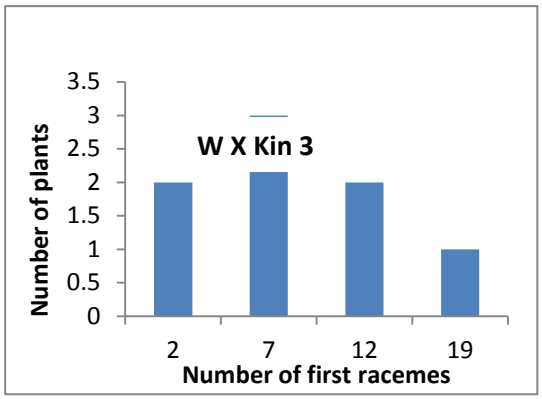


Distribution of racemes at first flowering in F_2 population of seven crosses

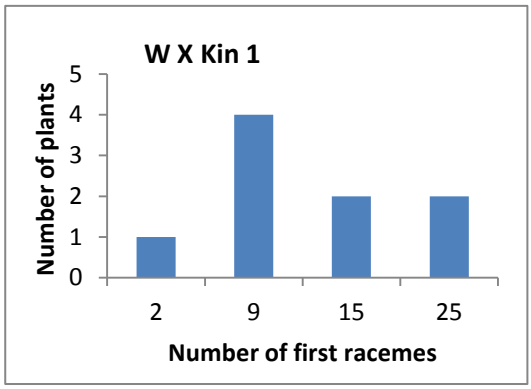
Kabete

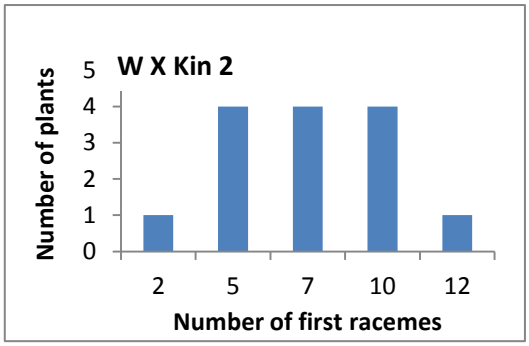


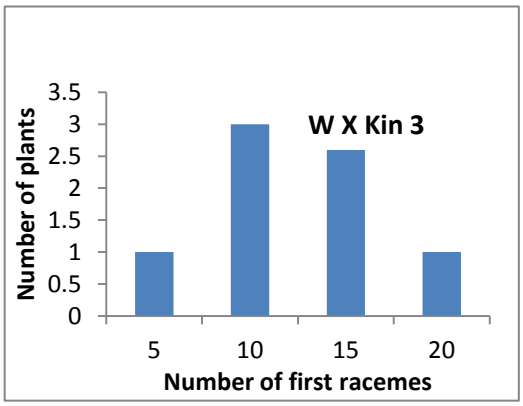




Ol Joro-Orok

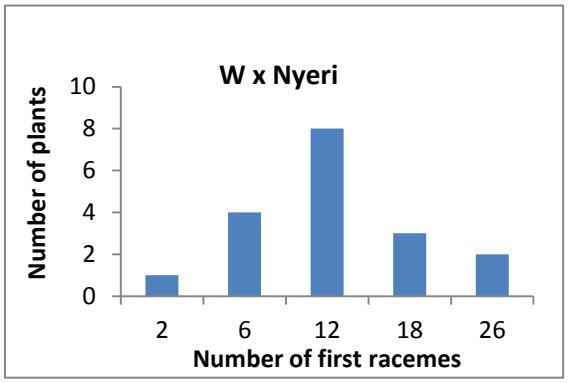


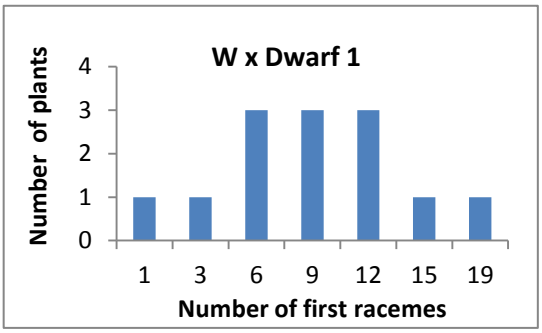


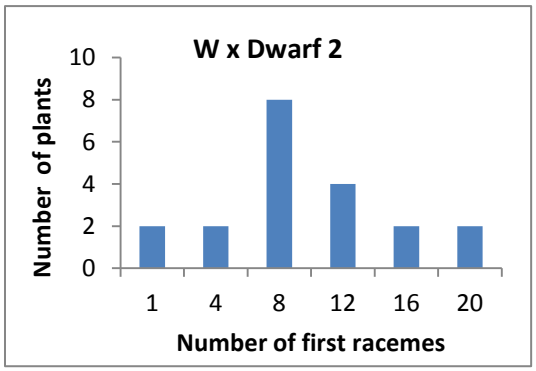


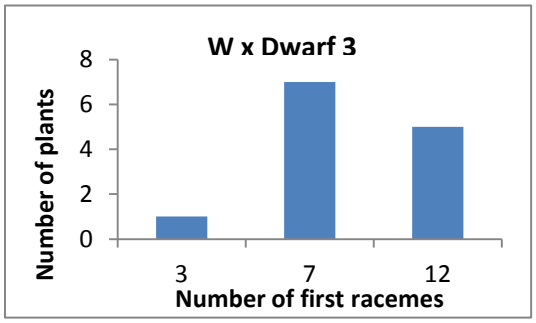
Distribution of number of racemes at first flowering in F_2 population of seven crosses

Kabete

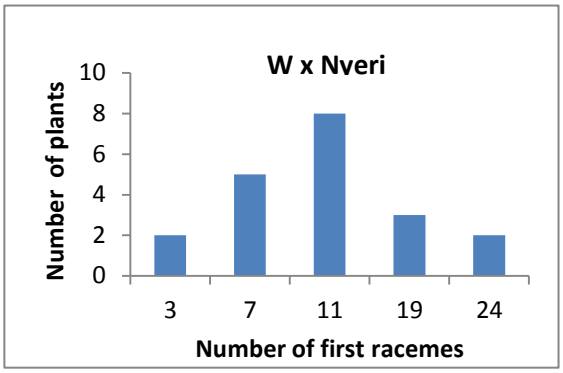


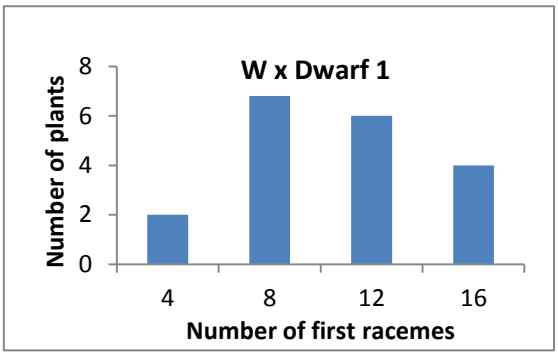


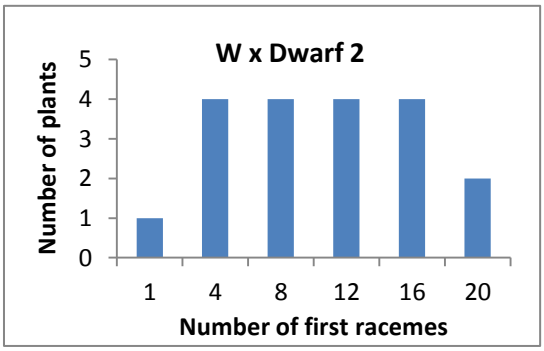


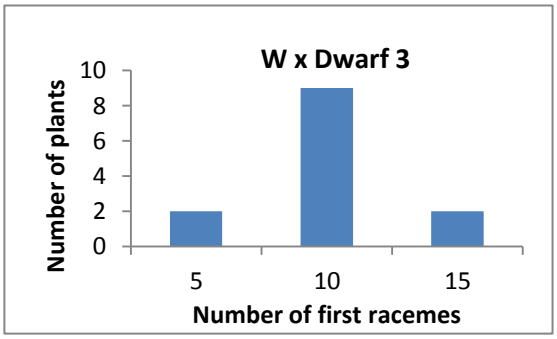


Ol Joro-Orok



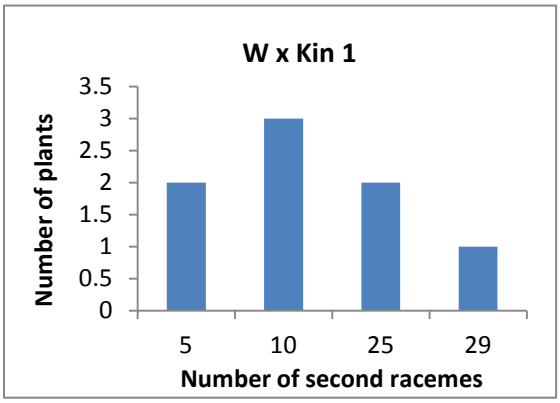


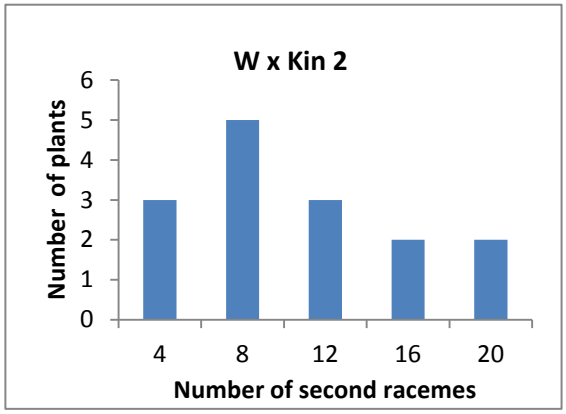


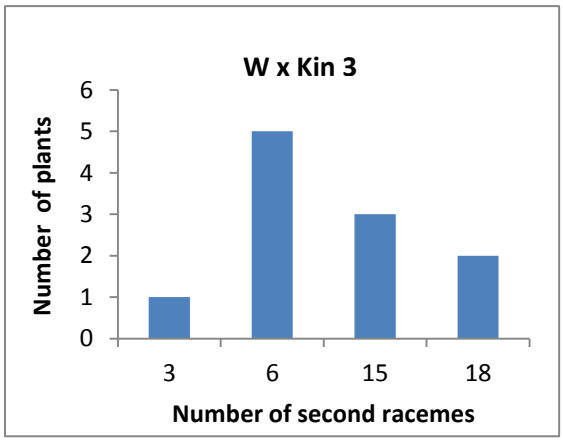


Distribution of racemes at second flowering in F_2 population of seven crosses

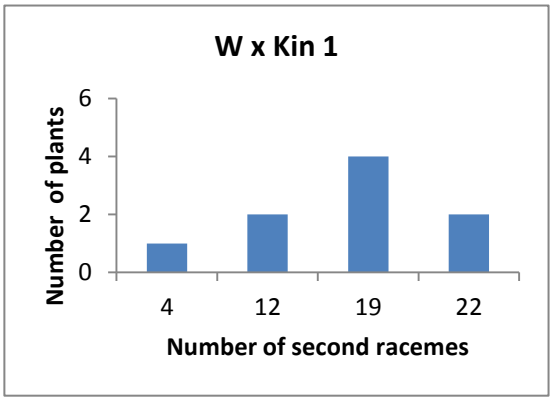
Kabete

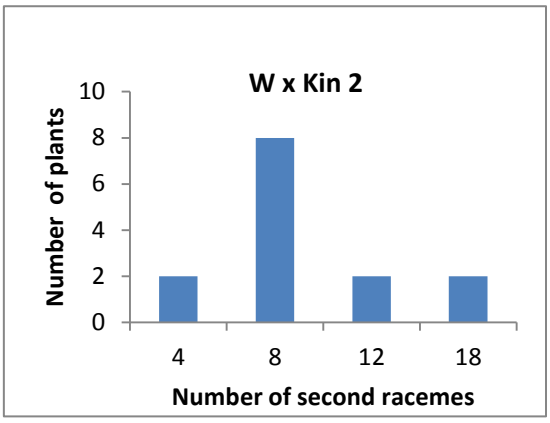


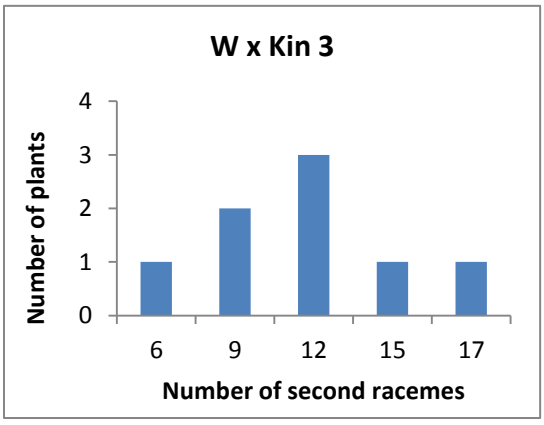




Ol Joro-Orok

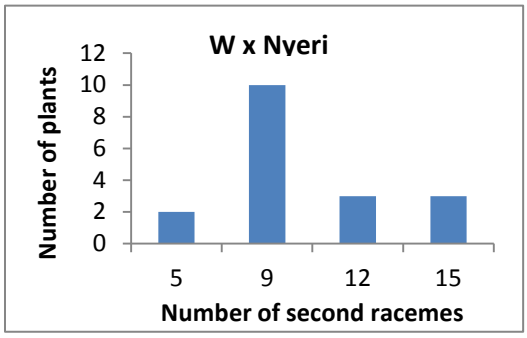


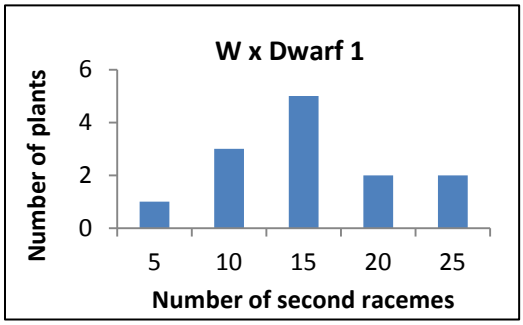


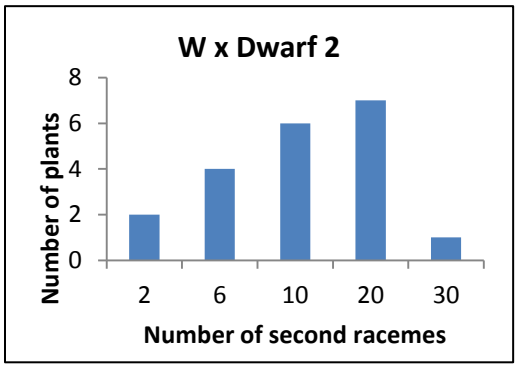


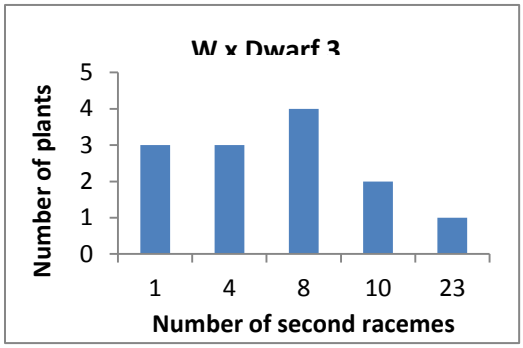
Distribution of number of racemes at second flowering in F2 population of seven crosses

Kabete

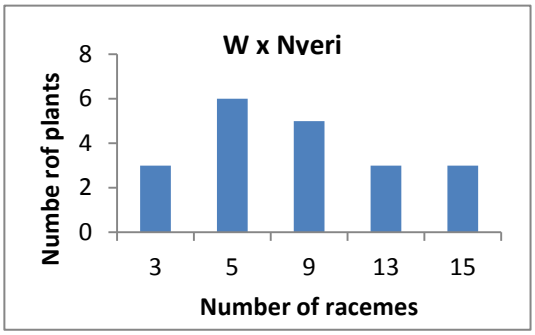


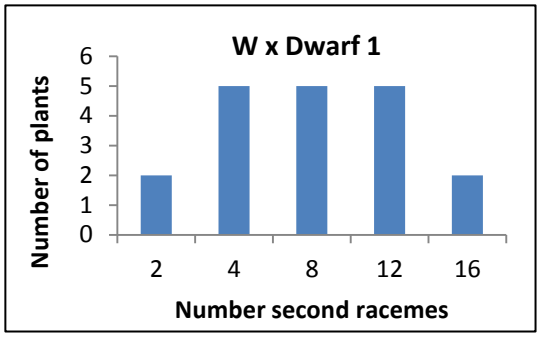


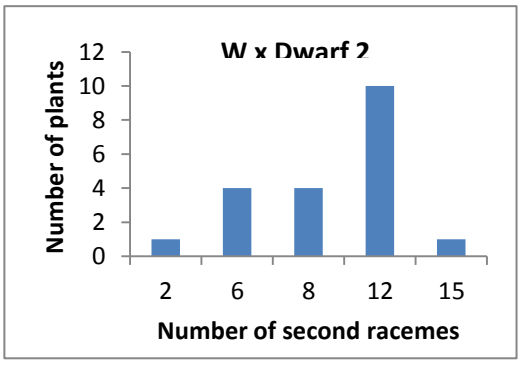


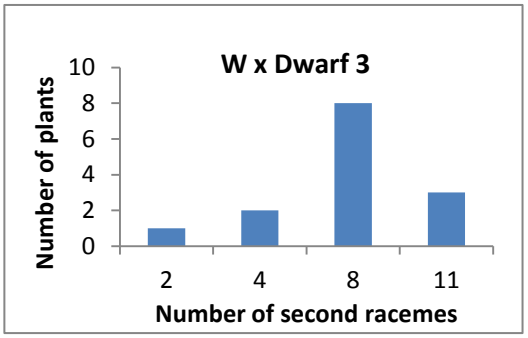


Ol Joro-Orok



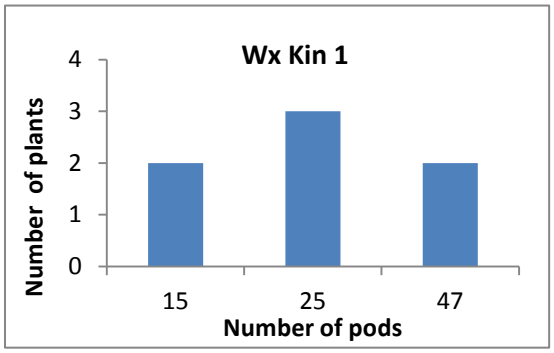


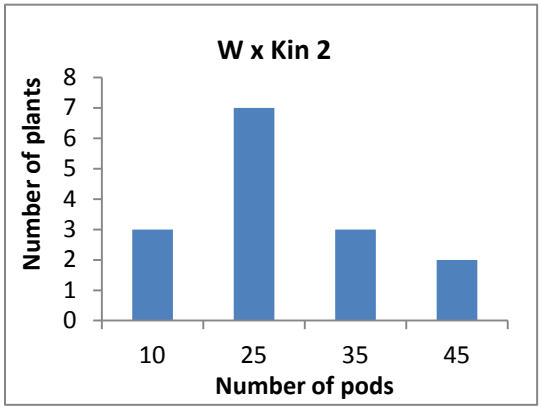


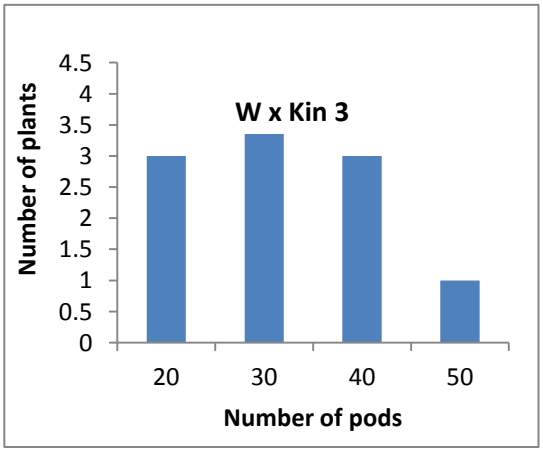


Distribution of number of pods in F_2 population of seven crosses

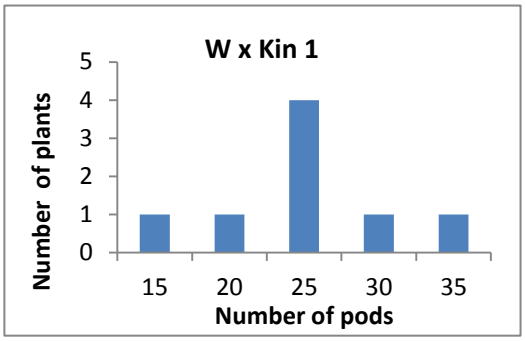
Kabete

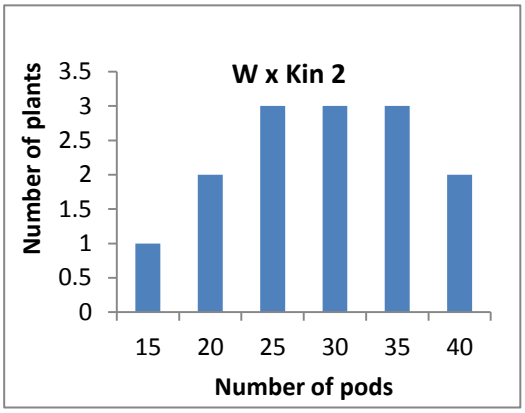


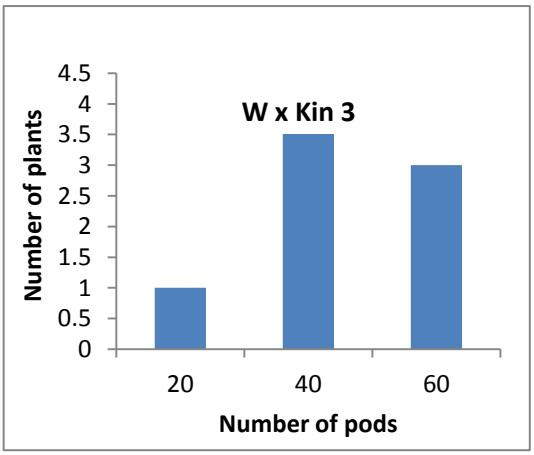




Ol Joro-Orok

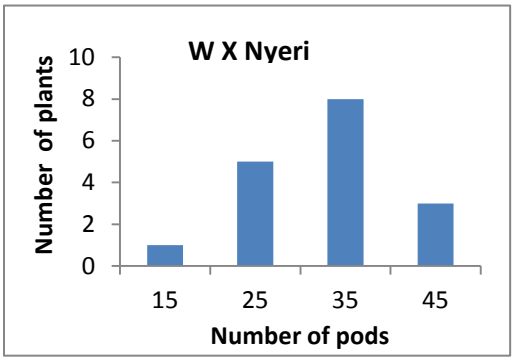


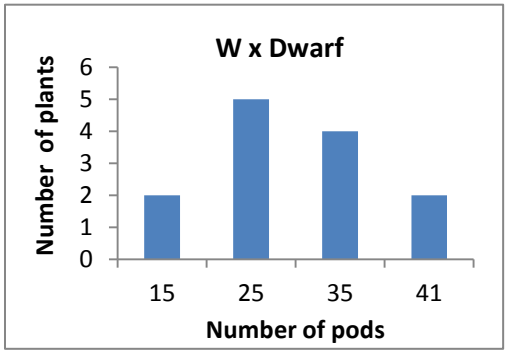


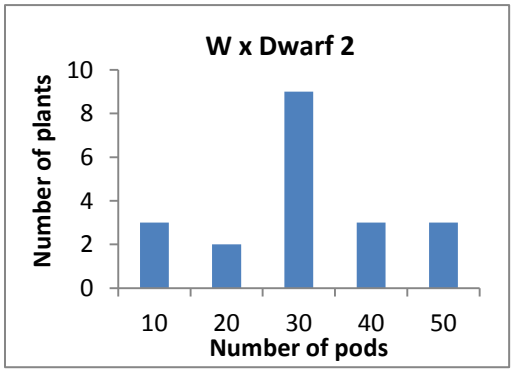


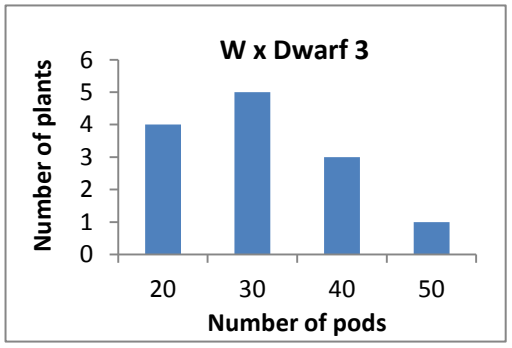
Distribution of number of pods in F_2 population of seven crosses

Kabete









Ol Joro-Orok