PERFORMANCE OF BEAN GENOTYPES UNDER DISEASE PRESSURE IN DIFFERENT ENVIRONMENTS AND PLANTING DATES IN WESTERN KENYA

YONA OTSYULA MASHETI

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN CROP PROTECTION

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION

FACULTY OF AGRICULTURE

UNIVERSITY OF NAIROBI

2019

DECLARATION

This thesis is my original work and has not been presented for a degree in this or any other University.

Yona Otsyula Masheti Signature.....Date.....

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

Prof. James W. Muthomi Signature……..Date……

Department of Plant Science and Crop Protection

University of Nairobi

Prof. Agnes W. Mwang'ombe Signature…….Date……

Department of Plant Science and Crop Protection

University of Nairobi

Dr. Sammy Ajanga Signature……..Date……

Kenya Agricultural and Livestock Research Organization,

Industrial Crop Research Institute

Molo.

DECLARATION OF ORIGINALITY

DEDICATION

To my loving Grandmother Flora Rasoah Ilavusa Otsyula who passed away in the course of this study. Her boundless love will forever be missed. May her soul rest in eternal peace.

ACKNOWLEDGEMENTS

I would like to thank the Universe for seeing me through this research. I convey my sincere appreciation to my supervisors Prof. James W. Muthomi, Prof. Agnes W. Mwang'ombe and Dr. Sammy Ajanga for their patience, invaluable support, training, guidance and advice. I acknowledge Kenya Agricultural and Livestock Research Organization-Kakamega for giving me a scholarship and the Kirk House Trust for funding this project. I also acknowledge the farmers for being part of this project, their generosity and cooperation throughout the study. I am also grateful to Mr. Fred Mulusa, Mr. Moses Wambulwa, Mr. Shamir Misango and many others attached to Kenya Agricultural and Livestock Research Organization - Kakamega for their assistance in my fieldwork. I want to extend my gratefulness to my family and friends for their unconditional support and goodwill throughout my study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

AEZ	Agro-Ecological Zone
ALS	Angular Leaf Spot
AMMI	Additive Main effects and Multiplicative Interaction
ANOVA	Analysis of variance
Asl	Above Sea Level
BCMD	Bean Common Mosaic Diseases
BCMNV	Bean Common Mosaic Necrosis Virus
BCMV	Bean common mosaic virus
CBB	Common bacterial blight
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CV	Coefficient of variation
FAO	Food and Agriculture Organization
G	Grams
FLS	Floury Leaf Spot
GEA-R	Genotype X Environment Analysis with R for Windows
GLP 1127	Global legume program eleven twenty seven
GLP 2	Global legume program two
GLP 585	Global legume program five eighty five
GLP X92	Global legume program ninety two
GxE	Genotype X Environment Interaction
GxL	Genotype X Location Interaction
HSW	Hundred seed weight
IITA	International Institute of Tropical Agriculture
IPDM	Integrated Pest and Disease Management
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
KAT B9	Katumani nine
KAT X56	Katumani fifty six
Kg	Kilogram

KK 071	Kakamega zero seven two
KK 072	Kakamega zero seven two
KK 15	Kakamega fifteen
KK 22	Kakamega twenty two
KK 8	Kakamega eight
LM 2	Lower Midland Two
LSD	Least Common Difference
M	Meters
M.A.S.L	Meters above sea level
Mm	Millimeters
PCA 1	Principal Component Analysis one
t/ha	Tons per hectare
t/y	Tons per Year
UM 1	Upper Midland One
UM 2	Upper Midland two
UM 2-T	UM 2 Transition
UM 3-4	Upper Midland three four
UM 4	Upper Midland Four
USD	United States Dollars

ABSTRACT

The common dry bean (*Phaseolus vulgaris* L.), plays an important dietary role as the second most important source of human dietary protein and the third most important source of calories of all agricultural commodities produced in eastern and southern Africa. Dry bean farming in Western Kenya faces challenges of diseases attributed to a limited number of released bean varieties with multiple disease resistance. This study assessed the performance of bean genotypes under varying disease pressure over multiple environments and different planting dates. Common bean varieties were planted in upper-midland zone 1 and upper-midland zone 3-4 in Kakamega County and upper-midland zone 2, upper-midland zone 4 and lower-midland zone 2 in Bungoma County over different sowing dates in the short rains of 2016 and the long rains of 2017. Natural infection of the genotypes by diseases was allowed to occur. Disease intensity, yield and yield components data were collected and subjected to combined analysis of variance with differences between treatments compared at $p \leq 0.05$.

Diseases observed were anthracnose (*Colletotrichum lindemuthianum*), scab (*Elsinoë phaseoli*), angular leaf spot (*Pseudocercospora griseola*), rust (*Uromyces appendiculatus*), floury leaf spot (*Mycovellosiella phaseoli*), Cercospora leaf spot, common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*), halo blight (*Pseudomonas savastanoi* pv. *phaseolicola*), bacterial brown spot (*Pseudomonas syringae* pv. *syringae*), bean common mosaic virus, bean common mosaic necrosis virus and golden mosaic virus.

The environment had an effect on both disease pressure and yield as the agro-ecological zones performed significantly ($p \leq 0.05$) different to each other. Upper midland zone 1 was significantly ($p \leq 0.05$) the best performing environment with 1.9 t/ha in the long rains and 1.5 t/ha in the short rain season. Upper midland zone 1 and UM 2 also had higher disease pressure compared to lower lying UM 4 and LM 2. Rust and scab had the highest intensity

among the diseases with 44.7 and 51.8% respectively in the short rain season. Genotypes reacted variably to disease pressure in the environments with variety Red 16 generally having the least disease pressure and highest yields of 2.2 and 1.3 t/ha in the long and short rains, respectively. There was significantly ($p \leq 0.05$) less disease pressure in the early plantings compared to late plantings. Yield significantly ($p \leq 0.05$) decreased as disease pressure increased with lateness of sowing therefore late planting had a combination of high disease pressure and low yields compared to early planting.

This study shows that at the environment level, abiotic factors such as precipitation outweigh diseases in their influence on the overall performance of the genotypes. However, disease intensity has an important role on the performance of varieties within an environment. The highest yields are achieved through early planting, as this is when overall disease pressure is lowest. Early planting of beans is a strategy that can effectively manage diseases and should be included in integrated pest and disease management (IPDM) strategies. Varieties Red 16, Cal 33 and Cal 194 showed multiple disease resistance, were high yielding and stable and can be recommended to farmers or further improved by incorporating missing resistances

CHAPTER ONE: INTRODUCTION

1.1 Background

The common dry bean (*Phaseolus vulgaris* L.), is the most important pulse for direct consumption in the world. It has over 40,000 varieties and shows tremendous variability in growth habit, seed character, duration to maturity and other adaptations (Jones, 1999). In Sub-Sahara Africa, average production of 600 kg ha^{-1} is still below the world's average of 750 kg ha^{-1}, as gains made around the world have not been realized in these resource-poor regions (Namugwanya *et al*., 2014). In East Africa, the per capita consumption stands between 50 and 60 kg per year. In Kenya, Western region has the leading common bean consumption rate at 66 kg per person per year (Katungi *et al.* 2009).

Common bean total production in Kenya was 846,000 metric tons in 2017, an improvement from the previous year where it was 728,160 metric tons (Food and Agriculture Organization, 2017). Productivity is however still below actual yield potential due to biophysical stresses such as unpredictability of the climate, loss of soil fertility, pests and diseases (Katungi *et al*., 2011). Important diseases include bean common bacterial blight (*Xanthomonas axanopodis* pv. *phaseoli*), anthracnose (*Colletotrichum lindemuthianum*), halo blight (*Pseudomonas savastanoi* pv. *phaseolicola*), bean leaf rust (*Uromyces appendiculatus*), angular leaf spot (*Pseudocercospora griseola*), root rots and bean common mosaic Potyvirus. A management method that requires use of few inputs, is environmentally friendly and favorable to smallholder farmers, is necessary to combat disease challenges. The use of bean varieties with desirable agronomic traits and that possess multiple disease resistance is one method that is suitable for smallholder farmers. Since disease resistance may vary with the environment, genotypes that are best adapted to specific environments and climatic conditions within a region should be developed (Fininsa and Tefera, 2006).

1.2 Problem statement

Bean farming in Kenya is mainly done by small scale farmers and faces challenges such as poor farming practices, lack of inputs, land over use, loss of soil fertility, droughts, weed competition and stress, and pest and disease damage. Diseases such as common bacterial blight, root rots, angular leaf spot, anthracnose, bean common mosaic virus (BCMV) and bean common mosaic necrosis virus (BCMNV) have been identified as major constraints on bean production in Kenya (Muthomi *et al*., 2007; Mangeni *et al*., 2014; Leitich *et al.*, 2016). In Western Kenya, where bean production and consumption is highest in the country, effects of these constraints are compounded by farmers' use of low-yielding varieties that are poorly adapted to the environment. Although in some cases sources of resistance are known, diseases are still on the increase due to a limited number of released bean varieties with multiple disease resistance, inoculum build-up in the environment and limited information on adaptability of available varieties in different environments hindering adoption (Otsyula, 2016). National release of varieties is based on optimum growing conditions such as planting at the onset of the rain season, which is not an accurate depiction of farmers' practice in Western Kenya. This is because in this region, beans are cultivated throughout the year due to lack of a true demarcation between the long rain and short rain season as rainfalls tends to be more or less continuous with only brief stops (Jaetzold *et al.,* 2005). Despite this, there is limited information on the effects of planting date on disease intensity and bean productivity in the region.

1.3 Justification

Understanding the interaction of the environments and planting dates with genotypes in relation to diseases is important for the development of bean varieties with wide adaptations. Some varieties were bred for resistance to specific diseases but were not tested for reaction to

other diseases that also occur in farmers' fields. Information on the adaptability of released varieties over variable environments and sowing dates is useful in selecting high yielding and stable cultivars (Getachew *et al.*, 2015) for farmers in varied locations and environments, which will protect them against losses caused by diseases (Fininsa and Tefera, 2006). Determination of genotype and environment interactions based on diseases severity, yield and related agronomic traits is useful in the identification of widely adapted varieties and mapping them to various agro-ecological zones over time and space in smallholder farmer fields.

1.4 Objective

The general objective is to improve common bean productivity through identification of bean varieties with multiple disease resistances suited to varying environmental conditions and planting dates.

Specific objectives

i. To determine the effect of environment on disease incidence and severity in common bean genotypes

ii. To determine the effect of sowing date on disease incidence and severity in common bean genotypes

1.5 Hypothesis

i. The environment has an effect on disease incidence and severity in common bean genotypes

ii. Sowing date has an effect on disease incidence and severity in common bean genotypes

CHAPTER TWO: LITERATURE REVIEW

2.1 Bean production trends in Western Kenya

Globally the common bean averages a production of approximately 715 kg/year/ha with about 28 million hectares under cultivation. As of 2008, the average worldwide yield stood at 750 kg/year/ha (Namugwanya *et al*., 2014). Africa accounts for more than four million hectares with some of the world's highest per capita consumption of 50kgs to 60kgs recorded in Eastern Africa. Such high demands have resulted in bean sales exceeding 500 million USD annually making the dry bean a secure and rewarding income earner for numerous households around the region (Chirwa *et al*., 2011).

The dry bean is the most common pulse in Kenya and is incorporated in various cropping systems. The main production areas range in altitude of between 1500 m to 2500 m asl and are found in the former Eastern, Central, Western and Lake Victoria regions (Kimiti *et al*., 2009). Common bean total production in Kenya was 846,000 metric tons in 2017, an improvement from the previous year where it was 728,160 metric tons (Food and Agriculture Organization, 2017). The total common bean production area in Kenya is approximately half a million hectares giving an actual yield of 250 kg/ha which in most cases is usually under mixed or intercropped systems. Yields of as high as 700 kg/ha have been reported in Kenya under pure stands, which are not common, this is still some way off potential yields of up to 5000 kg/ha achieved under field conditions in Mexico (Mauyo *et al*., 2010).

In Western Kenya, common bean is second only to maize in popularity and its cultivation is mainly done by smallholder farmers (One Acre Fund, 2013). It is usually grown for subsistence and is typically in association with other crops because of land scarcity caused by human over population. To most growers in subsistence production systems, yield stability is

prioritized over productivity of the variety; this is especially true for poor farmers in areas with infertile soils as seen in western Kenya. The farmer's priority is a stable source of food rather than risk hunger for the sake of high yields (CIAT, 2004). Consequently there is partial adoption of released varieties with high variety diversification being seen at both micro and macro levels, this diversification may give low yields at farm level but improved yield stability since no one bean variety has all the attributes farmers prefer (CGIAR, 2012).

2.2 Common bean production constraints in Kenya

The leading common bean production constraints are poor farming practices, soil infertility, drought, insufficient improved cultivars, competition with weeds and pest and disease damage. These constraints are grouped into biotic (comprised of pests and diseases) and abiotic comprised of moisture stress, excessive rain, soil infertility, heat and cold stress (Chirwa *et al*., 2011). The constraints may have complex interactions between them as seen in trials in the Great Lakes region that have shown soil fertility and diseases to be the two most important limiting factors. A clear negative interaction between soil fertility and disease is often found whereby improving soil fertility result in a reduction in disease incidences (CIAT, 2004). In Western Kenya, soils are infertile due to the high amount of rainfall received in the area causing nutrient leaching and a high population density that has made cultivatable land scarce. The available land is over exploited further compounding soil depletion (Tittonell *et al*. 2008; One Acre Fund, 2013).

The emphasis of bean breeding especially in Africa has been to make available to farmers improved bean varieties that are resistant to multiple environments and climate linked stresses, both biotic and abiotic, have increases micronutrients content and are of high value targeting niche markets (Chirwa *et al*., 2011). Although breeding programs have focused on combating the major production constraints, farmers are still growing varieties that were

released 15-20 years ago indicating that the adoption of new varieties is not only low but also slow. This has been pinned on lack of improved varieties that constitute all farmer-preferred qualities.

2.3 Diseases affecting common beans in Kenya

Beans are susceptible to pathogens resulting in wide fluctuation in yields. All over the world and especially in the tropics wherever you find beans, you find pathogens (Corrales, 2006). When the common bean was introduced to the highlands of eastern Africa about 400 years ago, they seem to have come with most of the seed borne pathogens than now occur both in East Africa and in the Americas (Schwartz *et al.*, 1989). Some of the most economically important dry bean diseases found around the world such as anthracnose, common bacterial blight, rust and bean common mosaic also occur in Africa. All the main pathogen groups; fungi, bacteria, viruses and nematodes, cause important diseases of beans in Kenya.

2.3.1 Common bacterial blight

According to Wortmann (1998), common bacterial blight (CBB) is the fourth most important dry bean disease in Africa causing yield losses of up to 220,000 t/year where about 146,000 t/year is lost in Eastern Africa. Only angular leaf spot, anthracnose and root rot are ranked higher in yield losses caused. Common bacterial blight intensity varies with country and from season to season. In Kenya, CBB is a major restraint to dry bean production with observed crop losses of between 10 to 75% (Cabi.org, 2015). The bacterial pathogen *Xanthomonas axonopodis* pv. *phaseoli* causes common bacterial blight of beans (Öztürka and Aksoy, 2018). The pathogen is a Gram-negative, aerobic, rod-shaped flagellated bacterium characterized by formation of mucoid, convex shaped, bright-yellow growth in culture that is because of the production of a non-water soluble carotenoid pigment. It is also non-spore forming (Harveson, 2009; Öztürka and Aksoy, 2018).

Common bacterial blight symptoms include water-soaked spots that first appear on the leaves, these spots then enlarge to initially flaccid then brown necrotic lesions with lemon yellow borders. These lesions may further coalesce forming broad tissue damage resulting in leaf loss. In cases where the pathogen spreads to the vascular system, wilting occurs (Öztürka and Aksoy, 2018). Water-soaked spots appear on the pods and enlarge into dark-red sunken lesions that might be filled with yellow exudate (Hagedorn and Inglis, 1986). As a warm weather disease, common bacterial blight is favored by temperatures of between 28 to 32°C. Common bacterial blight is a seed-borne disease (Bastas and Sahin, 2016). Factors that favour rapid CBB development and spread include high temperature, precipitation and humidity in the field (Karavina *et al*., 2011). The spread of inoculum is by windblown rain, soil and plant debris, runoff and splash from irrigation water, wet plant leaves coming into contact and activities of animals and insects like leaf miners within the field (Karavina *et al*., 2011).

2.3.2 Halo blight

Halo blight has a widespread distribution making it a disease of significant economic importance especially in mid- to high-altitude areas (Boersma *et al.*, 2015). Halo blight losses of up to 43% have been recorded in some places (Allen, 1996). *Pseudomonas savastanoi* pv. *phaseolicola* is the causal agent of this disease (Öztürka and Aksoy, 2018). Symptoms appear as small water-soaked spots on the leaves and progress into chlorotic yellow-green haloes on the upper surface of the leaflet. General chlorosis occurs in cases of systemic infections of halo blight. In case the inoculum is from infected seeds, the seedlings may rot at the nodes. Water-soaked spots or dark-brown to black streaked lesions that sometimes produces whitish excaudate appear on pod, stems, and petioles (Öztürka and Aksoy, 2018).

This disease is favored by humid conditions being more severe when temperatures are cool to moderate. Its occurrence varies annually subject to biological, climatic and farm management factors (Direk *et al.,* 2002). Between 18 to 23^0C, symptoms are severe as the pathogen produces chlorosis-inducing chemicals (Allen, 1996). Halo blight, like most bacterial diseases, is favoured by seasons and environments of high rainfall and strong winds. The disease flourishes under humid conditions and cool temperatures of between 18 to 22 ^{0}C (University of Illinois, 2000). Halo blight is a seed-borne disease (Boersma *et al*., 2014; Chatterton *et al.,* 2016) therefore, use of clean seeds can control the disease, though with no guarantee as other inoculum sources exist (Fourie, 2011). The pathogen spreads within or between fields through water-splash, aerosols and on contaminated equipment and farm personnel. The pathogen survives between seasons on weeds, infested crop debris and contaminated seed.

2.3.3 Bean anthracnose

Bean anthracnose is a major disease of dry bean in East Africa. In terms of losses, at 247,400 tons per year, anthracnose is the 3rd most significant constraint to dry bean production in Eastern Africa with only angular leaf spot (281,300 t/y) and nitrogen deficiency (263,600 t/y) resulting in greater losses (Wortmann *et al*., 1998). *Colletotrichum lindemuthianum* is the fungal pathogen responsible for the bean anthracnose disease (Padder *et al.,* 2017). Upon infection, the disease symptoms include black sunken cankers in the bean pod that have salmon coloured ooze centers formed by millions of conidia in acervuli. Characteristic sunken lesions filled with spores also occur in affected leaf veins, petioles, stems and seeds (Bardas *et al*., 2007).

The disease is favoured by cool and wet weather with temperatures of 13 to 26^0C and an optimum of 17^0C, above 92% relative humidity and free moisture (Mohammed, 2013).

Moisture favors spore formation and germination. Under optimum conditions such as susceptible host and favourable environment, losses can reach 100% (Mahuku *et al*., 2002). The pathogen is primarily seed transmitted where it can remain dormant in mycelium form within the seed or survive as spores, also within the seed. Outside the seed *C. lindemuthianum* can survive in crop debris by sclerotia formation (Bardas *et al*., 2007; Conner *et al.*, 2019).

2.3.4 Bean leaf rust

Bean leaf rust occurs worldwide wherever beans are grown but it is most prevalent in damp tropical and subtropical regions causing yield losses of about 25-100% (Schwartz, 1991; Allen, 1996; Wagacha *et al.,* 2007). The disease is caused by *Uromyces appendiculatus,* which has some of the highest pathogenic variability among fungal pathogens (Nyang'au *et al*., 2016). The pathogen can vary within a small area such as a single spore sample from a leaf or field populations (Jochua *et al.,* 2008).

Once a plant in infected with rust, small, yellow, raised spots appear on both the upper and lower surface of the leaf in addition to appearing on the petioles and pods. These spots expand to break the epidermis resulting in reddish brown uredial pustules surrounded by yellow haloes that may also be surrounded by rings of smaller secondary pustules (Jochua *et al.,* 2008). The leaf becomes chlorotic with the advancement of the infection even as the tissue colonized by the fungus remain green giving the appearance of "green islands". Pigmented, thick walled, single-celled teliospores are produced causing the pustules to darken further and the leaf gradually dies (Allen, 1996). The extent of rust damage on a cultivar depends on the developmental phase of the plant at the time infection occurs, susceptibility of the cultivar and the conditions of the environment (Arunga *et al*., 2012). High humidity, cloudy weather, heavy dew and temperatures of between 21 to 27^0C favour

dispersal and development of rust (Allen *et al.*, 1996). Spread of the rust propagules occurs mainly by wind.

2.3.5 Angular leaf spot

Angular leaf spot (ALS) occurs widely in tropical and sub-tropical regions where it negatively affects pod quality and causes high yield losses (Schwartz *et al*., 1989; Ddamulira *et al*., 2014). In the Great Lakes region of Africa, ALS is ranked the number one disease constraint to bean production with losses estimated at 281,300 tons per year in East Africa (Wortmann *et al*., 1998). The disease is caused by *Pseudocercospora griseola*, a fungus (Rezene *et al*., 2017).

Angular leaf spot lesions are most characteristic on leaves where they appear as gray or brown irregular-shaped spots occasionally bordered by a chlorotic halo. The lesions are angular in shape and become necrotic producing black conidia on the lower leaf surface. The fungus produces large and regular shaped reddish brown spots on the pods, usually surrounded by a darker-colored border. Dark brown extended lesions might also develop on petioles and stems of infected plants (Leitich *et al*., 2016). Angular leaf spot infection and development varies with soil types, rainfall and temperatures (Mwang'ombe *et al*., 2007). Favourable conditions for the successful infestation of the host by the ALS pathogen include moderate temperature and damp conditions (Stenglein *et al.*, 2003; Ddamulira *et al*., 2014). Angular leaf spot increases dramatically when several bean crops are planted in the same environment within a year (Allorent and Savary, 2005). The pathogen can remain inactive in infected plant debris while waiting for favourable conditions to occur (Monda *et al*., 2001). Genotype susceptibility also influences the occurrence and spread of ALS (Wagara *et al*., 2011).

Infected seeds and plant debris are important sources of *P. griseola* inoculum (Stenglein *et al*., 2003; Icishahayo, 2014). *Pseudocercospora griseola* can survive for up to 12 months on infected seed and 19 months on host plant debris in the absence of the living host (Sindhan and Bose, 1979). In Kenya, ALS is mainly seed transmitted due do farmers use of seed saved from previous seasons (Wachenje, 2002). The use of farm saved seeds coupled with nonstop cropping and poor field sanitation leads to inoculum build-up and consequently increased disease intensity. *P. griseola* is disseminated within or across fields via water and air (Stenglein *et al*., 2003; Ddamulira *et al*., 2014).

2.3.6 Bean scab

Bean scab is widely distributed across East and Southern Africa where it is thought to be endemic (Allen *et al*. 1996). It occurs on *P. vulgaris* in Kenya, Tanzania, Malawi, Zambia and Zimbabwe with reported yield losses of up to 70% (Schwartz, 1991). Bruner and Jenkins (1933) first described this pathogen on lima beans, *Phaseolus lunatus*, however in Africa it has not been reported on any other crop (CIAT, 1981).

Bean scab is caused by a fungal pathogen known as *Elsinoë phaseoli* Jenkins (Fan *et al*., 2017). The fungus attacks all plant parts except the flowers. Initial symptoms appear on stems and leaves causing distortion (Fan *et al*., 2017). Leaf lesions are typically circular corky outgrowths of 2 mm to 3 mm in diameter occurring largely on the upper surface (Phillips, 1994). These lesions appear superficial but are not easily removed by scrapping. The center of the lesions has a “shot-hole” appearance after falling out (Allan 1996). Stem lesions are also corky but elongated distorting and frequently curling at the tip. Affected plants have stunted growth and die before maturity. On the pods there are white to grey slightly sunken lesions that cause considerable distortion and turn red brown and slightly raised on maturity (Phillips, 1994; Allen, 1996). Bean scab development and establishment is favored by high

relative humidity and temperature while strong winds are also important for the spread of the disease (Mutitu, 1979). The disease is seed borne and infected seeds spread the disease internationally (Phillips, 1996). Spores are spread by wind and rain and may disseminate effectively by plant-to-plant contact.

2.3.7 Root rots

Root rots are caused by several fungal pathogens that include *Fusarium oxysporum*, *Fusarium solani*, *Pythium ultimum*, *Macrophomina phaseolina* and *Rhizoctonia solani*, which may occur singly or as a complex (Mwang'ombe *et al*., 2007). Root rot symptoms vary according to the causal agent. *Rhizoctonia* spp. symptoms appear as reddish brown lesions on the root and the lower hypocotyl which in severely infected seedlings or young plants may cause death or breaking off at the infected and weakened portions of the hypocotyl. *Pythium* species typical symptoms occur as water-soaked spots on roots and hypocotyls that coalesce resulting in a tan-brown appearance (Medvecky *et al*., 2007). Pythium may further cause seed decay and seedling death as severely infected plants commonly wilt and die. Symptoms of *Fusarium* spp. appear as small tan-red lesions on the lower hypocotyl and the entire root system that may coalesce resulting in a reddish brown necrosis (Hagedorn and Inglis, 1986; Abawi *et al.*, 2011). Fusarium root rot seldom kills plants whereas its aboveground symptoms are difficult to see however, they may first appear on lower leaves as a general yellowing and wilting and progress upward to the younger leaves (Allan, 1996).

2.3.8 Bean common mosaic viruses

Bean common mosaic viruses (BCMV) together with bean common mosaic necrosis virus (BCMNV) have a worldwide distribution and importance (Feng *et al.*, 2014). In Kenya, BCMV was first identified by Kulkarni (1973). Both mosaic and black root have been

reported in farmers' fields and in Phaseolus germ-plasm collections with incidence of as high as 100% coupled with yield losses of between 35-98% reported (Mangeni *et al.,* 2014).

Bean common mosaic virus and BCMNV belong to the genus Potyvirus of the family Potyviridae. These viruses usually occur in a complex of strains showing differences in virulence on common bean cultivars. Drijfhout (1978) described eight different BCMV and BCMNV pathogenicity groups based on host reactions and assigned all isolates to them (Miklas *et al*., 2015). Because of this grouping BCMV strains were categorized into groups ranging from PG I through to PG VII. These strains further fell into two different serotypes with serotype A consisting of NL3, NL5 and NL8 pathotype and serotype B having other non-necrotic inducing BCMV strains. Further grouping based on serological and symptomatic difference between the two groups resulted in Serotype A being renamed as the BCMNV (Mangeni *et al.,* 2014). All known genes for bean common mosaic diseases are correspondent to a particular pathotype within a pathogenicity group.

Bean common mosaic virus and BCMNV are closely related viral diseases that may induce similar symptoms (Flores-Estevez *et al.,* 2003). Bean common mosaic virus symptoms range from common mosaic symptoms accompanied by leaf malformations to death of the entire plant through vascular necrosis (Mangeni *et al.,* 2014). The type of symptom induced is influenced by whether the infection was seed borne or vector transmitted, genotype of cultivar, strain of the virus and growth stage of the plant at infection. Other common mosaic diseases symptoms include puckering, blistering, distortion, downward curling and rolling and a mild or severe green-on green mosaic mottle. Infection at a young stage may cause stunting and distortion. The dominant 'I' gene is known to overcome all other recorded BCMV strains. However, plants develop systemic lethal necrosis because of a hypersensitive response stimulated by BCMNV overcoming the resistance (Mangeni *et al.,* 2014).

The viruses are more destructive to the dry bean crop due to its longer vegetative cycle (Zitter and Provvidenti, 1984). Under typical growing temperatures of 26 to 28^{0}C, a severe mosaic, leaf curling, banding of the veins, mottling and pod malformation may appear while at elevated temperatures of above 30^{0}C systemic necrosis appears (Mavrič and Šuštar-Vozlič, 2004). Host susceptibility is an important factor for development of BCMV and BCMNV (Drijfhout, 1978). Poor nutrition of the host plant leads to more expression of symptoms while nutritional factors that favor plant growth also favor increased host susceptibility. These viruses are transmitted by seed and aphids (Feng *et al*., 2014), where aphids transmit them in a non-persistent manner (Zitter and Provvidenti, 1984).

2.4 Factors that affect development of diseases on common beans

2.4.1 Effect of temperature on disease development

The development of a disease is favoured by temperature that is optimum for pathogen development and is below or above the optimum for host development (e-Krishi, 2011; Juroszek and Tiedemann, 2011). Each pathogen has its optimum temperature for growth. For example, CBB development and spread is favoured by temperatures of between 28 to 32^{0}C whereas halo blight thrives under cool and humid conditions, with temperatures of between 18 to 22^{0}C (University of Illinois, 2000). Halo blight symptoms are severe between 18 to 23^{0}C as the pathogen produces chlorosis-inducing chemicals at this temperature (Allen, 1996). Different fungal growth stages, such as sporulation, germination and mycelial growth may also have slightly different optimum temperature (e-Krishi 2012). Anthracnose is favoured by temperatures of 13 to 26^{0}C with an optimum of 17^{0}C whereas bean rust dispersal and development is favored by temperatures of between 21 to 27^{0}C (Allen *et al.,* 1996; Mohammed, 2013). Effects of temperature may mask or alter the symptoms of certain viral diseases with the example of bean common mosaic virus where under typical growing

temperatures of 26 to 28^{0}C severe mosaic symptom may be observed. However, at temperatures above 30^{0}C, systemic necrosis appears (Mavrič and Šuštar-Vozlič, 2004).

2.4.2 Effect of moisture on disease development

Common bean performs best in moderate rainfall and does not tolerate highly humid environments as it causes high disease pressure (Food and Agricultural Organization, 2015) and other agronomic challenges**.** Moisture may exist in the environment in form of relative humidity and as dew or water on the surface of the plant or around the roots. Moisture facilitates the spread and development of almost all bacterial and fungal pathogens as it enables spore germination and host penetration by the germ tube, activation of pathogens before infection of the plant and as medium for the dissemination of the pathogens on the same plant or to other plants (e-Krishi, 2012).

Bean scab, angular leaf spot, rust and anthracnose development are all favoured by availability of moisture in the environment (Allen *et al.*, 1996). Bean scab and angular leaf spot development and establishment is favored by high relative humidity while dispersal and development of rust and spore formation and germination of anthracnose require high relative humidity of up to 92% and heavy dew (Allorent and Savary, 2005; Mohammed, 2013). Levels of disease resistance on dry bean genotypes may be increased with increased temperature and decreased soil moisture content as a result of the channeling of resources into the host's resistance mechanisms and increase in phenolic acid content in the cell cytoplasm, which hinder disease development (Sallam, 2011; Hailu, 2017).

The appearance of a disease in a certain region is sometimes associated with the seasonal rainfall amount and distribution. Moderate precipitation together with warm weather causes an increase in viral diseases as it favours the development and spread of possible pathogen vectors (Cadle-Davidson, 2005). High rainfall is associated with a reduction of vector

transmitted viral diseases as it negatively affects the mobility of the vectors (Kone *et al.,* 2017). Bacterial diseases favour seasons and environments that receive high rainfall (University of Illanois, 2000) while the occurrence of fungal diseases such as angular leaf spot in different agro-ecological zones in Western Kenya is influenced by environmental factors such as variation in seasonal rainfall (Mwang'ombe *et al.,* 2007).

2.4.3 Effect of soil characteristics on disease development

Differences between agro-ecological zones affect infection and disease development due to varying environmental factors such as soil types (Mwang'ombe *et al*, 2007). Soils vary in their structure, moisture content, pH and fertility while disease pressure fluctuates due to suitability of the pathogen to these variations. These interactions result in inconsistent pathogen responses across space and time. For example, disease resistance levels of the bean genotypes may be improved when temperatures increase and soil moisture content decreases because of deployment of resources into the host drought resistance mechanisms such as reduced stomata size (Hailu *et al*, 2017). A clear negative interaction between soil fertility and disease is often found (Schwartz *et al*., 1989) where by improving soil fertility results in a reduction in disease incidences (Buruchara *et al.,* 2010). In Western Kenya, soils are infertile due to the high amount of rainfall received in the area and a high population density over exploiting the available land (One Acre Fund, 2013). Effects of climate change and intense crop cultivation have also resulted in soil degradation, loss of soil fertility and increased pest and disease pressure.

2.4.4 Effect of wind on disease development

Fungi, bacteria and viruses occur in epidemic proportions and spread over large areas either by wind acting directly or indirectly through its influence on insect vectors (e-Krishi, 2012; Icishahayo, 2014). Bacterial diseases favour seasons and environments of high rainfall and

strong winds. Common bacterial blight development and spread is facilitated by spread of inoculum by windblown rain, soil and plant debris (University of Illinois, 2000; Karavina *et al.,* 2011). Fungal pathogens such as *Colletotrichum lindemuthianum* can be spread by wind (Kiryowa, 2016).

2.4.5 Effect of cropping practices on disease development

Cropping factors such as crop rotation, appropriate spacing and mulching affect disease occurrence and development (Icishahayo, 2014). Appropriate spacing of the bean crop stand makes the environment less conducive to the pathogen and use of mulching cushions the fall of raindrops preventing spread of the inoculum by splashing (Buruchara *et al.*, 2010). Most important common bean pathogens are primarily seed transmitted which facilitates their spread over long distances especially in Africa where most farmers save seeds from previous harvest for sowing in the next season (Bardas *et al.,* 2007).

Planting date can be adjusted to make the host escape the pathogen or reduces disease occurrence in the most susceptible host stages (Lourenço *et al.,* 2017). Time factor emphasizes the idea that disease onset and intensity are affected by the period that the susceptible host, virulent pathogen and right environment are aligned (Moore *et al.,* 2016). Planting date also affects disease development as diseases occur with varying intensities across the sowing dates due to variations in environmental conditions that affect pathogens and the host (Juroszek and Tiedemann, 2011). Early planting may result in reduction of vector transmitted viral diseases as it coincides with high rainfall that negatively affects the mobility of vectors (Kone *et al*., 2017). A disease may also be prevalent in late sowing dates due to its secondary spread and development (Phillips, 1994).

In Western Kenya, smallholder farmers mainly intercrop maize and beans to produce enough food on their small pieces of land (Tittonell *et al*. 2008; One acre Fund, 2013). Pure stand

cropping systems of beans have higher incidences of common bacterial blight, halo blight, anthracnose and scab compared to intercrops of maize and beans (Rheneen *et al*., 1981). Intercropping improves soil fertility and structure and suppresses weeds and diseases resulting in increased crop yields. This effect maybe because of creation of favourable habitat for predatory insects that control insect pests and disease vectors, increased distance between crops of the same species and reduced soil erosion due to better ground cover (Odhiambo and Ariga, 2001; Carlson, 2008).

2.4.6 Effect of host susceptibility on disease occurrence

The host is the bean cultivar itself and may be infected by many different diseases or only particular ones depending on its genetics. Without a susceptible host, the pathogen cannot cause any harm. Therefore, understanding the genetics of the cultivar and planting disease resistant forms prevent diseases. Genes conferring resistances to diseases such as CBB, BCMV, rust, and anthracnose have been identified (Allen *et al.,* 1996; Mangeni *et al.,* 2014). Groups of genotypes have been observed to perform differently when challenged against certain diseases. For example, small seeded genotypes such as red haricot show more resistance to bean scab compared to large seeded varieties and early maturing forms which all show high susceptibility to the pathogen (Mutitu, 1979).

It has also been observed that snap bean materials from the Mesoamerican gene pool show resistance to bean rust in parts of Kenya whereas those from the Andean gene pool are more susceptible (Arunga *et al.,* 2012). Genotypes that are mostly grown in Western Kenya such as KK 8, KK 22, KK 071, KK 072, Red 40, Cal 33, Red 13, Cal 194 and KK 16 have varying levels of tolerance to root rots (Kenya Plant Health Inspectorate Service, 2015; KALRO, 2016). KK 072, Glp 1127, KK 22, and Glp 585 have a wide adaptation resistance to BCMV. However, KK 072 and KK 22 have the dominant ‘I’ gene incorporated in them that result in a

hypersensitive necrosis reaction when they are exposed to BCMNV (Mangeni *et al.*, 2014**;** Kenya Plant Health Inspectorate Service, 2015; KALRO, 2016).

2.4.7 Effect of planting time on disease occurrence

Planting date affects disease development due to variations in environmental conditions that affect pathogens and the host. Variations in disease intensity across plantings could also be primarily due to altering micro- and macro-environmental conditions (Icishahayo, 2014; Mani *et al.*, 2017). Delay in planting date has been observed to facilitates the development of narrow brown leaf spot of rice caused by *Cercospora janseana* due to build up inoculum from earlier planted rice, as well as an increase in infection cycles (Mani *et al*., 2017). Weeds and early-planted crops could act as an inoculum source for a late-planted crop. Date of sowing has also been shown to affect the development of Roselle (*Hibiscus sabdariffa* L.) leaf spot disease caused by *Coniella musaiensis* Var. *hibisci* **(**Apeyuan *et al.*, 2017**)**. Time of sowing has been identified as an important agronomic practice affecting chickpea growth, productivity and incidence of fungal diseases (Fotiadis *et al.*, 2017).

2.5 Management of bean diseases

2.5.1. Cultural practices

For effective common bean disease management, taking preventive measures should be the first consideration (Juroszek and Tiedemann, 2011). Understanding the disease triangle and disease cycle concepts is vital in understanding how to manage a disease since interrupting one part of the cycle could arrest disease development (Nelson, 1994). Preventive strategies include minimizing the planting of susceptible varieties, planting disease free seeds early in the season when disease-transmitting vectors such as aphid pressure is low, destroying possible alternate hosts such as weeds or other legumes during farm preparation for sowing

and during growth of the bean crops (Buruchara *et al.*, 2010; Icishahayo, 2014). Bacterial infections such as CBB caused by *Xanthomonas campestris* pv. *phaseoli*, can occur in newly opened areas where certified seeds have been used indicating that some common weeds may be acting as reservoirs (Allen *et al.*, 1996). Fungal infection such as *Colletotrichum lindemuthianum* can be spread by wind, rain splash, and physical contact between plants and through seeds (Conner *et al.,* 2019). Use of clean treated and certified seeds will greatly reduce the occurrence of most diseases (Bastas and Sahin, 2016) but this strategy may be impractical in many parts of Africa where farmers save seeds from previous harvest (Icishahayo, 2014).

Good farm sanitation practices are also essential in minimizing the spread of diseases. Such practices aim at minimizing initial pathogen inoculum and minimizing the spread of bacteria between plants (Juroszek and Tiedemann, 2011). Plant residues play a role in bacteria survival while high rainfall and humidity also favour the disease (Öztürka and Aksoy, 2018). Plant residues can be managed by practicing good sanitation such as removal of remnant plant debris from the field after harvest then burning or burying them. Deep ploughing during land preparation can also cover the debris. Other sanitation measures include avoiding or limiting field activities when the leaves are wet and avoiding use of overhead irrigation techniques as water splash aid in pathogen spread. Seeds for planting must also be stored in clean facilities to prevent contamination (Buruchara *et al.,* 2010).

Other cultural methods for bean disease management include practicing crop rotation cycle with a non-host crop (Conner *et al.*, 2019), wide spacing of the bean crop stand to limit the environment being conducive to the pathogen and use of mulching to cushion the fall of rain drops and therefore prevent spread of the inoculum by splashing. Mulching also helps to avoid pod contact with the ground (Buruchara *et al.*, 2010). Post-harvest flooding of growing fields can suffocate pathogens such as *Sclerotium sclerotiorum* that causes white mold on

beans. Improving soil fertility by application of soil amendments like farm yard manure or even inorganic fertilizers while avoiding over application of nitrogen fertilizer helps to control diseases. Crops may be planted on raised ridges and incase of infection by Fusarium or Rhizoctonia root rots soil is hilled up around the stem to boost the re-growth of adventitious roots.

2.5.2. Host resistance

Planting disease resistant cultivars where available is the most effective way of preventing common bean diseases in which genes for resistance have been identified. This is important since small-scale African farmers do not regularly adopt other disease management measures (Icishahayo, 2014). Diseases with known resistances include angular leaf spot (Rezene *et al*., 2018), anthracnose (Kiryowa *et al*., 2016), rust (Arunga *et al*., 2012), common bacterial blight and the bean common mosaic diseases (Mangeni *et al.,* 2014). Although genes for diseases such as anthracnose and rust been identified, their utilization is complicated by the pathogens many physiological races (Nyang'au *et al*., 2016). The most effective and practical method of controlling bean common mosaic virus is known to be the use of resistant cultivars. BCMV is seed transmitted in susceptible cultivars but is not carried in seed of bean genotypes possessing hypersensitive resistance conferred by the dominant 'I' gene (Mangeni *et al.,* 2014). Possession of the 'I' gene causes vulnerability to black root thus the best control strategy is to use genotypes with the single bc-3 gene or a combination of the 'I' gene with the bc-22 gene which is recessive (Mangeni *et al.*, 2014).

2.5.3. Use of chemicals

Treatments of beans with copper and the systemic azoxystrobin can give the best results in controlling epi- and endophytic fungal pathogen communities (Prior *et al*., 2017). Chemicals such as micronized basicop and streptomycin can be applied for curative management of

bacterial diseases such as common bacterial blight while spraying the crop with either a protectant or systemic fungicide such as Kocide can be a curative method of managing bean anthracnose (Buruchara *et al.*, 2010). In addition to curative application, chemicals such as thiram, ziram, arsan and cerasan can be used preventively by application on the seed coat (Buruchara *et al.*, 2010).

2.5.4. Integrated pest and disease management practices

Crops should be monitored for early signs of disease to prevent potential problems and safeguard the harvest. Integrated pest and disease management (IPDM) is a combination of disease control strategies that offers a holistic approach to disease management compared to single control strategies. Such strategies may involve integrating pesticide use with use of resistant cultivars and cultural disease management practices that in turn minimize pesticide use while utilizing the complimentary positive effects of other management practices (Buruchara *et al.*, 2010).

2.6 Interactions between genotypes and the environment

Genotype by environment interactions (GxE) can be defined as the failure of genotypes to perform consistently across different environments (Baker, 1988; Hardner, 2017). These interactions result in variations in genotypic responses to external environmental factors such as temperature and soil characteristics such as their type, fertility level and moisture content from place to place and time to time. A certain cultivar may fail to show similar phenotypic characteristics in different environments resulting in variability in crop yields due to suitability of variety to specific growing seasons or conditions while different genotypes may also respond differently to a specific environment due to GXE effect (Khan and Tyagi, 2010).

To identify superior genotypes for target regions, plant-breeding programs routinely carry out multiple-environment trials. These trials facilitate the subdivision of the regions into different mega-environments that in turn helps in the allocation of resources for a breeding program, allow for precise genotype distribution to appropriate environments and aid in information exchanges amongst breeding programs (Coffman *et al*., 1983; Laghari *et al*., 2015). Only genotype x location (GxL) interaction, rather than all kinds of GxE interactions, is useful for showing adaptation patterns as it is the only interaction that can be exploited for selecting for specific adaptations and by growing specifically adapted genotypes (Food and Agriculture Organization, 2015).

2.7 Yield stability and reliability

A genotype with high yield stability will have the capacity to yield consistently, either at high or low levels, across a wide range of environments. Most stability measures are linked to two contrasting concepts of stability (Food and Agriculture Organization, 2015), i.e. static stability also called type 1 stability and dynamic or type 2 stability. In static stability, a cultivar tends to sustain a constant yield across environments, that is, greater environmental sensitivity of a genotype would translate to low yield stability. Dynamic stability concept on the other hand depends on the performance of a genotype in a specific set of tested genotypes so that a variety is said to be stable if its mean response in each test environment is always parallel to the mean response of the tested genotypes, that is, shows zero GE interaction.

Lin and Binns (1991) mention a Type 4 concept of stability that is closely related to the static stability concept but emphasizes yield consistency exclusively in time, that is, across crop cycles within locations. Static concept relates to consistency across time and space. Breeding for high yield stability is useful when the relevant GxE interaction variation is wide. GxE and GxL effects that contribute to yield stability can be exploited through breeding and growing

genotypes that show better response in unfavorable environments as in static stability concept. Effects of GxE/GxL interaction can be minimized by using materials that are stable according to the concept of dynamic stability. Ideally, a selected or recommended genotype should give stable yields across both location and time/crop cycle (Piepho, 1998).

A highly stable genotype may show low mean yield whereas a low stable genotype may have high mean yield consequently complicating variety selection and recommendation. Yield reliability concept developed because of the practical need of combining high mean yield levels and stability. A reliable variety would therefore be that which gives consistently high yield across variable environments (Food and Agriculture Organization, 2015).

CHAPTER THREE

EFFECT OF THE ENVIRONMENT ON DISEASE INTENSITY ON COMMON BEAN GENOTYPES IN WESTERN KENYA

3.1 Abstract

Dry bean farming in Western Kenya faces challenges of diseases and limited information on adaptability of bean varieties to different environments. This study assessed the effect of environment on fungal, bacterial and viral disease pressure on common beans. Eighteen bean varieties were planted in upper-midland zone 1 and upper-midland zone 3-4 in Kakamega County and upper-midland zone 2, upper-midland zone 4 and lower-midland zone 2 in Bungoma County in the short rains of 2016 and the long rains of 2017. Natural infection of the genotypes by diseases was allowed to occur. Disease severity, disease intensity, yield, seed weight and data on seed damage were collected and subjected to combined analysis of variance with differences between treatments compared at $p \leq 0.05$.

The environment had an effect on both disease and yield of the genotypes as they generally performed significantly ($p \leq 0.05$) different to each other in both seasons. Genotypes planted in agro-ecological zone UM 1 had the highest overall disease pressure with 44.7 and 51.8% for rust and scab respectively both in the short rain season. The genotypes reacted variably to disease pressure with Red 16 generally having the least disease pressures of as low as 16.7% for most diseases. Genotypes in agro-ecological zone UM 1 were significantly ($p \leq 0.05$) the best performing with a maximum yield of 1.9 and 1.5 t/ha in the long and short rains respectively with Red 16 leading with yields of 2.2 and 1.3 t/ha in the long and short rain seasons respectively. This study showed that disease intensity has an important role on the performance of varieties within an environment.

3.2 Introduction

Common bean provides a food rich in proteins as well as iron and zinc. Beans also have the ability to improve soil fertility through nitrogen fixation (Chirwa *et al*., 2011).The common bean is a highly variable crop having over 40,000 varieties worldwide with varying growth habits, phenotypic characteristics, stress tolerance and other adaptations (Jones, 1999). Beans are notoriously susceptible to pathogens resulting in wide fluctuation in yields (Corrales, 2006). In Western Kenya, an area characterized by resource constrained bean cultivation practices, productivity is still at less than 25% of potential yields due to a combination of stress factors including diseases (Katungi *et al.*, 2011).

Despite concerted efforts to manage them, common bean diseases are still on the increase due to a limited number of released bean varieties with multiple disease resistance, inoculum build-up due to growing of susceptible varieties in fragile environments and limited information on adaptability of available varieties to different environments hindering adoption. Understanding the interaction of the environments with the genotypes in relation to diseases is important for the development of bean varieties (Fininsa and Tefera, 2006).

It is important to develop genotypes with wide adaptation to environments and climatic conditions to protect farmers across varied locations (Fininsa and Tefera, 2006). A large number of released bean varieties need to be disseminated over time to increase the chances of a farmer finding the right balance between yield stability and productivity (CGIAR, 2012) mitigating changes in the climate. Information on the adaptability of available bean varieties to diseases over different environment is lacking. Therefore, the objective of this study was to determine the effect of environment on disease incidence and severity of bean genotypes grown in Western Kenya.

3.3 Material and Methods

3.3.1 Description of the study area

The study was conducted in the main bean growing agro-ecological zones (AEZ) of Western Kenya as advised by KALRO-Kakamega grain legume research office, during the short rains of 2016 and the long rains of 2017. Smallholder farms were selected based on their location in the selected AEZs, history of growing beans and past interactions with KALRO-Kakamega. The farms were spaced at a distance of 2 to 5 kms between them in Upper Midland zone (UM) 2 and UM 3-4 in Kakamega County and UM 2, UM 4 and Lower Midland zone (LM 2) in Bungoma County. A sixth AEZ was picked from a transitional zone between UM 1 and UM 2 and named UM 2-T. Three farms were selected in each zone as replicates (Table 3.1).

Table 3. 1: Characteristics of different agro-ecological zones used for this study in Western Kenya during the 2016 short rains and 2017 long rains.

Agro-ecological zone	Area name	Altitude	Annual Mean Temperature	Annual Mean Rainfall
UM 1	Kakamega	1550m	20 (27Max-13Min)	2019-1820mm
UM 4	Tongaren	1500-1900m	21-18.9^{0}C	1000-1600mm
UM 2	Chwele	1500-1900m	21-18.8^{0}C	1425-1230mm
LM 2	Kibabii	1200-1350m	22-20.9^{0}C	1350-1550mm
UM 3-4	Lugari	1500-1900m	21-18.9^{0}C	1375-1220mm
UM 2-T	Mukuyuni	Area occurs in transition between agro-ecological zones UM 1 and UM 2		

UM= Upper Midland Zone , LM= Lower Midland zone; M= Meters above sea level; mm =milliliters; C=Degrees Celsius, T= Transition zone

Source: Jaetzold *et al*., 2005

3.3.2 Experimental Materials

Eighteen common bean varieties recommended by KALRO-Kakamega bean research office as mainly grown by farmers in Western Kenya were used in the study (Table 3.2). The seeds were obtained from KALRO Kakamega grain legume research office.

Table 3.2: Characteristics of bean genotypes used in the study.

Variety name/ Code	Year of release	Breeder	Optimal production alt. range (Masl)	Maturity Time (months)	Yield (t/ha-1)	Special attributes
KAT-Bean 9	1998	KARI	900-1600	2.5-3	1-1.8	Heat Tolerant
KAT X56	1995	KARI	900-1800	2.5-3	1.5-1.8	High yielding
GLP x92	1982	KARI/KSC	900-1600	2 to 3	1.2- 1.5	Drought tolerant
KK 15	1997	KARI	1500-1800	2.5 – 3	1.8-2	BRR Tolerant
GLP-X1127	1982	KARI/KSC	1000-1500	2.5 – 3	1 - 1.5	Wide adaptation Resistant to BCMV. Rust Tolerant
KK 22 (RWR719)	1996	KARI	1500-1800	2.5 – 3	1.8-2	BRR Tolerant
KK 8 (SCAM-80/15)	1997	KARI	1500-1801	2.5 – 3	1.8-2	BRR Tolerant
Chelalang	2008	Edgerton University	1800-2200	2.5 – 3.5	1.2 – 2.2	
Tasha	2008	Edgerton University	1500-2000	2.5 – 3.5	1.1 – 2.1	
KK071	NA	KALRO KK	Above 1500	3	1.5-1.8	BRR Resistant
KK072	NA	KALRO KK	Above 1500	3	1.6-1.8	BRR Resistant
RED 40	NA	KALRO KK	1200-1500	2.5	1.2-1.6	BRR Resistant
CAL 33	DUS 2015	KALRO KK	Above 1500	3	1.8-2.0	BRR Resistant
GLP 2 Rosecoco	1982	KARI/KSC	1500-2000	2 – 3	1.8-2	High yielding, wide adaptation,
RED 13	DUS 2015	KALRO KK	Above 1500	3	1.6-1.8	BRR Resistant
KK 16	2015	KALRO KK	Medium & high altitude	2.5	1.8 - 2.0	BRR and ALS Resistant
Cal 194	2015	KALRO	Medium & high altitude	2.5	1.8 - 2.0	BRR and ALS Resistant
GLP-585 Red haricot	1982	KARI	1500-2000	2.5 – 3	1 - 1.5	Suitable for high rainfall areas Resistant to BCMV

Masl=Meters above sea level; t/ha=tons per hectare; KAT=Katumani, KK= Kakamega, GLP=Global Legume program; KARI= Kenya Agricultural Research Institute, Kenya Agricultural and Livestock Research Organization, KSC= Kenya Seed Company; BRR= Bean root rot, BCMV= Bean Common Mosaic virus, ALS= angular leaf spot.

Source: Kenya Plant Health Inspectorate Service (2015) and KALRO (2016).

3.3.3 Experimental design

Eighteen common bean genotypes described in Table 2 were planted in agro-ecological zones UM 1, UM 2, UM 4 and LM 2 at the onset of the short rain season in September 2016; and in UM 1, UM 2-T, UM 2, UM 3-4, UM 4 and LM 2 at the onset of the long rain season in March 2017. Each genotype was planted in four rows of three meter long with 50 x 10 cm spacing between plants for a 1.5 x 3 m plot size. The genotype plots were spaces at 0.5 m between them giving blocks of eighteen genotypes that were folded in half to reduce length thereby reducing error and increasing uniformity. The folding gave nine plots on each side of the block resulting in a 14 x 6.5 m block size. The layout was a randomized complete block design with three replications and each replication was an individual farm giving three farms per AEZ.

Clean seed from the KALRO Kakamega bean laboratory was planted with no fertilizer. A single application of di-ammonium phosphate fertilizer was administered at the rate of 200 kg ha^{-1} immediately after emergence. Plots were sprayed with Karate pesticide once after emergence of the hypocotyl and the second time during primary leaf formation stage to control bean fly. The fields were manually weeded by hand to reduce weed competition. Data collected from the plots include emergence, disease incidence, disease distribution, disease severity, stand count at harvest, plot yield weight, seed weight and seed damage.

3.3.4 Assessment of disease intensity

Assessment of diseases took place from four weeks after germination at the vegetative, flowering and pod filling growth stages. Diseases were identified based on symptoms following preliminary identification studies conducted at the KALRO-Kakamega research station. Reaction of the genotypes to fungal and bacterial diseases was determined by recording data on disease incidence, distribution and severity. Disease distribution was

assessed on a scale of 0 - 2, where 0 = no disease, 1 = spots, 2 = scattered distribution. Incidence was determined by counting the number of plants showing symptoms and expressing it over the total number of plants in the plot. Disease severity was assessed as using a 0 to 3 scale (Mbugua, 2016) where 0 = no disease in the case where disease fails to occur in the environment, 1 = resistant, 2 = tolerant and 3 = susceptible. Disease intensity calculated by summing up the scores of distribution, incidence and severity and converting it to a percentage using the formula used by Muthomi *et al.*, (2017) which was modified from McKinney (1923).

$$\text{Diseases Intensity} = \frac{\text{Incidence} + \text{Severity} + \text{Distribution}}{\text{Max IS} + \text{Max SS} + \text{Max DS}} \text{ X } 100$$

Where Max IS = Maximum incidence score, Max SS =maximum severity score and Max DS = maximum distribution score.

For viruses, only disease incidence data was collected as a score of one was given for the presence of a symptom on a plant and a score of 0 for the absence of the symptom (Chilagane *et al.,* 2013). The number of plants with a score of one in a plot were summed up and converted to a percentage of the total number of plants in the plot.

3.3.5 Assessment of grain yield and yield components

The genotypes were harvested at 50% physiological maturity and sun dried on station before being threshed manually. Yield data collected include plot yield weight, 100 seed weight and the percentage of damaged seed. The dry weight of seeds harvested in the net plot was recorded as grain yield weight and extrapolated to yield in kg ha^{-1} at 12 % moisture content as follows (Food and Agriculture Organization, 1995);

$$\text{Grain yield (kg/ha)} = \frac{\text{Plot yield(Kgs X 1000)}}{\text{Plot size in Meters}}$$

Seed weight was determined by hand picking 100 clean and uniform seeds from each plot harvest and weighing them in grams. For seed damage, wrinkled, shriveled and discolored seeds were removed through hand sorting from seeds weighed for grain yield retaining only 'quality' seeds based on market requirements, as advised by farmers. The weight of the 'quality' seed was then subtracted from the grain yield weight and the difference converted to a percentage.

3.3.6 Data Analysis

Quantitative data collected in this experiment was subjected to analysis of variance (ANOVA) using the Genstat statistical software. Variances among the genotypic means as well as between treatments were compared at LSD test of 5% probability level. Genotype by environment interactions (GxE) and effects and stability analysis were carried out using the CIMMYT GEA-R (Genotype X Environment Analysis with R for Windows) software (Pacheco *et al*., 2016). For GxE, an Additive main effect and multiplicative interaction analysis (AMMI) model was used. The model separated the additive variance from the multiplicative variance and then applied principal component analysis in comparing genotypes and environments generating figures presented in the result section (Pacheco *et al*., 2016).

3.4 Results

3.4.1 Diseases affecting beans in different agro-ecological zones

In this study, more symptoms were observed in the long rains compared to the short rain season. A higher number of diseases were observed in the upper lying agro-ecological zones UM 1 and UM 2 compared to the lower lying agro-ecological zones UM 4 and LM 2

(Appendix I). The fungal, bacterial and viral disease symptoms observed on bean genotypes in this study are shown in Figure 3.1, Figure 3.2 and Figure 3.3 respectively.

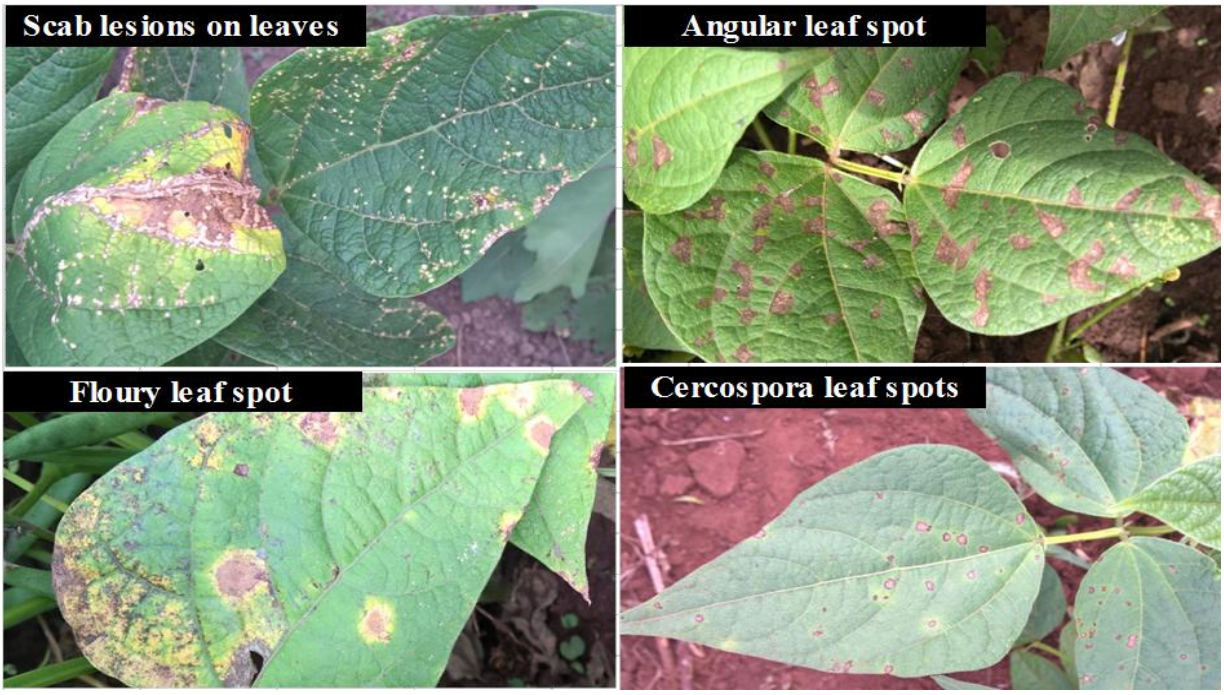


Figure 3.1: Fungal disease symptoms observed in the environments

Figure 3. 2:Bacterial disease symptoms observed in the environments

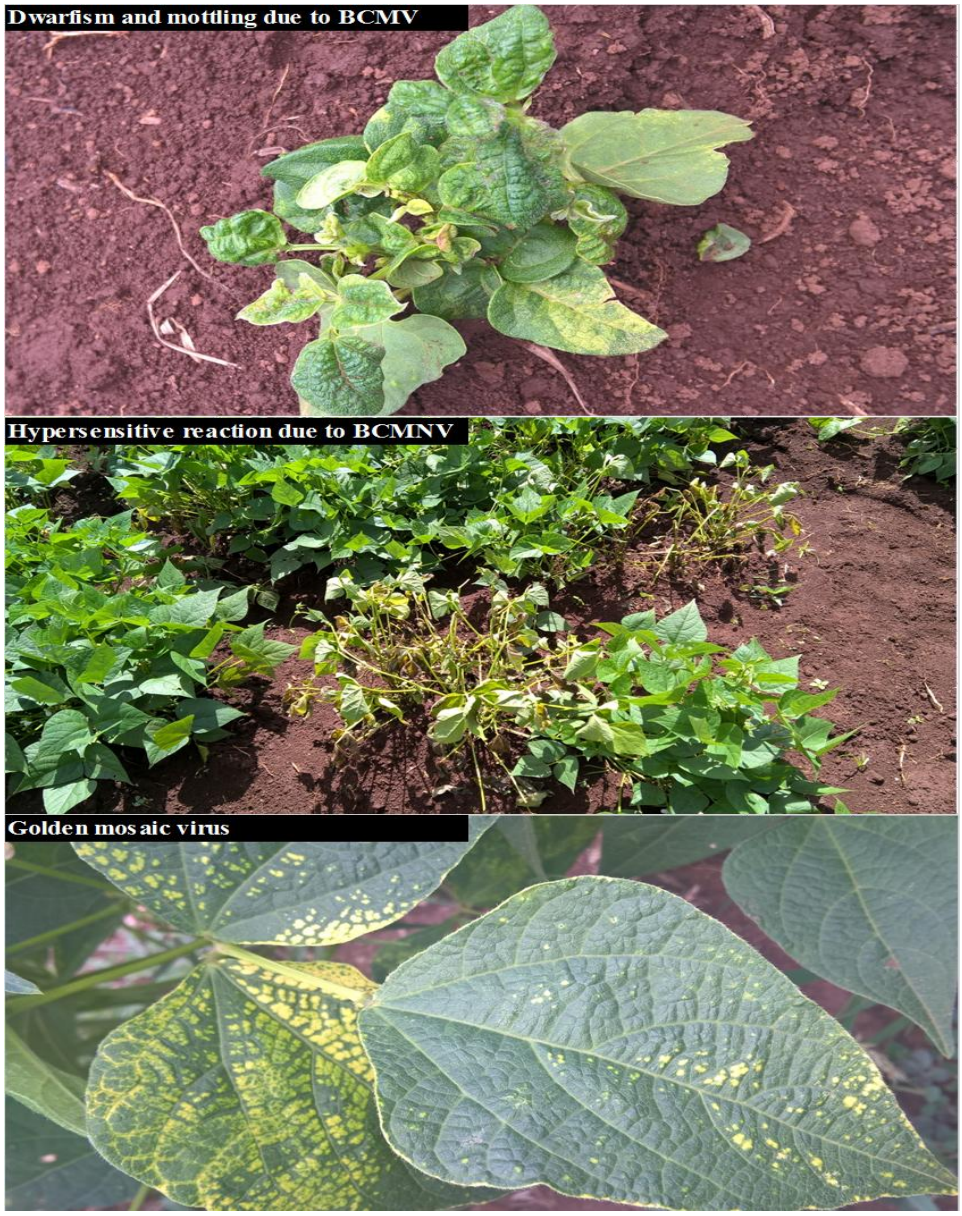


Figure 3. 3: Viral disease symptoms observed from the environments

3.4.2 Bacterial diseases observed in different agro-ecological zones

Bacterial diseases observed were common bacterial blight (*X. axonopodis* pv. *phaseoli*), halo blight (*P. savastanoi* pv. *phaseolicola*) and bacterial brown spot (*P. syringae* pv. *syringae*). Both the genotypes and the environments showed significant ($p \leq 0.05$) variations in their CBB intensity during the long and short rain seasons. In the long rains, both crops in the upper and lower lying agro-ecological zones had high disease intensities with agro-ecological zone UM 2 crops having the highest overall intensity of up to 35.2% while agro-ecological

zone UM 3-4 crops were the best performing with average CBB intensity of 18.0% (Table 3.3). The worst performing genotype was variety GLP 585 with the highest overall disease intensity of 41.9% while variety Red 16 was the best with the lowest overall CBB intensity of 18.7% (Table 3.3). In the short rains, genotypes in agro-ecological zone UM 4 had the highest overall CBB intensity of 38.5% whereas agro-ecological zone UM 1 was the best performing environment with overall CBB intensity of 24.5% in the crops. The highest CBB intensity was on variety Chelalang with 53.8% in agro-ecological zone UM 2 while variety Cal 194 had the lowest overall intensity with 16.7% (Table 3.4).

The genotypes had significantly ($p \leq 0.05$) different halo blight intensities across crops established in the six long rain environments in long rain season. The highest intensity was in crops in the upper lying agro-ecological zone UM 1 which had a score of 28.4% while the lower lying agro-ecological zone LM 2 crop was the best performing with mean halo blight intensity of 17.3% (Table 3.5). The worst performing genotype across the environments was variety KAT x56 with an overall disease level of 33.9% while the best performing were varieties KK 15, KK 22 and Red 16 with diseases levels of as low as 16.7% (Table 3.5). During the short rain season, halo blight pressure was low with no significant ($p \geq 0.05$) differences between the environments or the genotypes therefore data for this season was not tabulated.

Bacterial brown spot symptoms were observed only in crops in the upper lying agro-ecological zones UM 1 and UM 2 during the long rain season with no significant ($p \geq 0.05$) difference between the two environments. Only genotypes in agro-ecological zone UM 1 had significantly ($p \leq 0.05$) different brown spot intensities with variety Kat B9 having the highest overall disease intensity in this season with 65.0%. Since the rest of the environments had relatively low levels of the disease and no significant ($p \geq 0.05$) differences between the genotypes, bacterial brown spot data for this season was not tabulated.

Table 3.3: Percentage intensity of common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*) on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone						Mean
	UM 1	UM 2-T	UM 2	UM3-4	UM 4	LM 2	
GLP 585	67.8	28.8	47.2	16.7	53.7	37.0	41.9
Chelalang	63.9	34.1	35.1	16.7	39.9	54.6	40.7
KK 15	45.3	35.1	51.6	28.3	16.7	46.8	37.3
GLP 1127	69.5	33.7	51.1	16.7	16.7	34.0	36.9
KK 072	39.6	47.1	47.2	16.7	35.7	34.5	36.8
Cal 33	39.5	28.9	57.2	16.7	51.0	16.7	35.0
KAT X56	22.4	16.7	55.6	16.7	28.2	34.3	29.0
KK 071	28.3	40.0	35.1	16.7	22.4	28.3	28.5
Red 40	28.1	34.2	45.8	16.7	28.7	16.7	28.4
GLP X92	33.9	16.7	45.2	16.7	33.8	23.6	28.3
Tasha	16.7	16.7	16.7	28.2	34.2	40.5	25.5
KAT B9	45.8	16.7	22.4	16.7	16.7	34.3	25.4
KK 8	22.5	16.7	33.8	16.7	16.7	34.1	23.4
KK 22	29.6	16.7	16.7	16.7	16.7	33.8	21.7
Red 13	16.7	16.7	16.7	16.7	16.7	40.9	20.7
GLP 2	16.7	16.7	16.7	16.7	34.2	16.7	19.6
Cal 194	16.7	16.7	22.4	16.7	28.3	16.7	19.6
Red 16	16.7	16.7	16.7	16.7	29.1	16.7	18.7
Mean	34.1	24.9	35.2	18.0	28.8	31.1	28.7
CV%	65.2	66.6	55	37.8	74.6	64.9	65.5
$LSD_{(p \leq 0.05)}G$	37.2	27.6	32.1	11.3	35.7	33.5	12.37
$LSD_{(p \leq 0.05)}$ E	7.1						
$LSD_{(p \leq 0.05)}I$	30.3						

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

Table 3.4**:** Percentage intensity of common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*) on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone			Mean
	UM 1	UM 2	UM 4	
KK 22	52.1	*	*	52.1
GLP 585	42.0	39.9	52.4	44.7
Chelalang	28.4	53.8	46.0	42.7
GLP 1127	41.7	34.3	51.6	42.5
Red 40	29.6	28.4	51.3	36.4
KK 072	28.7	34.1	45.9	36.2
KK 15	16.7	34.8	52.5	34.6
Red 13	16.7	27.9	52.3	32.3
Cal 33	16.7	33.6	39.4	29.9
KK 071	16.7	39.5	28.6	28.3
KAT B9	28.9	28.3	22.3	26.5
Red 16	16.7	22.3	39.3	26.1
GLP X92	16.7	16.7	39.3	24.2
KK 8	16.7	22.3	28.4	22.5
KAT x56	22.5	28.2	16.7	22.4
GLP 2	16.7	28.1	16.7	20.5
Tasha	16.7	16.7	28.0	20.5
Cal 194	16.7	16.7	16.7	16.7
Mean	24.5	31.3	38.5	31.4
CV%	48.1	53.8	31.0	43.3
$LSD_{(p \leq 0.05)}G$	19.5	26.6	19.0	12.7
$LSD_{(p \leq 0.05)}$ E	5.19			
$LSD_{(p \leq 0.05)}I$	22.35			

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype; E=Environment; I= Genotype by Environment Interaction; *=Missing data.

Table 3.5: Percentage intensity of halo blight (*Pseudomonas savastanoi* pv. *phaseolicola*) on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone						Mean
	UM 1	UM2-T	UM2	UM3-4	UM 4	LM 2	
KAT x56	40.9	28.4	34.2	48.8	34.3	16.7	33.9
KK 071	44.3	16.7	40.0	36.9	28.7	16.7	30.5
GLP 2	35.5	16.7	41.1	16.7	28.1	16.7	25.8
Cal 194	22.4	28.1	16.7	37.8	16.7	28.7	25.1
KAT B9	50.8	16.7	16.7	16.7	28.3	16.7	24.3
Red 40	35.0	16.7	28.1	16.7	16.7	16.7	21.6
Tasha	28.2	25.2	16.7	25.3	16.7	16.7	21.5
KK 8	40.5	16.7	16.7	16.7	16.7	16.7	20.6
GLP 585	28.3	16.7	16.7	28.1	16.7	16.7	20.5
GLP x92	16.7	16.7	38.2	16.7	16.7	16.7	20.3
Chelalang	16.7	22.5	16.7	25.2	16.7	16.7	19.1
GLP 1127	29.0	16.7	16.7	16.7	16.7	16.7	18.7
Cal 33	28.3	16.7	16.7	16.7	16.7	16.7	18.6
KK 072	28.0	16.7	16.7	16.7	16.7	16.7	18.6
Red 13	16.7	22.5	16.7	16.7	16.7	16.7	17.6
KK 15	16.7	16.7	16.7	16.7	16.7	16.7	16.7
KK 22	16.7	16.7	16.7	16.7	16.7	16.7	16.7
RED 16	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Mean	28.4	19.1	22.1	22.3	19.6	17.3	21.5
CV%	71.8	43.0	82.8	65.6	51.0	28.4	67.4
$LSD_{(p \leq 0.05)}G$	33.8	13.6	30.4	24.3	16.6	8.2	9.5
$LSD_{(p \leq 0.05)}$ E	5.5						
$LSD_{(p \leq 0.05)}I$	67.4						

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

3.4.3 Fungal diseases observed in different agro-ecological zones

Fungal diseases observed include anthracnose (*C. lindemuthianum*), scab (*E. phaseoli*), angular leaf spot (*P. griseola*), rust (*U. appendiculatus*), floury leaf spot (*M. phaseoli*) and

Cercospora leaf spots. The environments showed significant ($p \leq 0.05$) variations in anthracnose symptoms during the long rains. However, anthracnose only appeared on seven genotypes across three environments (Table 3.6). Only genotypes in agro-ecological zones UM 2 and UM 3-4 crops showed significant differences ($p \leq 0.05$) in their anthracnose intensities with variety Red 13 having the highest disease level in the season with 57.2% in agro-ecological zone UM 2 (Table 3.6).

The genotypes had no significant ($p \geq 0.05$) differences in their bean scab intensity across the long rain environments. The highest scab intensity occurred in crops in relatively higher lying agro-ecological zones with up to 27.0% in crops in agro-ecological zone UM 2-T while crops in the lower lying zones had the best performances against the disease with an intensity of as low as 17.3% in genotypes in agro-ecological zone UM 3-4 (Table 3.7). Only genotypes within agro-ecological zones UM 2-T and UM 3-4 had significant ($p \leq 0.05$) variations in their bean scab intensity with variety GLP 2 intensity of 56.4% observed in agro-ecological zone UM 2-T being the highest in the season. The genotypes had significant ($p \leq 0.05$) differences in their scab intensity in the short rain season with their highest mean intensity found in genotypes in the upper lying agro-ecological zone UM 1 with 51.8% while genotypes in agro-ecological zone UM 2 had the lowest mean disease pressure with 44.9%. The worst performing genotype across the environments was KK 071 with an overall disease intensity of 64.1%, whereas variety KK 22 was the best performing with 12.7% (Table 3.8).

There was relatively low angular leaf spot pressure in the long rain season with no significant differences between treatments therefore the results are not tabulated. In the short rain season, ALS appeared with significant ($p \leq 0.05$) differences in both the environments and the genotypes (Table 3.9). The highest ALS intensity was in crop planted in high lying agro-ecological zone UM 2 with 37.2% whereas lower lying UM 4 crop had the lowest overall ALS intensity of 19.4%. The worst performing genotype across the environments was KAT

B9 with overall diseases level of 46.3% whereas variety Chelalang was the best performing with an overall ALS intensity of 16.7% (Table 3.9). Both the genotypes and the environments showed significant ($p \leq 0.05$) differences in their rust intensity during the short rain season (Table 3.10) while the disease did not appear in the long rains. The highest rust pressure of up to 44.7% occurred in the high lying agro-ecological zone UM 1 crop in the long rains while the lower lying agro-ecological zone UM 4 crop was overall the best performing with rust intensity of as low as 21.6%. The worst performing genotype across the environments was variety KK 15 with overall diseases level of 61.8% whereas varieties Cal 194 and Red 13 were the best performers with 16.7% (Table 3.10).

Table 3.6: Percentage intensity of bean anthracnose (*Colletotrichum lindemuthianum*) on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone		
	UM 2	UM 1	UM 3-4
Red 13	57.2	16.7	16.7
Chelalang	28.3	16.7	39.0
KK 071	34.4	16.7	16.7
Red 40	33.8	16.7	16.7
KK 15	16.7	29.2	16.7
Red 16	28.7	16.7	16.7
KK 8	16.7	28.0	16.7
Tasha	28.1	16.7	16.7
Mean	22.8	18.0	18.0
CV%	66.2	37.1	50.8
$LSD_{(P \leq 0.05)}G$	25.1	11.1	15.1
$LSD_{(P \leq 0.05)}$ E	3.0		
$LSD_{(P \leq 0.05)}I$	12.7		

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

Table 3.7: Percentage intensity of bean scab (*Elsinoë phaseoli*) on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone					Mean
	UM1	UM2-T	UM2	UM3-4	UM4	
GLP 2	34.1	56.4	45.6	16.7	16.7	28.2
Red 16	47.7	45.5	16.7	16.7	16.7	23.9
Chelalang	16.7	51.7	40.0	16.7	16.7	23.6
KK 071	16.7	34.2	33.9	16.7	16.7	19.7
KAT x56	51.0	16.7	16.7	16.7	16.7	19.6
KK 072	16.7	34.7	16.7	16.7	28.0	18.8
GLP 585	28.5	16.7	34.1	16.7	16.7	18.8
Red 40	45.3	16.7	16.7	16.7	16.7	18.7
GLP 1127	16.7	34.8	16.7	16.7	22.5	17.9
Red 13	16.7	28.3	16.7	28.0	16.7	17.7
Tasha	34.4	16.7	16.7	16.7	16.7	16.9
Cal 194	16.7	34.0	16.7	16.7	16.7	16.8
Cal 33	16.7	16.7	34.0	16.7	16.7	16.8
KK 15	29.2	16.7	16.7	16.7	16.7	16.0
GLP x92	28.3	16.7	16.7	16.7	16.7	15.8
KAT B9	16.7	16.7	16.7	16.7	16.7	13.9
KK 22	16.7	16.7	16.7	16.7	16.7	13.9
KK 8	16.7	16.7	16.7	16.7	16.7	13.9
Mean	25.9	27.0	22.5	17.3	17.6	18.4
CV%	69.9	73.2	65.4	26.8	29.7	69.7
$LSD_{(P \leq 0.05)}G$	30.0	32.8	24.4	7.7	8.7	8.4
$LSD_{(P \leq 0.05)}$ E	4.86					
$LSD_{(P \leq 0.05)}I$	20.26					

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

Table 3.8: Percentage intensity of bean scab (*Elsinoë phaseoli*) on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone			Mean
	UM 1	UM 2	UM 4	
KK 071	66.0	74.4	51.9	64.1
Red 16	67.0	68.6	51.6	62.4
KK 072	73.0	55.0	58.1	62.0
Red 13	70.0	61.6	52.0	61.2
KK 8	73.4	56.0	52.8	60.7
Red 40	68.6	61.2	52.1	60.6
GLP 2	61.5	49.3	58.5	56.4
KAT x56	56.7	55.0	56.5	56.1
GLP 1127	63.1	53.3	51.0	55.8
Cal 194	58.1	47.8	51.6	52.5
Chelalang	74.2	28.1	55.1	52.5
Cal 33	55.8	46.5	51.1	51.1
Tasha	33.7	42.6	64.9	47.1
KAT B9	44.8	28.6	42.5	38.7
GLP x92	16.7	35.7	16.7	23.0
GLP 585	16.7	16.7	22.3	18.5
KK 15	16.7	16.7	22.2	18.5
KK 22	16.7	*	*	*
Mean	51.8	44.9	45.7	47.4
CV%	20.9	30.7	16.1	25.8
$LSD_{(P \leq 0.05)}G$	17.96	23.96	12.76	11.43
$LSD_{(P \leq 0.05)}$ E	48.68			
$LSD_{(P \leq 0.05)}I$	19.8			

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype; E=Environment; I= Genotype by Environment Interaction; *=Missing data.

Table 3.9: Percentage intensity of angular leaf spot (*Pseudocercospora griseola*) on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone			Mean
	UM 1	UM 2	UM 4	
KAT B9	58.7	63.7	16.7	46.3
GLP X92	28.4	51.8	30.2	36.8
KAT X56	30.2	49.8	16.7	32.2
KK 15	16.7	35.2	44.6	32.2
KK 071	30.6	40.5	16.7	29.3
GLP 1127	41.3	28.6	16.7	28.8
Cal 33	16.7	51.9	16.7	28.4
GLP 585	16.7	39.8	28.3	28.3
Cal 194	16.7	40.3	16.7	24.5
GLP 2	16.7	40.1	16.7	24.5
KK 072	16.7	40.0	16.7	24.5
Red 13	16.7	40.0	16.7	24.5
Red 40	16.7	34.1	16.7	22.5
KK 8	16.7	34.0	16.7	22.4
Tasha	28.9	16.7	16.7	20.8
KK22	16.7	*	*	*
Red 16	22.3	16.7	16.7	18.5
Chelalang	16.7	16.7	16.7	16.7
Mean	23.5	37.2	19.4	26.7
CV%	50.6	53.8	49.3	54.0
$LSD_{(P \leq 0.05)}G$	19.77	33.66	16.23	13.49
$LSD_{(P \leq 0.05)}$ E	5.51			
$LSD_{(P \leq 0.05)}I$	23.37			

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction; *=Missing data.

Table 3.10: Percentage intensity of bean leaf rust (*Uromyces appendiculatus*) on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone			Mean
	UM 1	UM 2	UM 4	
KK 15	62.4	74.4	48.6	61.8
GLP 585	59.4	57.5	48.4	55.1
GLP X92	65.2	52.7	28.3	48.7
KK 22	52.8	*	*	*
KK 072	59.1	39.7	16.7	38.5
Red 40	55.2	22.3	16.7	31.4
KAT X56	60.7	16.7	16.7	31.4
GLP 1127	60.1	16.7	16.7	31.1
Tasha	59.3	16.7	16.7	30.9
KAT B9	44.3	28.0	16.7	29.7
Chelalang	52.5	16.7	16.7	28.6
KK 071	28.7	34.0	16.7	26.5
GLP 2	45.5	16.7	16.7	26.3
KK 8	27.9	22.3	16.7	22.3
Cal 33	16.7	27.9	16.7	20.4
Red 16	22.3	16.7	16.7	18.5
Cal 194	16.7	16.7	16.7	16.7
Red 13	16.7	16.7	16.7	16.7
Mean	44.7	29.4	21.6	31.9
CV%	25.0	43.0	42.6	34.4
$LSD_{(P \leq 0.05)}G$	18.53	20.68	14.94	
$LSD_{(P \leq 0.05)}$ E	4.19			
$LSD_{(P \leq 0.05)}I$	17.79			

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype; E=Environment; I= Genotype by Environment Interaction; *=Missing data.

3.4.4 Viral diseases observed in different agro-ecological zones

Viral diseases observed include bean common mosaic virus and bean common mosaic necrosis virus. The genotypes had significant ($p \leq 0.05$) differences in their BCMNV incidence in the long rain season (Table 3.11). The highest incidence was in crops in the upper lying agro-ecological zones with a necrosis incidence of up to 8.7% in genotypes in agro-ecological zone UM 1 while genotypes in the low-lying agro-ecological zone LM 2 did not show any reaction and were therefore not presented in Table 3.11. The worst performing genotype across the environments was variety KK 22 with an overall disease incidence of 25.6% (Table 3.11). In the short rain season of 2016, necrosis symptoms were only observed on six genotypes in agro-ecological zone UM 1 with significant ($p \leq 0.05$) differences in their reactions. The worst performing genotype among them was variety KK 22 with 24.3% incidence (Table 3.11).

The genotypes and the environments had significant ($p \leq 0.05$) differences in their mosaic virus incidence in the long rain season (Table 3.12). The highest BCMV incidence was in crops in the upper lying agro-ecological zones with a mean of 3.9% for genotypes in agro-ecological zone UM 2-T while genotypes in the low-lying agro-ecological zone LM 2 did not show symptoms and are therefore not represented in Table 3.12. The worst performing genotype across the environments was Tasha with an overall disease incidence of 7.9%, whereas varieties GLP 2, KK 8 and Red 13 were the best performers, as they did not show BCMV symptoms in any environment (Table 3.12). There were no significant differences ($p \geq 0.05$) in the BCMV incidences between the environments or among the genotypes in the short rain season (Table 3.13).

Table 3.11: Percentage incidence of viral necrosis on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2016 short rains and the 2017 long rains

Genotype	Agro-Ecological Zone						Mean
	2016	2017					
	UM1	UM1	UM2-T	UM2	UM3-4	UM4	
KK 22	24.3	75.8	26.9	0.9	42.7	7.0	25.6
KK 072	8.4	53.0	0.0	0.0	2.2	0.0	9.2
GLP 1127	3.5	20.5	0.0	0.0	0.0	0.0	3.4
KAT B9	3.2	0.0	0.0	0.0	0.0	0.0	0.0
KK 8	1.5	0.0	0.0	0.0	0.0	0.0	0.0
KK 15	0.4	0.0	0.0	0.0	0.0	0.0	0.0
KK 071	0.0	5.0	0.0	0.0	0.0	0.0	0.8
GLP X92	0.0	1.4	0.0	0.0	1.0	0.0	0.4
GLP 585	0.0	1.5	0.0	0.0	0.0	0.0	0.3
Mean	2.3	8.7	1.5	0.1	2.5	0.4	2.2
CV%	110.3	102.4	469.8	734.8	119.7	734.8	223.9
$LSD_{(P \leq 0.05)}G$	4.19	14.8	11.6	0.6	5.1	4.8	3.2
$LSD_{(P \leq 0.05)}$ E		1.9					
$LSD_{(P \leq 0.05)}I$		7.9					

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

Table 3.12: Percentage incidence of bean common mosaic virus on genotypes planted in different agro-ecological zones of Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone					Mean
	UM 1	UM 2-T	UM 2	UM 3-4	UM 4	
Tasha	3.3	25.6	9.6	2.3	6.4	7.9
Red 40	1.0	16.1	6.5	2.9	0.0	4.4
GLP 1127	0.0	1.1	3.1	3.1	4.6	2.0
KAT B9	2.6	1.3	0.0	0.0	6.7	1.8
GLP 585	1.5	5.6	2.3	0.0	0.0	1.6
KAT X56	0.0	5.7	1.9	0.0	0.0	1.3
Chelalang	0.0	3.8	0.7	0.0	1.3	1.0
GLP X92	0.0	3.0	0.0	0.0	1.7	0.8
KK 072	0.0	0.0	0.0	0.0	3.5	0.6
KK 22	0.0	3.0	0.0	0.0	0.0	0.5
Cal 194	0.0	2.2	0.9	0.0	0.0	0.5
KK 071	0.0	0.0	1.7	0.0	1.2	0.5
Red 16	0.0	0.0	0.0	0.0	2.2	0.4
KK 15	0.0	0.0	2.1	0.0	0.0	0.4
CAL 33	0.0	1.9	0.0	0.0	0.0	0.3
GLP 2	0.0	0.0	0.0	0.0	0.0	0.0
KK 8	0.0	0.0	0.0	0.0	0.0	0.0
Red 13	0.0	0.0	0.0	0.0	0.0	0.0
Mean	0.5	3.9	1.6	0.5	1.5	1.3
CV%	408.2	113.2	154.5	425.3	180.3	198.9
$LSD_{(P \leq 0.05)}G$	3.1	7.2	4.1	3.3	4.6	1.7
$LSD_{(P \leq 0.05)}$ E	0.99					
$LSD_{(P \leq 0.05)}I$	4.2					

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

Table 3.13: Percentage incidence of bean common mosaic virus on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone			Mean
	UM 1	UM 2	UM 4	
GLP 2	0.0	0.0	3.3	1.1
Tasha	0.0	0.7	2.3	1.0
KAT B9	1.5	1.0	0.0	0.8
GLP X92	0.5	0.3	1.1	0.6
Chelalang	0.4	0.0	0.6	0.4
Red 40	0.0	0.9	0.4	0.4
GLP 585	0.0	0.4	0.4	0.3
KK 071	0.0	0.8	0.0	0.3
KK 8	0.0	0.0	0.7	0.2
KK 15	0.0	0.7	0.0	0.2
GLP 1127	0.0	0.5	0.0	0.2
Cal 33	0.0	0.0	0.4	0.1
Red 16	0.0	0.0	0.4	0.1
Mean	0.1	0.3	0.6	0.3
CV%	493.3	220.7	328.3	361.0
$LSD_{(P \leq 0.05)}G$	1.07	1.13	3.06	1.11
$LSD_{(P \leq 0.05)}$ E	0.452			
$LSD_{(P \leq 0.05)}I$	1.917			

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

3.4.5 Yield and yield components in different agro ecological zones.

During the long rains there were no significant ($p \geq 0.05$) differences between the yields in different environments (Appendix II). The genotypes had significant ($p \leq 0.05$) differences in their yields across the environments with variety Red 16 having the highest overall yield of 2.2 t/ha while the worst performing genotype was KK 22 with the lowest overall yield of 1.3 t/ha (Table 3.14). Both the environments and the genotypes showed significant ($p \leq 0.05$) differences in their yields in the short rain season. Genotypes in the Upper lying agro-ecological zone UM 1 led with a mean yield of 1.5 t/ha while those in agro-ecological zone UM 2 were the worst performers with a mean of 0.6 t/ha (Table 3.15). The best performing genotype was GLP 2 with the highest overall yield of 1.3 t/ha while the worst performing genotypes were varieties KK 072, GLP 585 and KK 22 with overall yields of as low as 0.7 t/ha.

Figure 3.4 and 3.5 show the relationship between the genotypes and the different environments in the long and short rain seasons respectively. The yield (X-axis) was in tons per hectare while the principle component analysis 1 (Factor 1) (y-axis) contained the score for the influence of different environments on variability so that the further away an environment was from point 0.0 the more influence it had on the overall yield variation in a season. Factor 1 accounted for 49.61 and 54.96% of the total variability observed between the environments in the long and short rain season respectively. An angle of less than 90^o between environment vectors indicate that they classified the genotypes similarly, if the angle is close to 90^o they did not classify similarly and when the angle is close to 180^o the environments classified the genotypes inversely.

The closer to an environmental vector a genotype is the more it is favoured by that particular environment whereas environmental and genotype vectors in the opposite direction had

negative interactions. In the long rain season, the environments ranked the genotypes differently with agro-ecological zone LM 2 classifying them inversely to agro-ecological zones UM 3-4, UM 1, UM 2, as vector angle between the UM environments and agro-ecological zone LM 2 is close to 180. However, agro-ecological zone LM 2 classified the genotypes similarly to agro-ecological zone UM 4 as angle between their vectors is less than 90. Agro-ecological zones UM 3-4, UM 1, UM 2 and UM 2-T classified genotypes similarly in this season (Figure 3.4). The environments also ranked the genotypes differently in the short rain season with agro-ecological zone UM 1 classifying them inversely to both agro-ecological zones UM 2 and UM 4, which classified the genotypes in forms similar (Figure 3.5).

For figure 3.6 and 3.7, a big mean yield (X-axis) and small CV (Y-axis) of a genotype indicates more stability. Genotypes with stable yields in the long rains were varieties Cal 194, Cal 33, GLP 2, KK 072, KK 8, Red 13 and Red 16 as their yields were above the season average and had low CVs. Other genotypes in this season such as varieties Glp 585, Glp x92, KAT B9, KK 071 and KK 15 had low CVs but yielded below the mean whereas variety Red 40 and Tasha had above average yields but with high CVs and were therefore not stable (Figure 3.6). In the short rain season, 10 genotypes comprising of varieties Cal 194, Cal 33, Glp 2, KAT B9, KAT X56, KK 8, Red 13, Red 16 and Red 40, had above average yields but also high CVs while the rest combined both poor yields and high CVs. There was therefore no stable genotype in this season (Figure 3.7).

Table 3.14: Grain yield in tons per hectare of common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2017 long rains.

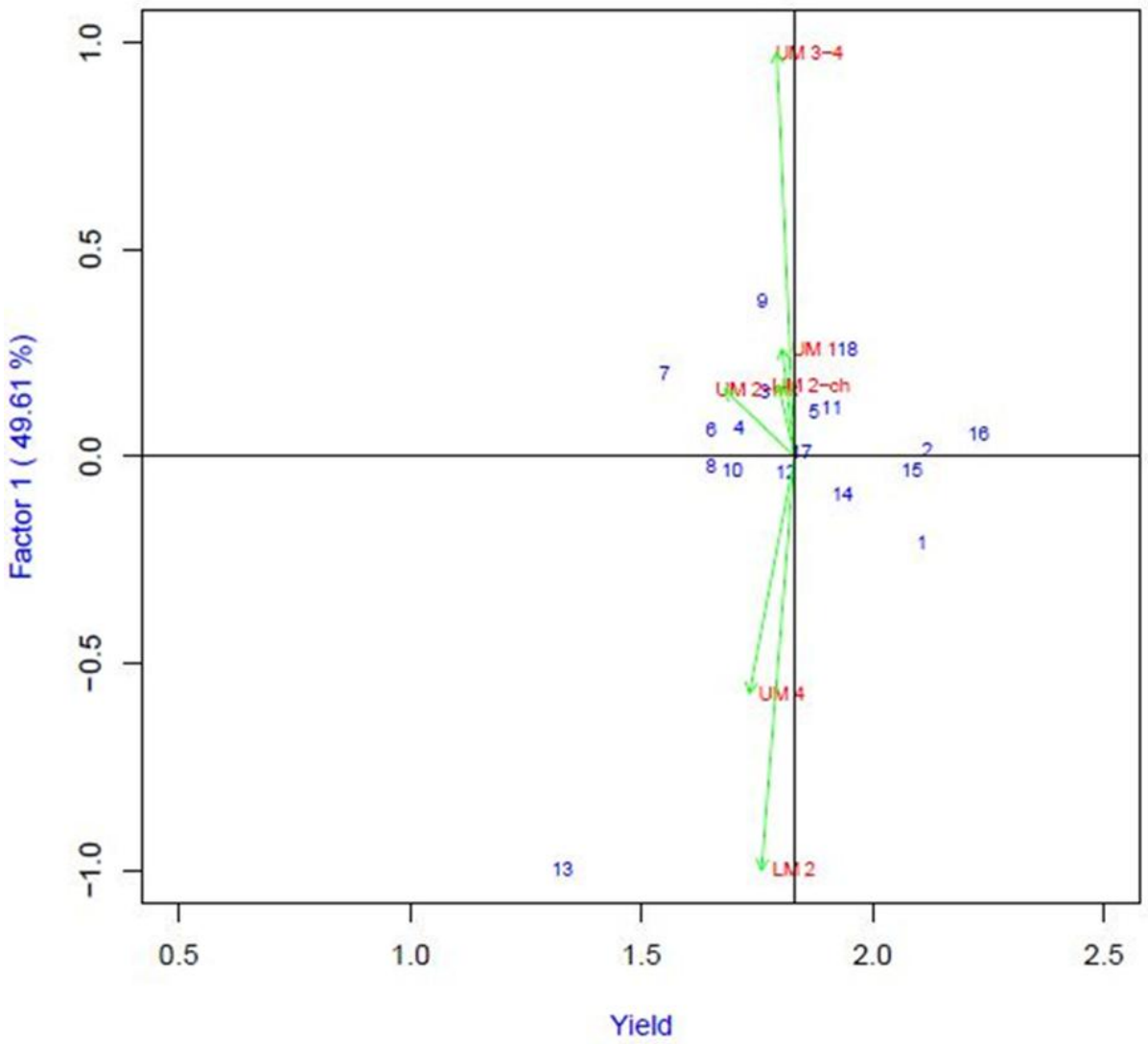
Genotype	Agro-Ecological Zone						Mean
	UM 1	UM 2-T	UM 2	UM3-4	UM 4	LM 2	
Red 16	2.2	2.2	2.5	2.2	2.1	2.2	2.2
Cal 33	2.3	2.1	2.0	2.2	2.2	2.1	2.1
Red 13	2.2	2.1	2.2	2.0	2.1	2.0	2.1
Cal 194	2.1	2.1	2.3	1.9	2.1	2.2	2.1
KK 8	1.9	2.1	1.8	1.8	1.9	2.0	1.9
KK 072	1.9	1.9	1.8	2.1	1.8	1.9	1.9
Tasha	2.1	1.6	2.0	2.3	1.8	1.9	1.9
GLP 2	1.9	2.0	1.9	2.0	1.6	1.9	1.9
Chelalang	1.7	1.6	1.9	1.9	2.0	1.5	1.8
KK 15	1.9	1.8	1.9	1.7	1.8	1.7	1.8
KAT x56	1.9	1.7	1.8	2.1	1.7	1.4	1.8
Red 40	2.0	1.5	1.8	2.0	1.7	2.0	1.8
GLP 1127	1.8	1.5	2.0	1.7	2.0	1.3	1.7
KK 071	1.6	1.6	1.9	1.7	1.5	1.8	1.7
KAT B9	1.7	1.5	1.5	1.7	1.6	1.7	1.6
GLP 585	1.7	1.6	1.5	1.8	1.4	1.8	1.6
GLP x92	1.6	1.6	1.5	1.7	1.4	1.4	1.5
KK 22	1.2	1.0	1.2	0.8	1.7	2.0	1.3
Mean	1.9	1.7	1.9	1.9	1.8	1.8	1.8
CV%	22.5	21.6	17.3	28.8	14.1	25.7	24
$LSD_{(P \leq 0.05)}G$	0.7	0.63	2.53	0.89	0.42	0.78	0.29
$LSD_{(P \leq 0.05)}$ E	0.17						
$LSD_{(P \leq 0.05)}I$	0.71						

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

Table 3.15: Grain yield in tons per hectare of common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2016 short rains.

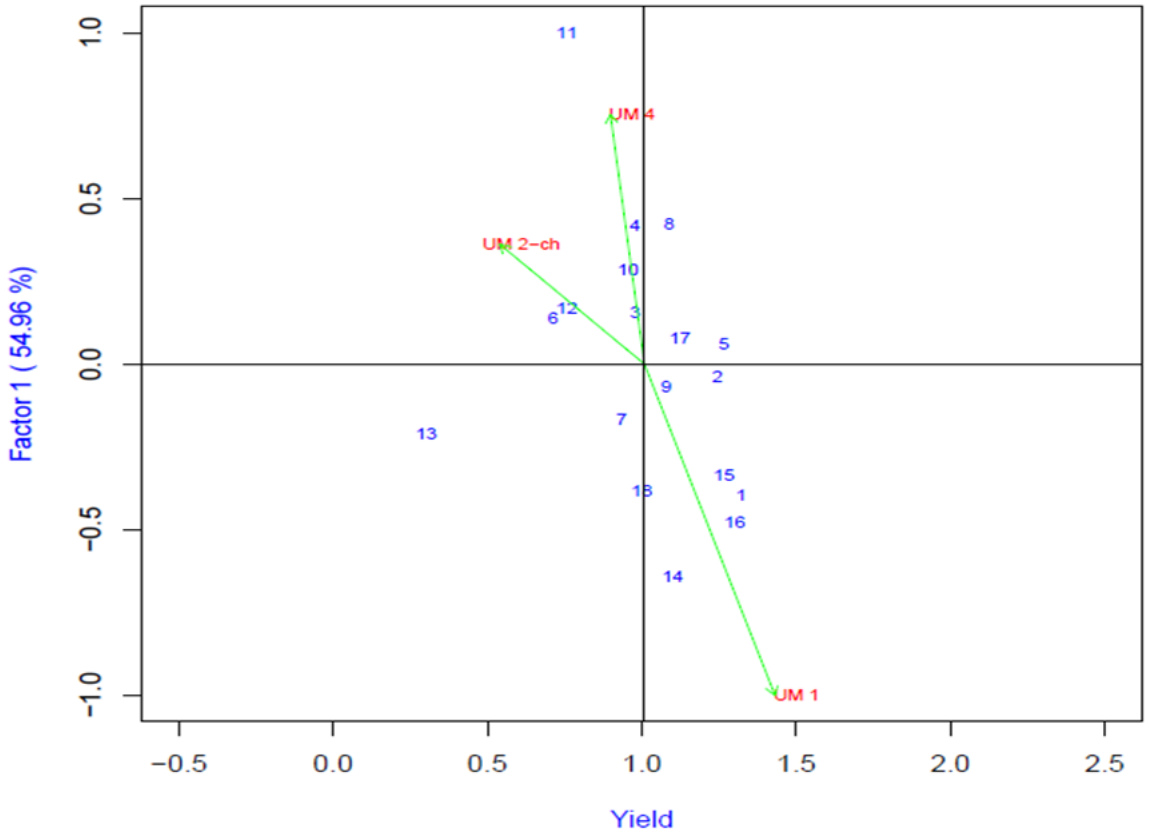
Genotype	Agro-Ecological Zone			Mean
	UM 1	UM 2	UM 4	
GLP 2	1.8	0.7	1.3	1.3
Cal 194	2.1	0.8	1.0	1.3
Red 13	2.2	0.6	1.0	1.3
Red 16	2.1	1.0	0.8	1.3
Cal 33	2.1	0.6	1.0	1.2
KAT B9	1.5	0.5	1.2	1.1
Red 40	1.5	0.8	1.1	1.1
KAT x56	1.5	0.8	1.0	1.1
KK 8	1.8	0.6	1.0	1.1
GLP 1127	1.1	0.6	1.2	1.0
Chelalang	1.4	0.7	0.8	1.0
KK 071	1.4	0.6	0.8	1.0
Tasha	1.7	0.6	0.7	1.0
GLP x92	1.5	0.3	1.0	0.9
KK 15	1.0	0.2	1.0	0.8
KK 072	0.8	0.6	0.8	0.7
GLP 585	1.2	0.3	0.6	0.7
KK 22	0.3	*	*	*
Mean	1.5	0.6	0.95	1.0
CV%	21.2	50.6	34.1	36.9
$LSD_{(P \leq 0.05)}G$	0.5	0.5	0.5	0.3
$LSD_{(P \leq 0.05)}$ E	0.14			
$LSD_{(P \leq 0.05)}I$	0.59			

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype; E=Environment; I= Genotype by Environment Interaction; *=Missing data.



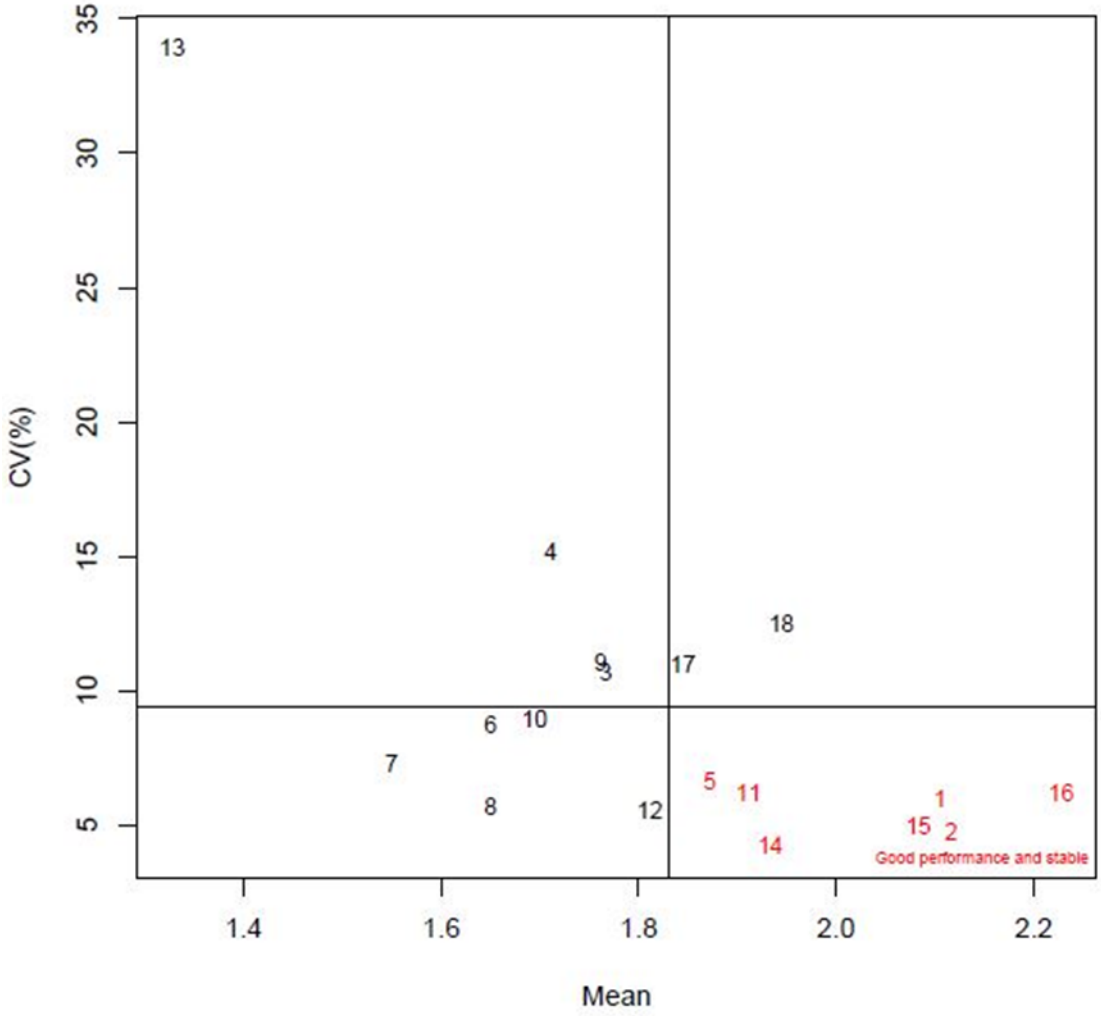
KEY	Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Genotype	CAL 194	CAL 33	Chelelang	Glp 1127	Glp 2	Glp 585	Glp X92	KAT B9	KAT X56	KK 071	KK 072	KK 15	KK 22	KK 8	Red 13	Red 16	Red 40	Tasha

Figure 3.4: Interaction between genotypes and the different agro-ecological zones of Western Kenya in the 2017 long rain season



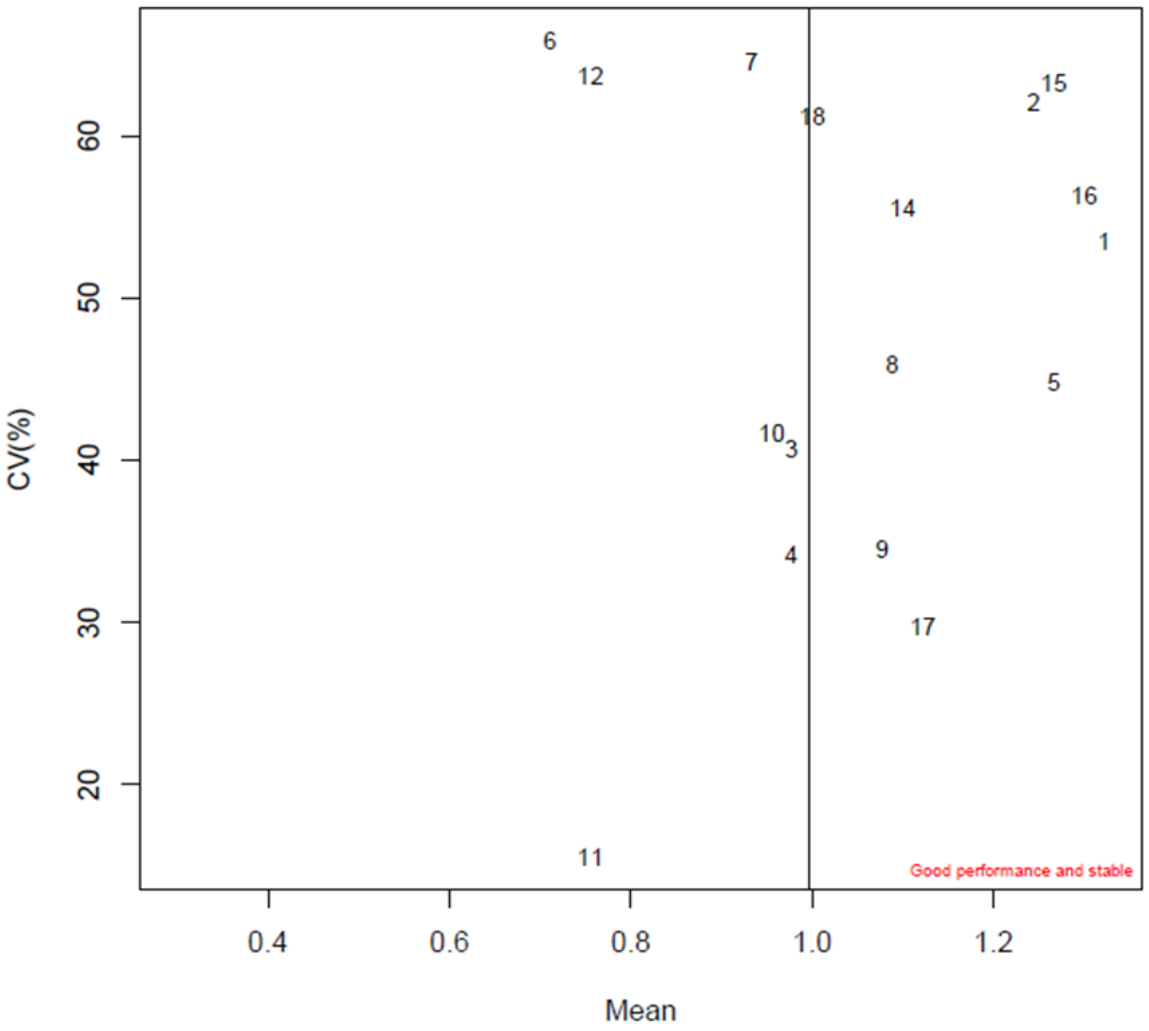
KEY	Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Genotype	CAL 194	CAL 33	Chelelang	Glp 1127	Glp 2	Glp 585	Glp X92	KAT B9	KAT X56	KK 071	KK 072	KK 15	KK 22	KK 8	Red 13	Red 16	Red 40	Tasha

Figure 3.5: Interaction between genotypes and the different agro-ecological zones of Western Kenya during the 2016 short rains



KEY	Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Genotype	CAL 194	CAL 33	Chelelang	Glp 1127	Glp 2	Glp 585	Glp X92	KAT B9	KAT X56	KK 071	KK 072	KK 15	KK 22	KK 8	Red 13	Red 16	Red 40	Tasha

Figure 3.6: Stability analysis for common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2017 long rains.



KEY	Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	Genotype	CAL 194	CAL 33	Chelelang	Glp 1127	Glp 2	Glp 585	Glp X92	KAT B9	KAT X56	KK 071	KK 072	KK 15	KK 22	KK 8	Red 13	Red 16	Red 40	Tasha

Figure 3.7: Stability analysis for common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2016 short rains.

Both the genotypes and the environments showed significant ($p \leq 0.05$) differences in their seed weight in the long and short rain season. During the long rains, the highest seed weight was found in high lying agro-ecological zone UM 1 crops with the best overall weight of 38.0 g while the worst performing crop was that in agro-ecological zone UM 3-4 with seed weight of 31.0 g (Table 3.16). The best performing genotype was GLP 2 with an overall seed weight of 44.7 g whereas variety KK 22 was the overall worst performer with a seed weight of 21.4 g (Table 3.16). The highest seed weight in the short rains was found in the upper lying agro-ecological zone UM 1 crop with a mean of 29.7 g while agro-ecological zone UM 2 and agro-ecological zone UM 4 crops were the worst performers with seed weight of as low as 27.6 g (Table 3.17). The best performing genotype was variety GLP 2 with overall seed weight of 35.4 g whereas variety KK 22 had the lowest seed weight in this season with 13.0 g in agro-ecological zone UM 1.

The genotypes showed significant ($p \leq 0.05$) difference in damaged seed in the long rain season with the most damage found in crops in upper lying agro-ecological zone UM 1 with 20.4% while agro-ecological zone UM 2-T crop was the best performing with a low seed damage of 9.3% (Table 3.18). The best performing genotypes were varieties KK 15, Red 16 and Glp 585 with overall damage of 6.9, 8.3 and 8.7% respectively while variety KK 22 was the worst performer with an overall of 21.5% damaged seeds (Table 3.18). In the short rain season, the environments showed significant ($p \leq 0.05$) differences in their seed damage with the lower lying agro-ecological zone UM 4 crop having the highest damage of 44.5% while the higher lying agro-ecological zone UM 1 crop had the least damage of 11.4% (Table 3.19). The genotypes did not show significant ($p \geq 0.05$) variations across the environments however, they had variations within agro-ecological zones UM 1 and UM 4 with Chelalang seed damage of 87.6% in agro-ecological zone UM 4 being the highest observed in the season (Table 3.19).

Table 3.16: Weight in grams of seeds of common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone						Mean
	UM 1	UM 2-T	UM 2	UM 3-4	UM 4	LM 2	
GLP 2	46.7	42.4	47.1	37.4	44.9	49.6	44.7
Cal 33	45.3	39.2	40.9	44.0	48.3	43.4	43.5
Tasha	44.6	41.2	41.7	37.1	48.0	37.5	41.7
KK 072	42.4	37.6	44.2	37.9	47.7	36.4	41.0
Chelalang	36.9	42.9	38.8	37.4	40.6	43.4	40.0
KK 8	39.6	39.9	44.7	32.7	39.4	42.2	39.8
GLP 1127	38.5	38.1	40.1	37.9	40.7	38.8	39.0
KK 071	44.4	40.6	39.8	31.2	36.8	37.9	38.5
Cal 194	37.5	35.9	34.2	31.1	34.8	37.8	35.2
KAT B9	43.1	38.7	36.2	33.4	39.1	17.0	34.6
Red 13	35.9	31.9	36.1	31.0	34.8	31.2	33.5
Red 16	38.0	32.2	36.7	30.0	30.3	33.5	33.5
KAT x56	36.9	34.8	34.3	33.1	38.3	20.9	33.1
GLP x92	38.5	30.5	38.3	26.9	37.5	20.2	32.0
KK 15	31.7	30.4	34.8	23.1	32.2	34.7	31.2
Red 40	31.4	28.6	30.1	24.1	35.1	27.8	29.5
GLP 585	33.2	19.1	23.1	15.4	21.2	24.3	22.7
KK 22	19.4	21.1	29.2	15.1	18.6	25.1	21.4
Mean	38.0	34.7	37.2	31.0	37.1	33.4	35.3
CV%	12.8	8.4	12.9	11.8	12.5	27.3	15.8
$LSD_{(P \leq 0.05)}G$	8.1	4.9	8	6.1	7.7	15.2	1.9
$LSD_{(P \leq 0.05)}$ E	1.1						
$LSD_{(P \leq 0.05)}I$	4.5						

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

Table 3.17: Weight in grams of seeds of common bean genotypes planted in different agro-ecological zones of western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone			Mean
	UM 1	UM 2	UM 4	
GLP 2	36.7	37.0	32.6	35.4
Cal 33	38.2	34.6	33.1	35.3
Tasha	34.8	35.9	33.7	34.8
Chelalang	34.8	34.0	31.4	33.4
KK 072	36.4	29.9	31.6	32.6
KK 071	32.9	30.9	33.7	32.5
KK 8	31.1	29.5	32.4	31.0
GLP 1127	31.2	27.6	31.7	30.2
Cal 194	34.4	29.7	26.4	30.2
KAT x56	27.3	27.1	29.4	27.9
KAT B9	27.9	28.0	27.2	27.6
Red 16	28.3	26.5	24.8	27.1
GLP x92	28.5	24.1	28.8	27.1
Red 13	30.1	26.3	24.3	26.9
KK 15	27.0	20.2	26.0	24.4
Red 40	25.0	22.0	21.6	22.9
GLP 585	16.6	18.3	19.3	18.6
KK 22	13.0	*	*	*
Mean	29.7	27.6	27.7	28.3
CV%	10.9	12.7	7.7	13.2
$LSD_{(P \leq 0.05)}G$	5.37	5.99	3.69	3.49
$LSD_{(P \leq 0.05)}$ E	1.42			
$LSD_{(P \leq 0.05)}I$	6.05			

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype; E=Environment; I= Genotype by Environment Interaction; *=Missing Data.

Table 3.18: Percentage damaged seed of common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone						Mean
	UM 1	UM 2-T	UM 2	UM3-4	UM 4	LM 2	
KK 22	33.6	6.5	4.2	21.7	25.0	37.8	21.5
KAT B9	17.7	9.9	26.6	8.8	39.7	18.6	20.2
KK 071	25.4	13.7	23.2	11.5	26.8	20.6	20.2
KAT x56	26.6	10.9	20.9	17.5	19.2	11.1	17.7
KK 072	37.3	9.3	23.5	11.7	14.4	16.6	18.8
GLP 1127	34.6	14.0	9.9	14.5	14.0	19.9	17.8
Red 40	18.1	5.9	11.6	8.9	13.4	33.3	15.2
Cal 33	31.6	11.4	17.1	16.5	10.0	20.7	17.9
Red 13	26.3	4.2	7.3	6.7	5.4	32.2	13.7
KK 8	13.3	9.4	17.8	9.8	9.1	13.6	12.2
GLP 2	12.9	8.9	17.8	6.8	12.5	11.8	11.8
GLP x92	18.5	15.0	7.2	5.4	7.9	17.5	11.9
Cal 194	13.8	15.7	9.1	5.3	7.5	17.5	11.5
Chelalang	18.6	7.9	10.5	12.0	6.9	15.2	11.8
Tasha	14.1	9.3	7.5	10.8	7.8	15.1	10.8
GLP 585	5.4	5.9	7.1	12.0	7.3	14.2	8.7
Red 16	9.9	4.2	5.6	14.7	5.6	9.8	8.3
KK 15	9.2	4.2	4.7	12.7	3.9	6.8	6.9
Mean	20.4	9.3	12.9	11.5	13.1	18.5	14.3
CV%	50.5	50.1	49.8	50.5	88.1	90.8	72.3
$LSD_{(P \leq 0.05)}G$	17.1	7.7	10.6	9.6	19.1	27.8	6.8
$LSD_{(P \leq 0.05)}$ E	3.9						
$LSD_{(P \leq 0.05)}I$	16.6						

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

Table 3.19: Percentage damaged seed of common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone			Mean
	UM 1	UM 2	UM 4	
Cal 194	5.8	20.7	60.4	29.0
Cal 33	10.6	13.4	43.9	22.7
Chelalang	8.5	8.6	87.6	34.9
GLP 1127	20.8	13.7	55.0	29.8
GLP 2	12.1	12.4	22.9	15.8
GLP 585	8.9	17.4	52.9	26.4
GLP X92	13.6	14.8	23.3	17.2
Kat B9	9.8	22.3	35.2	22.4
Kat X56	13.3	28.2	30.3	23.9
KK 071	1.1	26.9	60.7	30.4
KK 072	44.8	27.2	36.5	36.2
KK 15	9.2	42.3	18.6	23.4
KK 22	3.5	*	*	*
KK 8	14.4	16.0	50.1	26.9
Red 13	3.7	24.5	57.6	28.6
Red 16	5.4	28.2	38.0	23.8
Red 40	6.6	22.8	43.2	24.2
Tasha	14.0	14.2	46.3	24.8
Mean	11.4	22.2	44.5	26.1
CV%	56.1	88.2	38.2	59.9
$LSD_{(P \leq 0.05)}G$	10.65	32.54	28.23	14.63
$LSD_{(P \leq 0.05)}$ E	5.97			
$LSD_{(P \leq 0.05)}I$	25.34			

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype; E=Environment; I= Genotype by Environment Interaction; *=Missing data.

3.5 Discussion

3.5.1 Diseases affecting beans in different Agro-ecological zones

Diseases observed were anthracnose (*Colletotrichum lindemuthianum*), scab (*Elsinoë phaseoli*), angular leaf spot (*Pseudocercospora griseola*), rust (*Uromyces appendiculatus*), floury leaf spot (*Mycovellosiella phaseoli*), Cercospora leaf spots, common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*), halo blight (*Pseudomonas savastanoi* pv. *phaseolicola*), bacterial brown spot (*Pseudomonas syringae* pv. *syringae*), viral mosaic symptoms and systemic necrosis. Diseases generally appeared with significant variations between the environments and genotypes and at a higher incidence and intensity in crops in the mid-altitude environments of agro-ecological zones UM 1, UM 2 and UM 3 compared to crops in the lower lying agro-ecological zones UM 4 and LM 2. All the observed diseases occur in Western Kenya as reported by Allen *et al.* (1996), Mwang'ombe *et al.* (2007), Mangeni *et al.* (2014) and Leitich *et al.* (2016). In a study on beans in Tanzania, Mpayo (2010) also observed that the high altitude environments had high disease incidence and severity compared to lower lying zones.

The relatively high diversity of diseases in this study could be attributed to factors such as favorable environmental conditions, long history of bean cultivation in the region, depleted soil fertility and poor crop cultivation practices. The environmental conditions of the study area such as high rainfall and temperatures (Kenya Meteorological Department, 2016 and 2017; Jaetzold *et al.,* 2005) provide perfect conditions for the survival of a wide range of pathogens (Allen *et al.*, 1996; Buruchara *et al*., 2010). The diverse origins of the varieties may have provided susceptible materials for a wide range of pathogens. According to Schwartz *et al.* (1989), the 400-year-old long history of bean cultivation in the highlands of Eastern Africa may have facilitated the co-evolution of a wide range of pathogens and the

bean plant. Further, Western Kenya has infertile soils resulting from high amount of rainfall received in the area and a high population density overexploiting the available land (Tittonell *et al*. 2008). Buruchara *et al*. (2010) stated that there is a negative correlation between soil fertility and diseases pressure. Effects of climate change coupled with poor crop cultivation practices such as lack of crop rotation results in further soil degradation and increased pest and disease pressure (Tittonell *et al*., 2008; Buruchara *et al.,* 2010).

The range of diseases observed in the environments could be due to factors such as altitude and differences in environmental conditions. Wortmann *et al*. (1998) observed that altitude affects disease incidence and severity by affecting temperature. The differences in environmental conditions such as precipitation and temperature between the seasons ensured that only diseases favoured by an existing set of conditions appeared. Wortmann *et al.* (1998) further noted that disease occurrence vary considerably from season to season so that some diseases that are usually of little economic importance can, at times, be devastating. The environments generally experienced lower than normal rainfall and high temperatures during both the long rains of 2017 and the short rains of 2016 (Kenya Meteorological Department, 2016 and 2017) which may have had an effect on this study.

3.5.2 Bacterial diseases observed across the environments

Common bacterial blight, halo blight and bacterial brown spot were observed in both the short rains of 2016 and the long rains of 2017 where they occurred primarily in crops in agro-ecological zones UM 1 and UM 2 compared to the low-lying agro-ecological zones UM 4 and LM 2 crops. The genotypes also showed variations in the occurrence of the diseases within the environments with genotypes such as varieties Red 16 and Cal 194 consistently having low intensities of all bacterial diseases across seasons and environments whereas genotypes such as varieties GLP 585 and Chelalang were particularly susceptible to CBB.

Near similar observations were made by Hailu *et al.* (2017) who observed variations in CBB development between different environmental conditions and genotypes in Haramaya, Ethiopia in a study on the effects of temperature and moisture on growth of common bean and its resistance reaction against common bacterial blight strains.

The variations in bacterial intensity between sites could be because of variations in environmental conditions. The environment has been shown to have a significant effect on the occurrence of bacterial diseases by Wortmann *et al.* (1998), Mpayo (2010) and Karavina *et al.* (2011). Bacterial diseases are favoured by environments of high rainfall and strong winds with common blight and bacterial brown spot being favored by cloudy damp weather and relatively high air temperatures of 28 to 32^0C and halo blight thriving under damp and cooler conditions of 18 to 22^0C (University of Illinois, 2000). These requirements make agro-ecological zones UM 1 and UM 2 the most suitable environments for the occurrence of the diseases in western Kenya due to the relatively high rainfall, a favorable temperature range of between 13 to 27^0C, strong winds and cloud cover experienced in both seasons (Jaetzold *et al.*, 2005; Kenya Meteorological Department, 2016 and 2017).

The relatively low disease pressure experienced in agro-ecological zones UM 4 and LM 2 crops could be because of unfavorable environmental conditions of reduced precipitation and higher temperatures (Kenya Meteorological Department, 2016 and 2017**).** Hailu *et al*. (2017) observed that an increase in environmental temperature accompanied by a subsequent reduction in moisture reduced the development of bacterial diseases on bean genotype. This happens through various host resistant mechanisms such as reduced stomata size and increase in phenolic acid content in the cell cytoplasm that act to hinder disease development under adverse weather conditions (Sallam, 2011).

3.5.3 Fungal diseases observed across the environments

Fungal diseases observed across the environments included, angular leaf spot, rust, anthracnose, floury leaf spot and Cercospora leaf spots. Bean scab and angular leaf spot were observed in both long and short rain seasons whereas rust only appeared in the short rains while anthracnose, floury leaf spot and fungal leaf spot only appeared in the long rain season. All fungal diseases appeared at significantly varying intensities between the environments. Anthracnose appeared at low pressure with agro-ecological zone UM 2 crop in the long rain having the highest overall intensity. Bean scab only failed to appear in agro-ecological zone LM 2 crop in the long rain season while agro-ecological zone UM 1 crop significantly had the highest scab intensity in both seasons. Upper midland zone 2 crop in the short rains led in ALS pressure whereas for rust, agro-ecological zone UM 1 crop in the short rains, led in intensity and agro-ecological zone UM 4 crop had the least rust pressure in the same season.

The genotypes had significant variations in their reactions to all the fungal diseases. Small seeded genotypes had low scab pressure but generally had the highest rust intensities whereas large seeded types had significantly high reaction to scab but low reactions to bean leaf rust. Some genotypes listed as tolerant or resistant to particular diseases (Table 3.2) showed relatively high reactions to those diseases in this study. Genotype GLP 1127 had relatively high reactions to rust in agro-ecological zone UM 1 during the short rains despite being listed as tolerant to the pathogen while varieties Red 13 and Red 16, which are listed as resistant to ALS, had varied reactions to the pathogen. While variety Red 16 had low levels of the diseases across seasons and environments, variety Red 13 showed relatively high reactions to the pathogen in agro-ecological zone UM 2 during the short rain season.

Variations in fungal diseases across environments and between genotypes for diseases such as ALS, scab and rust have been observed in other studies (Mutitu, 1979; Mwang'ombe *et*

al., 2007; Leitich *et al*., 2016 and Arunga *et al*., 2012). Leitich *et al*. (2016) observed high Angular leaf spot incidence in short rains compared to the long rains while Mwang'ombe *et al*. (2007) lists agro-ecological zones UM 1, UM 2 and UM 4 as important environments for the occurrence of the disease. Wagara *et al*. (2011) observed that all genotypes that were resistant or moderately resistant to ALS were small-seeded types, whereas the popular large-seeded beans were generally susceptible.

However, mixed results were obtained in this study, as the two varieties that had the least disease reaction (varieties Red 16 and Chelalang) are medium and large seeded types. Leitich *et al*. (2016) reported variety KK 8, a large seeded type, as among the genotypes with the least ALS incidence, which was also true for this study. Mutitu (1979) observed differences in bean scab progress in Katumani and Kabete and that small-seeded genotypes such as red haricot showed more resistance to bean scab compared to large seeded varieties. Arunga *et al*. (2012) however reported conflicting results to this study in a study of rust on snap bean where most of the material from the Mesoamerican gene pool, associated with small seeded genotypes, showed resistance to the pathogen whereas beans from the Andean gene pool, associated with large seeded genotypes, were mostly susceptible.

The environmental conditions and inoculum build up in the soil may be the reason for variations in levels of fungal infections across the different agro-ecological zones while variations in the reactions of the screened genotypes was due to their varied genetics stemming from their different origins and characteristics. Weather conditions influence the occurrence of fungal diseases across both seasons and environments by supporting the growth and spread of the pathogen (Stenglein *et al.,* 2003). Bean anthracnose is favoured by cool and wet conditions therefore high temperatures and periodic dry spells experienced in the short rains of 2016 may be the reason for the absence of the disease in the season (Hagedorn and Inglis, 1986; Allen *et al.,* 1996). According to Seebold (2014) and Greenlife (2018),

anthracnose symptoms can be easily overlooked especially in a field as its most striking symptoms usually develop on the pods. Because this study concentrated on foliar and not pod symptoms, anthracnose may have appeared at a higher intensity than was observed.

Mutitu (1979) observed that bean scab progress was favoured by high temperature and humidity found in Katumani compared to Kabete. Temperatures were high in the short rain season compared to the long rain season **(**Kenya Meteorological Department, 2016 and 2017) of this study with UM 1 additionally experiencing relatively high humidity in the short rains (Appendix IV) which may have favored scab development**.** Verma and Sharma (1984) observed an inverse relationship between temperature increase and ALS occurrence which may explain why there was less ALS pressure in low-lying zones such as agro-ecological zones UM 4 and LM 2 crops which experience higher temperatures compared to crops in agro-ecological zones UM 1 and UM 2.

Fields used in agro-ecological zone UM 2 were the only ones that had bean crops in the previous season. A possible pathogen build-up on bean plant debris from the previous season (Allorent and Savary, 2005) may therefore be a reason for the significantly higher ALS intensity in the crop in this agro-ecological zone compared to agro-ecological zones UM 1 and UM 4 crops. Barros *et al*. (1958) in Columbia reported that ALS increased dramatically when several bean crops occur in the same environment within a year, as was the case in agro-ecological zones UM 2. This high inoculum concentration is what may have also resulted in the breakdown of variety Red 13 ALS resistance in this environment. High humidity and temperatures of between 21 to 27^0C favor rust dispersal and development (Allen *et al.,* 1996; Nyang'au *et al*., 2016). Such conditions were more pronounced in both agro-ecological zones UM 1 and UM 2 compared to agro-ecological zones UM 4, which experienced frequent dry spells in this season and was therefore unfavorable for rust development (Arunga *et al*., 2012).

Arunga *et al*. (2012) may have provided conflicting results to this study because the causal agent of rust, *Uromyces appendiculatus* has one of the highest pathogenic variability among fungal pathogens. Consequently, variety GLP 1127 which had relatively high reactions to rust in agro-ecological zone UM 1 during the short rains despite its listing as tolerant to the pathogen, may have been exposed to a different pathogen race to that which it was developed for. *Uromyces appendiculatus* can vary within an area such as a single spore sample from a leaf or field populations while resistance to the pathogen has been observed to be race specific (Liebenberg and Pretorius, 2004; Jochua *et al.*, 2008). Arunga *et al.* (2012) took place in French bean growing areas using differentials of known genetic base whereas this study took place in dry-bean growing areas using varieties of mostly unknown genetic backgrounds. This may explain why the results of genotypic reactions conflict when defined simply by seed size. Jochua *et al*. (2008) reported that where both Andean and Mesoamerican types were grown together in Honduras, as is the case of Western Kenya (CGIAR, 2012), there was a high diversity of *Uromyces appendiculatus,* further supporting pathogenic diversity as a possible reason for the contrasting results of the two studies.

3.5.4 Viral diseases observed across the environments

Viral diseases observed in this study were BCMNV and BCMV where both appeared with significant differences in incidence between the environments in at least one season. In the short rains, BCMNV appeared only in agro-ecological zone UM 1 crop while the long rain it appeared in crops in all environments except agro-ecological zone LM 1. Bean common mosaic virus showed significant environmental variation in the long rain season only. Although it appeared in the short rain season, it was at very low incidences. Genotypes KK 22, KK 072 and GLP 1127 showed significantly high BCMNV symptoms across all seasons and environments whereas variations in BCMV incidences were observed among genotypes in the long rain season only. Mangeni *et al*. (2014) observed a similar trend where during the

short rains, BCMNV infection was considerably higher to that of BCMV. Mangeni *et al.* (2014) also observed necrosis reaction on variety KK 072 while information from Otsyula (2016), the breeder of variety KK 22, also indicates the variety's tendency to have necrotic reactions.

The environment and susceptibility of the genotypes influenced the spread and incidence of BCMV and BCMNV. The environment affects the incidence and severity of both BCMNV and BCMV through its effect on both the virus and its vectors' population dynamics. All strains of BCMNV induce temperature insensitive necrosis in genotypes while some strains of BCMV cause temperature sensitive systemic vascular necrosis and death (Mavrič and Šuštar-Vozlič, 2004). Variations in environmental factors such as temperature and rainfall may have affected aphid populations resulting in the differences in viral incidence between the agro-ecological zones.

Periodic dry spells experienced in the short rains (Kenya Meteorological Department, 2016) and the relatively high temperatures and low rainfall in LM 1 compared to higher lying environments in the long rains (Jaetzold *et al*., 2005; Kenya Meteorological Department, 2017), could have resulted in reduced leaf area on bean plants and sparse vegetation cover in the fields. This may have negatively affected aphid populations minimizing virus transmission. Fajinmi *et al*. (2011) observed that sparse vegetation cover resulting from climatic conditions such as high temperature, low humidity and a long dry season before the onset of the rains might cause aphids to die as a result of non-availability of food source for survival.

Both BCMV and BCMNV are more destructive in a longer vegetative cycle (Zitter and Provvidenti, 1984). Periodic dry spell during the short rains of 2016 and higher temperatures in low-lying zones may have resulted in shorter vegetative cycles as the genotypes

experienced relatively early maturity**.** This may also explain the better manifestation of the symptoms during the long rains compared to the short rains and in the cooler agro-ecological zone UM 1 compared to lower lying environments, as maturity is known to accelerate under increased temperatures (Porch and Jahn, 2001; Nunes *et al.*, 2008).

Host resistance is an important factor for development of BCMNV and BCMV and is a cause for the differences in reactions between the genotypes (Drijfhout, 1978). Both varieties KK 22 and KK 072 are known to possess the dominant 'I' gene that overcomes almost all recorded BCMV strains (Mangeni *et al.*, 2014). However, plants with the dominant 'I' gene develop systemic lethal necrosis because of a hypersensitive response stimulated by BCMNV overcoming the resistance (Mangeni *et al.,* 2014). While the genetic character of variety GLP 1127 was not established, it is likely that its BCMV resistance listed in Table 3.2 is conferred by the 'I' gene. This would be the reason for the lethal necrosis reaction of the genotype in environments where BCMNV is reported to occur.

3.5.5 Grain yield, seed weight and seed damage in different agro-ecological zones.

Plot yield, seed weight and loss due to damaged seed were all observed with significant variations in the environments and between the genotypes in at least one season. Only long rain environments failed to show significant variations in their yields. However, both the short and long rain environments classified the genotypes variably indicating the presence of environmental effect. In the short rains, agro-ecological zone UM 1 crop was the best yielding while agro-ecological zone UM 2 crop was the worst performing, yielding lower even to agro-ecological zone UM 4 crop. Generally, the crop of agro-ecological zone UM 1 outperformed all other environments' crops in seed weight across both seasons. The genotypes also showed significant variations in their yield with varieties Red 16, Red 13, Cal 33 and Cal 194 being consistently the best performers. Large seeded genotypes generally out-

weighing small seeded forms. Genotypes such as varieties KK 22, GLP 1127, KK 072, KK 071 and KAT x56 generally had significantly higher levels of seed damage compared to the rest.

Both biotic and abiotic factors had an effect on performance of the genotypes in yield and seed weight. Franzon *et al*. (2015) noted that the yield of the genotypes varied according to environment while Mpayo (2010) and Mvile (2015) also observed significant differences in yield among the genotypes and environments. Mpayo (2010) and Nwadike and Terkimbi (2015) further reported significant differences in seed weight in both the genotypes and environments. Lima *et al*. (2005) observed that large seeded bean genotypes had a higher 100-seed weight compared to small seeded genotypes while Makelo (2010) and Mbugua (2016) observed variation in seed physical qualities between different environments and genotypes. All diseases observed in this study are known to negatively affect yield (Allen *et al.,* 1996; Mangeni *et al.,* 2014; Leitich *et al*., 2016; Hailu *et al*., 2017).

Long rains weather conditions were near optimum in all environments (Kenya Meteorological Department, 2017) and this may explain the uniformity in the environment yields in this season. Disease pressure may be the reason for the poor performance of the crop in agro-ecological zone UM 2 in the short rains when ALS and rust intensity were higher compared to crops in both agro-ecological zones UM 1 and UM 4 in the same season. Genotypes such varieties KK 22, GLP 1127, KK 072, KK 15, KK 071 and KAT X56 had high intensities of at least one disease and recorded corresponding high yield losses. For example, variety KK 15 had low yields in agro-ecological zone UM 2 in the short rain season where it also had relatively high ALS and rust scores whereas varieties KK 22, KK 072 and GLP 1127 had high incidences on BCMNV and matching low yields across the seasons and environments.

Pamela *et al.* (2014) in a study on the severity of ALS and rust in Uganda found a negative correlation between the two diseases and yield. Boersma *et al.* (2015) in a study on impact of CBB on yield, seed weight and quality loss of common beans in Canada concluded that CBB had a greater impact on yield reduction probably through a reduction in number of seeds per plant than on seed weight. Nwadike and Terkimbi (2015) observed that genetic variability, the environment, and their interactions all significantly affected the seed weight of bean genotypes. The environment influences seed weight through water stress especially during seed filling stage by affecting uptake of assimilates to the seeds or the length of the seed-feeling period (Yordanov *et al.*, 2003).

The environments may have influenced the ranking and performance of the genotypes in both seasons through variations in water stress level and ambient temperatures. Konsens *et al*. (1991), Gross and Kigel (1994) and Tom (2014) noted that the timing, length and degree of stress play an important role in yield. For example, high temperatures may cause a reduction in yield due to flower abortion or failure of fertilization (Tom, 2014) while Pettigrew (2004), Monneveux *et al.* (2006) and Webber *et al.* (2006) observed yield reduction due to water stress in crops such as cotton, maize and common bean. The genotypes performed significantly different to each other and ranked differently within the environments because they come from different genetic backgrounds and therefore have different characters and adaptations. Ahmad *et al.* (2001) and Nwadike and Terkimbi (2015) observed that genotypic variability significantly influenced yield. Shiringani (2007) on a study on cowpeas in South Africa also observed effect of both genotypes and environment on yield.

Diseases and the environment could cause seed damage through discoloration and shriveling of the seeds. Presence of a seed borne pathogen inoculum on surface of the seed is reported to cause seed damage (Icishahayo *et al.*, 2009). Makelo (2010) linked variations in seed damage between environments to a higher prevalence of bean diseases in a particular zone compared

to others due to favorable weather conditions. According to University of Illinois extension (2018), both halo blight and CBB affect the seed quality of beans by causing slight wrinkles, discoloration or shriveling while according to Hagedorn and Inglis (1986), anthracnose also causes discoloration and lesions on the seeds.

Disease effect may explain why genotypes such as varieties KK 22, GLP 1127, KK 072, KK 071 and KAT X56 had some of the highest disease pressures and also recorded high seed loss. Abiotic environmental factors such as temperature and rainfall also have an effect on seed quality as observed by Muasya *et al*. (2008) who noted that when temperatures are high and rainfall is little seed quality is negatively affected. Genotypes such as varieties Kat B9 and Kat X56 were developed for their earliness (Karanja *et al*., 2008) therefore their attaining maturity mid-season when there was still the high moisture levels in the environment may have resulted in seed damage.

CHAPTER FOUR

EFFECT OF PLANTING DATE AND ENVIRONMENT ON THE INTENSITY OF DISEASES OF COMMON BEANS IN WESTERN KENYA.

4.1 Abstract

The release of common dry bean varieties is based on their performance under optimum conditions including planting at the onset of rains. However, farmers in Western Kenya have been observed to plant at varied times, sometimes late in the season, exposing the crops to potential challenges such as diseases. This study assessed the performance of bean genotypes under varying disease pressure over different planting dates. Eighteen common bean varieties were planted at different sowing dates in varying agro-ecological zones of Upper-Midland 1, Upper-Midland 2, Upper-Midland 3-4, Upper-Midland 2 and Lower-Midland 2 in Western Kenya over two seasons. Natural infection with diseases was allowed to occur and disease intensity, yield and yield components data were collected and subjected to combined analysis of variance with differences between treatments compared at $p \leq 0.05$.

There was generally significantly ($p \leq 0.05$) less disease pressure in the early plantings compared to late plantings. Yield significantly ($p \leq 0.05$) decreased by up to 100% for late planted crops as disease pressure increased leaving genotypes in late sowing dates with disease intensity of as high as 100% and yields of as low as 0 t ha^{-1}. The results of this study showed that early planting results in low disease pressure and high yields and can be used in disease management. Early planting should be included in integrated pest and disease management (IPDM) strategies.

4.2 Introduction

The common dry bean (*Phaseolus vulgaris* L.), is a secure and nutritious food source as it provides households with proteins, carbohydrates, vitamins and other essential elements. Despite released bean varieties being grown in Western Kenya, productivity has remained at less than 25% of potential yield due to biophysical stresses such as unpredictability of the climate, loss of soil fertility, pests and diseases (Katungi *et al*., 2011). Adaptability of genotypes to sowing date is an important cultivation practice as it influences their growth and performance (El-Aal *et al.*, 2011), by influencing factors such as disease intensity.

Sowing date influences disease intensity through variations in climatic factors such as temperature, precipitation and humidity (Hailu *et al*., 2017). Disease may also gradually increase with lateness of planting due to inoculum build up in early-planted crops and subsequent secondary spread of the disease throughout the growing season to the late-planted crops (Nelson, 1994; Indiaagronet, 2018). This is possible in Western Kenya where most farms are small (Tittonell *et al*. 2008) and close to each other, thus making it easy for the pathogen to disperse between neighboring farms. The intensity of crop diseases has been observed to increase with lateness of planting in different crops (Gupta *et al.*, 2003; Hagan *et al.*, 2015). Sowing dates that coincide with moderate rainfall together with warm weather may show an increase in diseases as it favors the development and spread of possible pathogens and their vectors (Kone *et al*., 2017).

The optimum date of planting varies from crop to crop and even between genotypes (Kone *et al*., 2017). Traditional sowing dates are affected by fluctuating frequency and distribution of rainfall and temperatures (Tom, 2014). Different sowing dates will cause plant growth stages to fall in different weather conditions that present varied challenges. Appropriate sowing date is that which ensures the crop has an advantage over climatic conditions such as temperature,

humidity and day length (Mirzaienasab and Mojaddam, 2014). Throughout the world, it has been observed that delay in sowing beyond the optimum time usually results in yield reduction (Vange and Obi, 2006). The interaction involving genotypes and planting dates varies on both the morphological and yield attributes which can all be significantly different across different plantings (Joshi and Rahevar, 2014; Nwadike and Terkimbi, 2015), which is attributed to prevailing environmental condition (Ayoub and Abdalla, 2014).

Limited information is available concerning the effects of planting date on disease intensity and bean productivity in Western Kenya. Release of varieties is based on optimum growing conditions such as planting at the onset of rainy season or planting early maturing varieties in the short rains and late maturing varieties in the long rain season, which is not an accurate depiction of farmers' practice where beans are cultivated throughout the season. Further, there is no true weather demarcation between the long rain and short rain season in the area as rainfalls tends to be more or less continuous with only brief stops (Jaetzold *et al.*, 2005).

To select high yielding and stable cultivars, information on adaptability of released varieties over variable sowing dates is useful (Getachew *et al.*, 2015). This requires determination of the genotype and planting date interaction based on diseases severity and yield. The objective of this study was therefore to determine the effect of planting dates on disease incidence and severity on common bean genotypes grown in Western Kenya.

4.3 Material and Methods

4.3.1 Experimental design

The genotypes evaluated and sites and seasons used in these study were those described in section 3.3.1 and 3.3.2. Crops were established in four different planting dates in each agro-ecological zone during the short rain season, September 2016 and the long rain season, March

2017. The first crop was established at the onset of the rains in each environment with every subsequent planting occurring within 48 hours of 50% emergence of the previous crop resulting in crops of different growth stages occurring in the same environment. Early planting meant planting within a week of the onset of rains in the long season. For the short season, the first crops were established in September, immediately after the harvest of maize grown during the long rains, as is practiced by farmers in the region. The planting dates per agro-ecological zone were as shown in Table 4.1 below.

Table 4.1: Planting dates for different agro-ecological zones for the year 2016 and 2017.

Areas Name	AEZ	Planting Dates			
		1st	2nd	3rd	4th
		Short Rains 2016			
Kakamega	UM 1	20-Sep	28-Sep	10-Oct	22-Oct
Chwele	UM 2	16-Sep	24-Sep	05-Oct	13-Oct
Tongaren	UM 4	15-Sep	24-Sep	04-Oct	12-Oct
		Long Rains 2017			
Kakamega	UM 1	13-Mar	28-Mar	18-Apr	04-May
Chwele	UM 2	15-Mar	30-Mar	20-Apr	05-May
Lugari	UM 3-4	29-Mar	22-Apr	09-May	
Tongaren	UM 4	23-Mar	31-Mar	24-Apr	16-May
Kibabii	LM 2	14-Mar	30-Mar	19-Apr	12-May
Mukuyuni	UM 2-T	24-Mar	05-Apr	21-Apr	13-May

UM= Upper Midland zone; LM=Lower Midland zone; UM 2-T= Upper Midland zone 2 Transition (Areas fell between UM 1 and UM 2); AEZ=Agro-Ecological zone.

Each of the eighteen genotypes were planted in two row plots of two meter long with 50 x 10 cm spacing between rows and plants respectively for a 2 x 0.5 m plot. The genotype plots were spaces at 0.5 m between them so that all eighteen plots together gave a 14 x 4.5 m block. The layout was a randomized complete block design with three replications for each planting date and each replication was an individual farm giving three farms per AEZ.

Clean seed from the KALRO Kakamega bean laboratory was planted with no fertilizer. A single application of di-ammonium phosphate fertilizer was administered at the rate of 200 kg ha^{-1} immediately after emergence. Plots were sprayed with Karate pesticide once after emergence of the hypocotyl and the second time during primary leaf formation stage to control bean fly. The fields were manually weeded by hand to reduce competition from weeds. Data collected from the plots include emergence, disease incidence, disease distribution, disease severity, stand count at harvest, plot yield weight, seed weight and seed damage. Assessment of disease intensity, yield and yield components was as described in sections 3.3.4 and 3.3.5.

4.3.2 Data Analysis

Quantitative data collected in this experiment was subjected to analysis of variance (ANOVA) using the GenStat statistical software. Variances among the genotypic means as well as between treatments were compared at LSD test of 5% probability level.

4.4 Results

4.4.1 Diseases affecting beans in different planting times

More disease symptoms were observed in the long rains compared to the short rain season and in late plantings compared to early planting dates. A higher number of diseases were observed on genotypes in agro-ecological zones Upper Midland (UM) 1 and 2 compared the

lower lying agro-ecological zones UM 4 and Lower Midland (LM) 2. During the long rain season up to 11 different diseases were observed on genotypes in agro-ecological zones UM 1 compared to only eight in the short rain season. Genotypes in agro-ecological zone LM 2 only had six and four diseases in the long and short rains respectively (Appendix I).

Diseases observed in this study were anthracnose (*Colletotrichum lindemuthianum*), scab (*Elsinoë phaseoli*), angular leaf spot (*Pseudocercospora griseola*), rust (*Uromyces appendiculatus*), floury leaf spot (*Mycovellosiella phaseoli*), Cercospora leaf spot, common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*), halo blight (*Pseudomonas savastanoi* pv. *phaseolicola*), bacterial brown spot (*Pseudomonas syringae* pv. *syringae*), bean common mosaic virus, bean common mosaic necrosis virus and golden mosaic virus.

4.4.2 Bacterial diseases observed across different planting dates and environments

Bacterial diseases observed were common bacterial blight (*X. axonopodis* pv. *phaseoli*), halo blight (*P. savastanoi* pv. *phaseolicola*) and bacterial brown spot (*P. syringae* pv. *syringae*). Common bacterial blight appeared in all environments in the short and long rain seasons. The sowing dates were significantly ($P \leq 0.05$) different in all long rain environments. The highest CBB intensities generally occurred in the early planted crops with as high as 34.1% in the first planting of genotypes in agro-ecological zone UM 1 whereas the late planted crops performed best for this disease with overall levels of as low as 17.6% in genotypes in the second planting in agro-ecological zone UM 2-T (Table 4.2). The genotypes showed significant ($P \leq 0.05$) differences in CBB intensity in all environments except in agro-ecological zones UM 2 and LM 2 with the highest intensity of 52.1% observed on variety KK 15 in agro-ecological zone UM 1 (Table 4.2).

In the short rain season, only planting dates of agro-ecological zones UM 1 and UM 4 crops had significantly ($P \leq 0.05$) different CBB intensities. The late-planted genotypes in these

environments had the highest overall disease levels of as high as 54.3% in the third planting in agro-ecological zone UM 4 crops whereas the early-planted crops performed best with intensities of as low as 22.8% in the second planting in agro-ecological zone UM 1 (Table 4.3). Only genotypes planted in agro-ecological zone UM 1 showed significant ($P \leq 0.05$) variations across the short rain season where the highest disease levels of 61.1% was found on variety GLP X92 in the third planting of agro-ecological zone UM 4 crops (Table 4.3).

In the long rain season, only cropping dates and genotypes in agro-ecological zone UM 1 had significantly ($P \leq 0.05$) different halo blight intensities. Genotypes in the third planting in agro-ecological zone UM 1 had the highest overall halo blight intensity of as high as 28.8% whereas the best performing was the second planting of agro-ecological zone UM 2-T crops with disease level of as low as 17.0% (Table 4.4). Halo blight pressure was quite low in the short rain season with no significant ($P \geq 0.05$) difference in the environments, planting dates or genotypes therefore the data is not presented.

The sowing dates in all environments in the long rain season had significantly ($P \leq 0.05$) different bacterial brown spot intensities while the genotypes had significant ($P \leq 0.05$) variations in agro-ecological zone UM 1 crops only. The highest disease pressure generally appeared in the early plantings with levels of as high as 43.0% found in genotypes in the second planting date of agro-ecological zone UM 1 crops (Table 4.5).

Table 4.2: Percentage intensity of common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*) on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone																	
	UM 1				UM 2-T			UM 2			UM3-4				LM 2			
	1st	2nd	3rd	Mean	1st	2nd	Mean	1st	2nd	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Cal 194	16.7	33.6	16.7	22.3	16.7	16.7	22.8	22.4	16.7	19.5	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Cal 33	39.5	16.7	16.7	24.3	28.9	16.7	16.7	57.2	16.7	36.9	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Chelalang	63.9	27.9	16.7	36.2	34.1	16.7	25.4	35.1	16.7	25.9	16.7	16.7	16.7	16.7	54.6	16.7	16.7	29.3
GLP 1127	69.5	37.0	16.7	41.1	33.7	16.7	25.2	51.1	16.7	33.9	16.7	35.8	16.7	23.0	34.0	16.7	16.7	22.5
GLP 2	16.7	35.2	16.7	22.8	16.7	16.7	16.7	16.7	34.5	25.6	16.7	16.7	41.7	25.0	16.7	16.7	16.7	16.7
GLP 585	67.8	56.4	16.7	47.0	28.8	16.7	22.7	47.2	16.7	31.9	16.7	65.2	37.0	39.6	37.0	36.0	34.0	35.7
GLP X92	33.9	70.3	16.7	40.3	16.7	16.7	16.7	45.2	34.5	39.9	16.7	38.1	38.5	31.1	23.6	44.5	16.7	28.2
KAT B9	45.8	16.7	16.7	26.4	16.7	33.8	25.2	22.4	16.7	19.5	16.7	16.7	44.5	25.9	34.3	16.7	16.7	22.5
KAT X56	22.4	37.6	16.7	25.5	16.7	16.7	16.7	55.6	16.7	36.1	16.7	16.7	16.7	16.7	34.3	16.7	16.7	22.5
KK 071	28.3	33.9	16.7	26.3	40.0	16.7	28.4	35.1	16.7	25.9	16.7	38.9	16.7	24.1	28.3	34.5	16.7	26.5
KK 072	39.6	28.0	16.7	28.1	47.1	16.7	31.9	47.2	16.7	31.9	16.7	16.7	16.7	16.7	34.5	16.7	16.7	22.6
KK 15	45.3	64.5	46.6	52.1	35.1	16.7	25.9	51.6	34.5	43.1	28.3	28.5	36.5	31.1	46.8	16.7	34.1	32.5
KK 22	29.6	16.7	16.7	21.0	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	33.8	16.7	28.1	26.2
KK 8	22.5	16.7	16.7	18.6	16.7	16.7	16.7	33.8	16.7	25.2	16.7	16.7	16.7	16.7	34.1	16.7	16.7	22.5
Red 13	16.7	35.1	16.7	22.8	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	40.9	33.8	16.7	30.5
Red 16	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	37.0	23.5	16.7	35.3	16.7	22.9
Red 40	28.1	33.9	16.7	26.2	34.2	16.7	25.5	45.8	16.7	31.2	16.7	34.2	52.9	34.6	16.7	16.7	16.7	16.7
Tasha	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	28.2	16.7	16.7	20.5	40.5	23.5	16.7	26.9
Mean	34.1	33	18.3	28.6	24.9	17.6	21.3	35.2	19.6	27.4	18.0	24.5	26.2	22.9	31.1	22.6	19.2	24.3
CV%	65.2	68.1	57.2	66.0	66.6	39.6	59.8	55.0	53.6	58.2	37.8	69.3	82.3	71.9	64.9	85.0	57.8	73.0
$LSD_{(P \le 0.05)}G$	37.2	37.3	11.4	17.6	27.6	11.6	14.6	32.1	16.6	18.4	11.3	28.1	35.8	15.6	33.5	31.9	18.5	16.6
$LSD_{(P \le 0.05)}$ E	7.1^{**}	6.2^{**}	4.9^{**}	7.2^{***}			4.9^{***}			6.1^{***}				6.3^{***}				6.8^{***}
$LSD_{(P \le 0.05)}$I	30.3	26.3	20.7	30.5			20.7			26.0				26.6				28.8

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \le 0.05$); G=Genotype, E= Environment (Location & Planting Time); I= Genotype by Environment Interaction;**=LSD for comparing similar plantings across different environments;***=LSD for comparing different plantings within an environment.

Table 4.3: Percentage intensity of common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*) on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone												
	UM 1					UM 2				UM 4			
	1st	2nd	3rd	4th	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Cal 194	16.7	16.7	28.3	16.7	19.6	16.7	16.7	16.7	16.7	16.7	39.5	55.7	37.3
Cal 33	16.7	16.7	28.6	46.3	27.1	33.6	22.4	41.7	32.5	39.4	28.3	53.1	40.2
Chelalang	28.4	22.4	16.7	16.7	21.0	53.8	16.7	16.7	29.1	46.0	44.3	52.8	47.7
GLP 1127	41.7	35.5	22.5	55.9	38.9	34.3	28.4	16.7	26.5	51.6	52.0	56.9	53.5
GLP 2	16.7	16.7	22.6	16.7	18.2	28.1	16.7	29.2	24.6	16.7	52.4	54.7	41.2
GLP 585	42.0	28.6	41.5	55.4	41.9	39.9	28.3	42.6	36.9	52.4	39.8	55.6	49.3
GLP X92	16.7	29.6	29.5	16.7	23.1	16.7	33.9	16.5	22.4	39.3	28.1	61.1	42.9
KAT B9	28.9	16.7	28.4	16.7	22.7	28.3	40.2	29.9	32.8	22.3	40.5	54.9	39.2
KAT X56	22.5	16.7	16.7	22.4	19.6	28.2	16.7	41.7	28.9	16.7	41.5	55.o	37.7
KK 071	16.7	16.7	29.4	39.7	25.6	39.5	28.2	28.6	32.1	28.6	34.1	53.8	38.8
KK 072	28.7	16.7	16.7	39.7	25.4	34.1	29.2	16.7	26.6	45.9	28.7	55.4	43.3
KK 15	16.7	53.6	29.9	55.0	38.8	34.8	28.3	42.6	35.2	52.5	40.6	55.2	49.4
KK 22	52.1	28.1	16.7	51.5	37.1	*	34.2	16.7	26.8	*	39.5	54.0	43.7
KK 8	16.7	22.4	16.7	16.7	18.1	22.3	16.7	16.7	18.6	28.4	39.7	41.8	36.6
Red 13	16.7	16.7	29.0	16.7	19.8	27.9	16.7	28.1	24.2	52.3	39.6	53.5	48.5
Red 16	16.7	16.7	43.6	40.7	29.4	22.3	16.7	28.1	22.3	39.3	34.0	55.5	42.9
Red 40	29.6	16.7	16.7	28.5	22.9	28.4	16.7	34.7	26.6	51.3	28.2	52.9	44.1
Tasha	16.7	22.6	16.9	14.9	17.7	16.7	34.3	16.7	22.6	28.0	28.1	55.4	37.2
Mean	24.5	22.8	25.0	31.5	25.9	31.3	24.5	26.7	27.0	38.5	37.7	54.3	43.0
CV%	48.1	54.6	61.0	33.5	49.8	53.8	56.3	61.8	56.9	31.0	45.0	9.7	30.1
$LSD_{(P\leq0.05)}G$	19.5	20.6	25.8	17.7	10.4	26.6	22.9	27.4	14.3	19.0	28.1	8.7	12.1
$LSD_{(P\leq0.05)}$ E	5.2**	5.6**	5.1**		4.9***				5.9***				4.9***
$LSD_{(P\leq0.05)}I$	22.4	23.8	21.8		20.8				24.8				21.0

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p\leq0.05$); G=Genotype; E= Environment (Location & Planting Time); I= Genotype by Environment Interaction; *=Missing data; **=LSD for comparing similar plantings across different environments;***=LSD for comparing different plantings within an environment.

Table 4.4: Percentage intensity of halo blight (*Pseudomonas savastanoi* pv. *phaseolicola*) on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2017 long rains.

Genotypes	Agro-Ecological Zone																	
	UM 1				UM2-T			UM2			UM3-4				LM 2			
	1st	2nd	3rd	Mean	1st	2nd	Mean	1st	2nd	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Cal 194	22.4	16.7	16.7	18.6	28.1	16.7	22.4	16.7	16.7	16.7	37.8	16.7	16.7	23.7	28.7	28.5	16.7	24.6
Cal 33	28.3	16.7	16.7	20.5	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Chelalang	16.7	40.5	34.0	30.4	22.5	16.7	19.6	16.7	16.7	16.7	25.2	52	29.3	35.5	16.7	16.7	28.5	20.6
GLP 1127	29.0	28.3	16.7	24.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	38.2	23.8	16.7	16.7	16.7	16.7
GLP 2	35.5	16.7	34.6	28.9	16.7	16.7	16.7	41.1	16.7	28.9	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
GLP 585	28.3	16.7	16.7	20.5	16.7	16.7	16.7	16.7	16.7	16.7	28.1	16.7	16.7	20.5	16.7	16.7	16.7	16.7
GLP x92	16.7	16.7	16.7	16.7	16.7	16.7	16.7	38.2	16.7	27.5	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
KAT B9	50.8	16.7	44.5	37.3	16.7	16.7	16.7	16.7	16.7	16.7	16.7	34.4	16.7	22.6	16.7	16.7	16.7	16.7
KAT x56	40.9	16.7	72.2	43.3	28.4	22.4	25.4	34.2	16.7	25.4	48.8	16.7	16.7	27.4	16.7	16.7	16.7	16.7
KK 071	44.3	16.7	58.6	39.9	16.7	16.7	16.7	40.0	34.4	37.2	36.9	16.7	16.7	23.4	16.7	28.2	28.3	24.4
KK 072	28.0	16.7	16.7	20.4	16.7	16.7	16.7	16.7	16.7	16.7	16.7	34.6	16.7	22.7	16.7	16.7	16.7	16.7
KK 15	16.7	16.7	35.7	23.0	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	29.4	20.9	16.7	16.7	16.7	16.7
KK 22	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
KK 8	40.5	16.7	22.6	26.6	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Red 13	16.7	16.7	16.7	16.7	22.5	16.7	19.6	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
RED 16	16.7	22.5	16.7	18.6	16.7	16.7	16.7	16.7	34.6	25.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Red 40	35.0	16.7	16.7	22.8	16.7	16.7	16.7	28.1	16.7	22.4	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Tasha	28.2	16.7	49.0	31.3	25.2	16.7	20.9	16.7	16.7	16.7	25.3	34.1	16.7	25.3	16.7	16.7	16.7	16.7
Mean	28.4	19	28.8	25.4	19.1	17	18	22.1	18.7	18.7	22.3	21.6	19.3	21.1	17.3	18	18	17.8
CV%	71.8	36.7	56.9	64.7	43	13.8	33.4	82.8	56	73.9	65.6	68.4	50	64.5	28.4	38.2	38.2	34.8
$LSD_{(P\leq0.05)}G$	33.8	11.6	27.2	15.3	13.6	3.9	6.9	30.4	17.3	17.3	24.3	24.5	18.9	12.7	8.2	11.4	11.4	5.8
$LSD_{(P\leq0.05)}$ E	5.5^{**}	3.5^{**}	4.1^{**}	6.3^{***}			2.3^{***}			5.8^{***}				5.2^{***}				2.4^{***}
$LSD_{(P\leq0.05)}I$	67.4	14.8	17.3	26.6			9.8			24.5				22				10

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p\leq0.05$); G=Genotype, E= Environment (Location & Planting Time), I= Genotype by Environment Interaction; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

.

Table 4.5: Percentage intensity of bacterial brown spot (*Pseudomonas syringae* pv. *syringae*) on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone											
	UM 1			UM 2-T		UM 2			UM 3-4		LM 2	
	1st	2nd	Mean	2nd	Mean	1st	2nd	Mean	2nd	Mean	2nd	3rd	Mean
Cal 194	16.7	16.7	16.7	16.7	8.4	16.7	16.7	16.7	16.7	8.4	16.7	34.2	17.0
Cal 33	34.5	51.7	28.7	16.7	8.4	45.6	34.1	39.8	16.7	8.4	16.7	29.5	15.4
Chelalang	55.5	73.9	43.1	16.7	8.4	33.8	16.7	25.3	16.7	8.4	16.7	53.3	23.3
GLP 1127	48.2	84.1	44.1	16.7	8.4	33.9	35.0	34.4	35.0	11.7	16.7	41.3	19.3
GLP 2	28.4	34.5	21.0	16.7	8.4	41.2	16.7	28.9	16.7	8.4	16.7	16.7	11.1
GLP 585	29.9	75.7	35.2	16.7	8.4	34.6	16.7	25.6	16.7	8.4	16.7	16.7	11.1
GLP X92	16.7	16.7	16.7	16.7	8.4	16.7	16.7	16.7	16.7	8.4	34.7	34.3	23.0
KAT B9	65.0	61.6	42.2	16.7	8.4	16.7	16.7	16.7	16.7	8.4	33.3	36.0	23.1
KAT X56	47.1	80.0	42.4	34.2	17.1	55.2	16.7	35.9	16.7	8.4	48.6	55.6	34.7
KK 071	46.9	36.5	27.8	16.7	8.4	57.6	16.7	37.1	16.7	8.4	16.7	47.3	21.3
KK 072	36.8	34.7	23.9	16.7	8.4	36.1	16.7	26.4	16.7	8.4	40.3	16.7	19.0
KK 15	16.7	16.7	16.7	16.7	8.4	16.7	16.7	16.7	16.7	8.4	16.7	36.4	17.7
KK 22	16.7	16.7	16.7	16.7	8.4	36.4	16.7	26.5	16.7	8.4	33.3	16.7	11.1
KK 8	16.7	34.4	17.0	34.5	17.2	28.3	16.7	22.5	16.7	8.4	16.7	52.7	23.1
Red 13	34.7	28.0	20.9	16.7	8.4	34.0	16.7	25.3	16.7	8.4	16.7	16.7	11.1
Red 16	16.7	16.7	16.7	16.7	8.4	16.7	16.7	16.7	34.5	11.5	16.7	16.7	11.1
Red 40	16.7	16.7	16.7	16.7	8.4	58.3	16.7	37.5	16.7	8.4	16.7	35.0	17.2
Tasha	16.7	79.3	32.0	16.7	8.4	28.1	16.7	22.4	16.7	8.4	16.7	28.7	15.1
Mean	31.1	43.0	24.7	18.6	9.3	33.7	18.7	26.2	18.7	6.2	22.6	32.5	18.4
CV%	73.7	48.0	71.5	53.0	76.2	76.8	53.6	75.5	56.6	97.1	61.9	76.9	94.2
$LSD_{(P\leq0.05)}G$	38.0	34.3	6.7	16.4	8.2	42.9	16.6	15.2	17.6	5.7	23.2	41.4	16.2
$LSD_{(P\leq0.05)}$ E	5.5^{**}	5.2^{**}	6.7^{***}		2.7^{***}			6.2^{***}		2.3^{***}			6.6^{***}
$LSD_{(P\leq0.05)}I$	23.3	22.2	16.5		11.6			26.4		9.8			28.0

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p\leq0.05$); G=Genotype, E= Environment (Location & Planting Time), I= Genotype by Environment Interaction; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

.

4.4.3 Fungal diseases observed across different planting dates and environments

Fungal diseases observed were anthracnose, scab, angular leaf spot, rust, floury leaf spot and Cercospora leaf spots. The long rains sowing dates showed significant ($P \leq 0.05$) differences in scab intensity in all environments except in agro-ecological zone UM 2-T. The best performing crops were the early plantings with scab intensities of as low as 17.3% observed in crops in the first planting in agro-ecological zone UM 3. The late-planted genotypes were the worst performing with disease level of as high as 100% in the fourth planting of genotypes in agro-ecological zone UM 1 and the third planting of genotypes in agro-ecological zones UM 2 and LM 2 (Table 4.6). Small seeded genotypes were generally the best performers with scab levels of as low as 16.7% for varieties KK 22, KK 15 and GLP 585 in agro-ecological zone UM 2-T whereas large seeded genotypes generally had the highest intensities of the disease with as high as 74.2% on variety KK 071 in agro-ecological zone UM 2 (Table 4.6).

Scab symptoms appeared in all environments and plantings in the short rain season but only sowing dates of genotypes in agro-ecological zone UM 1 had significant ($P \leq 0.05$) variations. In this season, genotypes in agro-ecological zone UM 1 also had the highest overall scab intensities with up to 62.7% in the second sowing date whereas crops in agro-ecological zone UM 4 had the lowest disease levels of up to 25.5%. The genotypes showed significant ($P \leq 0.05$) differences in their scab intensities with variety KK 071 having the highest overall intensity of as high as 74.6% in agro-ecological zone UM 1 whereas varieties KK 15, KK 22, GLP 585 and GLP X92 were the best performing across the season with disease levels of as low as 16.7% (Table 4.7).

Angular leaf spot symptoms were observed in the short rains with only planting dates of genotypes in agro-ecological zones UM 1 and UM 2 showing significant ($P \leq 0.05$) variations

(Table 4.8). The highest disease pressure occurred in crops in agro-ecological zone UM 2 with up to 37.2% in its first planting whereas crops in agro-ecological zone UM 4 had the lowest ALS pressure with up to 17.0% in the third planting. The genotypes reacted significantly ($P \leq 0.05$) different in all environments with varieties GLP X92, KK 15 and GLP 585 consistently having the highest intensities of up to 64.4% for variety GLP X92 in the second crop in agro-ecological zone UM 2 (Table 4.8). Angular leaf spot pressure was low in the long rains season with no significant ($P \geq 0.05$) difference in the environments or planting times therefore, the data is not presented.

Only genotypes in agro-ecological zone UM 1 had significant ($P \leq 0.05$) variations in their rust intensities in the short rain season with the highest overall intensity of 44.7% found in the first planting (Table 4.9). The lowest disease levels occurred in crops planted in agro-ecological zone UM 4 with up to 20.3% in the third planting. The genotypes showed significant ($P \leq 0.05$) variations with the highest overall rust intensity found on variety KK 15 with 77.7% in agro-ecological zone UM 2 (Table 4.9). Rust pressure was low in the long rains season appearing only on variety KK 15 in UM 3-4 hence long rain data is not tabulated.

Floury leaf spot symptoms appeared only in crops in the second plantings in agro-ecological zones UM 1 and UM 3-4 in the long rain with only genotypes in agro-ecological zone UM 1 having significant ($P \leq 0.05$) variations (Table 4.10). In the short rain season, FLS appeared but with very low pressure and no significant difference between treatments, therefore the data is not tabulated. Bean anthracnose symptoms were observed only on genotypes in crops established for the first planting in agro-ecological zones UM 1 and UM 3-4 and the first and second plantings in agro-ecological zone UM 2 in the long rains with no significant ($P \geq 0.05$) difference between the genotypes in any of the environments therefore the data is not tabulated. Anthracnose symptoms did not appear in the short rain season.

Table 4.6: Percentage intensity of bean scab (*Elsinoë phaseoli*) on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone																		
	UM1					UM2-T			UM2				UM3-4				LM 2		
	1st	2nd	3rd	4th	Mean	1st	2nd	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean	2nd	3rd	Mean
Cal 194	16.7	16.7	46.2	100	44.9	34.0	16.7	25.3	16.7	28.6	100	48.4	16.7	28.3	33.9	26.3	16.7	100.0	38.9
Cal 33	16.7	16.7	69.8	100	50.8	16.7	45.4	31.1	34.0	75.8	100	69.9	16.7	33.9	16.7	22.4	33.9	100.0	44.6
Chelalang	16.7	16.7	69.4	100	50.7	51.7	34.2	42.9	40.0	76.9	100	72.3	16.7	33.9	16.7	22.4	16.7	100.0	38.9
GLP 1127	16.7	28.4	16.7	100	40.4	34.8	35.5	35.1	16.7	57.0	100	57.9	16.7	50.8	16.7	28.1	16.7	100.0	39.0
GLP 2	34.1	33.7	72.5	100	60.1	56.4	35.4	45.9	45.6	47.1	100	64.2	16.7	51.0	16.7	28.1	16.7	100.0	38.9
GLP 585	28.5	16.7	16.7	100	40.5	16.7	16.7	16.7	34.1	16.7	100	50.2	16.7	16.7	16.7	16.7	16.7	100.0	38.9
GLP x92	28.3	16.7	16.7	100	40.4	16.7	16.7	16.7	16.7	16.7	100	44.5	16.7	16.7	16.7	16.7	16.7	100.0	38.9
KAT B9	16.7	16.7	22.4	100	38.9	16.7	16.7	16.7	16.7	74.5	100	63.7	16.7	16.7	16.7	16.7	16.7	100.0	38.9
KAT x56	51.0	34.4	46.7	100	58.0	16.7	16.7	16.7	16.7	50.6	100	55.7	16.7	36.7	35.2	29.5	16.7	100.0	38.9
KK 071	16.7	16.7	75.4	100	52.2	34.2	35.9	35.1	33.9	88.6	100	74.2	16.7	57.8	35.8	36.8	40.0	100.0	46.7
KK 072	16.7	46.1	16.7	100	44.9	34.7	51.5	43.1	16.7	80.2	100	65.6	16.7	16.7	35.8	23.1	16.7	100.0	38.9
KK 15	29.2	16.7	16.7	100	40.6	16.7	16.7	16.7	16.7	16.7	100	44.5	16.7	16.7	16.7	16.7	16.7	100.0	38.9
KK 22	16.7	16.7	16.7	100	37.5	16.7	16.7	16.7	16.7	36.1	100	50.9	16.7	16.7	16.7	16.7	16.7	100.0	38.9
KK 8	16.7	16.7	45.6	100	44.7	16.7	28.3	22.5	16.7	44.5	100	53.7	16.7	16.7	34.6	22.7	16.7	100.0	38.9
Red 13	16.7	16.7	64.4	100	49.4	28.3	39.3	33.8	16.7	47.2	100	54.6	28.0	16.7	16.7	20.5	16.7	100.0	38.9
Red 16	47.7	33.8	69.4	100	62.7	45.5	33.7	39.6	16.7	60.5	100	59.0	16.7	16.7	35.0	22.8	16.7	100.0	38.9
Red 40	45.3	16.7	72.1	100	58.5	16.7	16.7	16.7	16.7	84.2	100	67.0	16.7	16.7	28.7	20.7	16.7	100.0	38.9
Tasha	34.4	16.7	35.5	100	46.6	16.7	52.5	34.6	16.7	16.7	100	44.5	16.7	28.4	52.5	32.5	16.7	100.0	38.9
Mean	25.9	21.8	43.9	100	47.9	27.0	29.2	28.1	22.5	51.0	100	57.8	17.3	27.1	25.5	23.3	18.9	100.0	39.7
CV%	69.9	63.9	32.0	0.0	28.0	73.2	79.0	76.9	65.4	40.4	0.0	22.5	26.8	73.1	71.0	71.1	60.7	0.0	17.1
$LSD_{(P \leq 0.05)}G$	30.0	23.2	23.3	0.0	10.8	32.8	38.2	24.5	24.4	34.2	0.0	14.0	7.7	32.9	30.0	15.5	19.1	0.0	6.3
$LSD_{(P \leq 0.05)}E$	4.9^{**}	7.1^{**}	4.6^{**}		5.1^{***}			8.3^{***}				5.7^{***}				6.3^{***}			2.6^{***}
$LSD_{(P \leq 0.05)}I$	20.3	30.3	19.6		21.6			35.2				24.2				26.8			11.0

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E= Environment (Location & Planting Time), I= Genotype by Environment Interaction; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

Table 4.7: Percentage intensity of bean scab (*Elsinoë phaseoli*) on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone												
	UM 1					UM 2				UM 4			
	1st	2nd	3rd	4th	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Cal 194	58.1	76.2	63.2	41.3	59.7	47.8	57.8	54.1	53.2	51.6	28.3	33.9	50.8
Cal 33	55.8	66.7	67.7	52.5	60.7	46.5	57.5	45.9	50.0	51.1	33.9	16.7	51.8
Chelalang	74.2	82.3	70.2	40.4	66.8	28.1	33.3	59.2	40.2	55.1	33.9	16.7	45.5
GLP 1127	63.1	63.6	70.3	34.7	57.9	53.3	43.8	73.5	56.9	51.0	50.8	16.7	47.9
GLP 2	61.5	72.2	78.8	53.1	66.4	49.3	47.2	64.3	53.6	58.5	51.0	16.7	55.2
GLP 585	16.7	28.4	28.7	16.7	22.6	16.7	16.7	34.6	22.7	22.3	16.7	16.7	22.4
GLP x92	16.7	16.7	16.7	16.7	16.7	35.7	29.6	37.9	34.4	16.7	16.7	16.7	24.8
KAT B9	44.8	74.8	66.7	52.7	59.8	28.6	55.5	50.5	44.9	42.5	16.7	16.7	47.3
KAT x56	56.7	72.2	63.6	52.0	61.1	55.0	64.6	62.0	60.5	56.5	36.7	35.2	50.4
KK 071	66.0	94.4	91.3	46.9	74.6	74.4	66.2	78.1	72.9	51.9	57.8	35.8	48.9
KK 072	73.0	75.0	59.9	40.0	62.0	55.0	49.9	50.2	51.7	58.1	16.7	35.8	50.4
KK 15	16.0	16.7	29.2	16.7	19.8	16.7	16.7	16.7	16.7	22.2	16.7	16.7	18.5
KK 22	16.7	16.7	16.7	28.5	19.6	*	28.4	28.9	27.8	*	16.7	16.7	16.7
KK 8	73.4	72.2	64.1	52.9	65.7	56.0	45.8	49.1	50.3	52.8	16.7	34.6	57.0
Red 13	70.0	77.3	63.2	51.6	65.5	61.6	49.7	44.7	52.0	52.0	16.7	16.7	48.4
Red 16	67.0	66.7	59.0	40.1	58.2	68.6	55.9	54.8	59.8	51.6	16.7	35.0	54.3
Red 40	68.6	83.3	66.0	65.9	70.9	61.2	44.8	70.1	58.7	52.1	16.7	28.7	55.3
Tasha	33.7	73.6	46.4	16.7	42.4	42.6	48.6	56.3	49.2	64.9	28.4	52.5	55.0
Mean	51.8	62.7	56.7	39.9	52.8	44.9	45.1	51.7	47.5	45.7	27.1	25.5	44.5
CV%	20.9	15.4	21.2	34.4	22.2	30.7	36.0	44.1	40.4	16.1	73.1	71.0	23.1
$LSD_{(P \leq 0.05)}G$	18.0	16.0	20.2	22.8	9.5	24.0	26.9	37.7	17.9	12.8	32.9	30.0	9.6
$LSD_{(P \leq 0.05)}$ E	48.7**	5.3**	6.2**		4.5***				7.3***				3.9***
$LSD_{(P \leq 0.05)}I$	19.8	22.5	26.3		19				31.1				16.6

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype; E= Environment (Location & Planting Time); I= Genotype by Environment Interaction;*=Missing data;**=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

Table 4.8: Percentage intensity of angular leaf spot (*Pseudocercospora griseola*) on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone												
	UM 1					UM 2				UM 4			
	1st	2nd	3rd	4th	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Cal 194	16.7	16.7	16.7	16.7	16.7	40.3	16.7	16.7	24.5	16.7	16.7	16.7	16.7
Cal 33	16.7	16.7	16.7	16.7	16.7	51.9	40.7	16.7	36.4	16.7	16.7	16.7	16.7
Chelalang	16.7	31.5	16.7	16.7	20.4	16.7	35.7	16.7	23.0	16.7	36.1	16.7	23.2
GLP 1127	41.3	31.9	16.7	16.7	26.6	28.6	28.6	16.7	24.6	16.7	16.7	16.7	16.7
GLP 2	16.7	47.5	16.7	29.2	27.5	40.1	16.7	16.7	24.5	16.7	16.7	16.7	16.7
GLP 585	16.7	16.7	16.7	22.4	18.1	39.8	29.1	16.7	28.5	28.3	28.4	16.7	24.5
GLP X92	28.4	16.7	22.5	22.5	22.5	51.8	64.4	48.6	54.9	30.2	16.7	16.7	21.2
KAT B9	58.7	35.1	31.1	16.7	35.4	63.7	28.7	28.6	40.3	16.7	16.7	16.7	16.7
KAT X56	30.2	28.7	22.6	28.7	27.5	49.8	16.7	16.7	27.7	16.7	28.3	16.7	20.5
KK 071	30.6	63.3	22.6	16.7	33.3	40.5	34.0	16.7	30.4	16.7	16.7	16.7	16.7
KK 072	16.7	22.6	22.5	16.7	19.6	40.0	22.4	16.7	26.4	16.7	16.7	16.7	16.7
KK 15	16.7	34.0	16.7	16.7	21.0	35.2	48.8	16.7	33.6	44.6	28.3	16.7	29.8
KK 22	16.7	47.2	43.4	28.8	34.0	16.7	40.2	16.7	32.6	16.7	22.4	22.4	22.9
KK 8	16.7	53.8	40.9	44.0	38.9	34.0	16.7	16.7	22.4	16.7	16.7	16.7	16.7
Red 13	16.7	16.7	29.2	28.1	22.7	40.0	28.1	28.6	32.2	16.7	16.7	16.7	16.7
Red 16	22.3	29.0	57.8	16.7	31.4	16.7	22.4	29.1	22.7	16.7	16.7	16.7	16.7
Red 40	16.7	43.1	63.0	16.7	34.9	34.1	39.8	16.7	30.2	16.7	16.7	16.7	16.7
Tasha	28.9	16.7	22.1	16.7	20.6	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Mean	23.5	31.5	27.5	21.4	26.0	37.2	30.4	20.5	29.5	19.4	20.0	17.0	19.0
CV%	50.6	47.0	46.1	54.6	50.8	53.8	48.2	58.2	56.0	49.3	48.4	13.7	41.5
$LSD_{(P \leq 0.05)}G$	19.8	24.6	21.3	19.7	10.7	33.7	24.3	19.8	15.5	16.2	16.1	3.9	7.4
$LSD_{(P \leq 0.05)}$ E	5.5^{**}	5.6^{**}	3.8^{**}		5.0^{***}				6.3^{***}				3.0^{***}
$LSD_{(P \leq 0.05)}I$	23.4	23.7	16.2		21.3				26.8				12.8

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E= Environment (Location & Planting Time); I= Genotype by Environment Interaction; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

Table 4.9: Percentage intensity of bean leaf rust (*Uromyces appendiculatus*) on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone												
	UM 1					UM 2				UM 4			
	1st	2nd	3rd	4th	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Cal 194	16.7	34.2	34.5	16.7	25.5	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Cal 33	16.7	16.7	28.6	16.7	19.7	27.9	16.7	16.7	20.4	16.7	16.7	16.7	16.7
Chelalang	52.5	69.7	60.0	54.5	59.2	16.7	30.6	16.7	21.3	16.7	16.7	16.7	16.7
GLP 1127	60.1	69.4	30.3	22.4	45.6	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
GLP 2	45.5	66.3	59.8	72.7	61.1	16.7	16.7	16.7	16.7	16.7	16.7	28.2	20.5
GLP 585	59.4	16.7	43.2	28.5	36.9	57.5	59.2	16.7	59.3	48.4	41.8	40.2	43.5
GLP X92	65.2	48.7	16.7	41.3	43.0	52.7	45.7	34.5	44.3	28.3	40.9	16.7	28.6
KAT B9	44.3	30.1	32.2	29.0	33.9	28.0	28.1	29.7	28.6	16.7	16.7	16.7	16.7
KAT X56	60.7	29.5	43.8	16.7	37.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
KK 071	28.7	47.8	38.1	16.7	32.8	34.0	16.7	16.7	22.5	16.7	16.7	16.7	16.7
KK 072	59.1	28.6	49.6	28.4	41.4	39.7	16.7	16.7	24.4	16.7	16.7	16.7	16.7
KK 15	62.4	29.4	29.3	22.4	35.9	74.4	76.4	82.2	77.7	48.6	61.6	40.4	50.2
KK 22	52.8	29.6	16.7	29.5	32.1	*	40.4	28.3	35.5	*	16.7	22.4	19.4
KK 8	27.9	28.7	31.4	16.7	26.2	22.3	16.7	16.7	18.6	16.7	16.7	16.7	16.7
Red 13	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	29.2	16.7	20.9
Red 16	22.3	28.9	16.7	16.7	21.1	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Red 40	55.2	16.7	32.3	16.7	30.2	22.3	16.7	16.7	18.5	16.7	16.7	16.7	16.7
Tasha	59.3	28.7	32.5	16.7	33.6	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7
Mean	44.7	35.4	34.0	26.4	35.1	29.4	26.7	25.1	27.1	21.6	22.6	20.3	21.3
CV%	25.0	47.8	57.6	53.4	48.8	43.0	43.0	36.3	40.9	42.6	39.8	40.1	41.1
$LSD_{(P \leq 0.05)}G$	18.5	28.1	32.7	23.8	13.8	20.7	19.1	15.2	10.4	14.9	14.9	13.5	8.2
$LSD_{(P \leq 0.05)}$ E	4.2^{**}	5.0^{**}	5.6^{**}		6.5^{***}				4.2^{***}				3.3^{***}
$LSD_{(P \leq 0.05)}I$	17.8	21.0	23.7		27.7				17.9				14.2

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype; E= Environment (Location & Planting Time); I= Genotype by Environment Interaction; *=Missing data; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

Table 4. 10: Percentage intensity of floury leaf spot (*Mycovellosiella phaseoli*) on common bean genotypes in the second planting of different agro-ecological zones of Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone		Mean
	UM 1	UM 3-4	
Red 13	43.7	16.7	12.1
KK 072	37.6	16.7	10.8
Red16	28.4	16.7	9.0
GLP 1127	16.7	28.2	9.0
KK 071	16.7	24.5	8.2
Mean	20.0	17.7	7.5
CV%	46.0	31.0	7.0
$LSD_{(P \leq 0.05)}G$	15.251	9.133	3.452
$LSD_{(P \leq 0.05)}$ E	1.819		
$LSD_{(P \leq 0.05)}I$	7.718		

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E= Environment (Location & Planting Time), I= Genotype by Environment Interaction.

4.4.4 Viral diseases observed across different planting dates and environments

Viral diseases observed were bean common mosaic virus, bean common mosaic necrosis virus and golden mosaic virus. There were significant ($P \leq 0.05$) differences in BCMNV incidence between the genotypes with only eight genotypes showing symptoms in the long rain season. Only plantings established in agro-ecological zones UM 2-T, UM 3-4 and LM 2 had significantly ($P \leq 0.05$) different BCMNV incidences (Table 4.11). Crops established as late plantings generally had more disease pressure with up to 12.7% in third planting in agro-ecological zone UM 1 crops whereas early planted crops performed best with incidences of as low as 0.1% in the first planting in agro-ecological zone UM 2. The genotypes showed significant ($P \leq 0.05$) variations in their incidence with variety KK 22 significantly ($P \leq 0.05$) the worst performing with BCMNV incidence of as high as 100% in the third planting in agro-ecological zone UM 1 (Table 4.11).

Necrosis symptoms appeared only in genotypes in agro-ecological zones UM 1 and UM 2 in the short rain season with significant ($P \leq 0.05$) variations in the sowing dates. The highest incidences were observed in genotypes in agro-ecological zone UM 1 with up to 11.7% in their second planting whereas variety KK 22 had the highest overall disease incidence of up to 33.3% in the third planting in agro-ecological zone UM 1(Table 4.12).

Viral mosaic symptoms appeared in crops in all sowing dates of the long rain season with only plantings and genotypes in agro-ecological zones UM 2-T and LM 2 showing significant ($P \leq 0.05$) variations (Table 4.13). The highest overall mosaic incidence was in crops in agro-ecological zone UM 3-4 with up to 8.0% in the last planting while agro-ecological zone UM 1 crops had the lowest disease levels of up to 0.3% in the second planting. The best performing genotypes were varieties KK 072, KK 8 and Red 13 as they did not to show BCMV symptoms in any environment whereas variety Tasha had the highest overall incidence with up to 25.6% in the first planting in agro-ecological zone UM 2-T (Table 4.13). Bean common mosaic virus pressure was low in the short rains season with no significant ($P \geq 0.05$) difference between the environments, planting dates or genotypes therefore short rain data is not tabulated.

Golden mosaic symptoms appeared only in genotypes in the second plantings in agro-ecological zones UM 1 and LM 2 and those of second and third planting in agro-ecological zone UM 3-4 in the long rain season (Table 4.14). The highest overall incidence was found in crops in agro-ecological zone UM 1 with 2.5% in the second planting whereas among the genotypes, variety Cal 33 was the worst performer with up to 20.0% in the second plant in the same environment.

Table 4.11: Percentage incidence of bean common mosaic necrosis virus symptoms on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone																	
	UM 1				UM 2-T			UM 2			UM 3-4				LM 2			
	1st	2nd	3rd	Mean	1st	2nd	Mean	1st	2nd	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
GLP 1127	20.5	25.7	100.0	48.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	20.0	7.4	0.0	15.9	54.9	23.6
GLP 585	1.5	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GLP X92	1.4	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.3	0.0	8.3	0.0	2.8
KAT B9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	0.0	6.7	0.0	0.0	0.0	0.0
KK 071	5.0	10.2	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KK 072	53.0	18.7	62.2	44.6	0.0	2.6	1.3	0.0	0.0	0.0	2.2	1.0	25.0	9.4	0.0	17.4	36.1	17.9
KK 22	75.8	98.7	66.7	80.4	26.9	69.1	48	0.9	33.3	17.1	42.7	18.5	80.0	47.1	0.0	73.7	97.9	57.2
Red 16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.8	4.9	0.0	0.0	0.0	0.0
Mean	8.7	8.5	12.7	10.0	1.5	4.0	2.7	0.1	2.2	1.1	2.5	2.3	7.8	4.2		6.4	10.5	5.6
CV%	102.4	106.4	142.6	129.3	469.8	163.3	243.8	734.8	636.0	876.2	119.7	462.8	183.1	251.6		131.1	117.9	155.6
$LSD_{(P \leq 0.05)}G$	14.8	15.0	30.1	12.1	11.6	10.8	7.7	0.6	23.0	11.3	5.1	17.8	23.6	9.9		13.9	20.5	8.2
$LSD_{(P \leq 0.05)}E$	1.9^{**}	3.9^{**}	5.0^{**}	4.9^{***}			2.6^{***}			3.8^{***}				4.0^{***}				3.3^{***}
$LSD_{(P \leq 0.05)}I$	7.9	16.4	21.3	21.0			10.9			16.0				17.2				14.2

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E= Environment (Location & Planting Time), I= Genotype by Environment Interaction; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

Table 4.12: Percentage incidence of bean common mosaic necrosis virus symptoms on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone					
	UM1					UM 2
	1st	2nd	3rd	4th	Mean	2nd
Cal 194	0.0	1.6	0.0	0.0	0.4	0.0
Cal 33	0.0	2.4	0.0	0.0	0.6	0.0
Chelalang	0.0	4.6	0.0	0.0	1.1	0.0
GLP 1127	3.5	0.0	0.0	0.0	0.9	0.0
GLP 2	0.0	27.6	0.0	0.0	6.9	0.0
KAT B9	3.2	33.3	0.0	0.0	9.1	0.0
KK 071	0.0	33.3	0.0	0.0	8.3	9.8
KK 072	8.4	20.3	33.3	0.0	15.5	3.8
KK 15	0.4	8.7	0.0	0.0	2.3	0.0
KK 22	24.3	26.7	33.3	21.5	26.4	18.7
KK 8	1.5	18.7	0.0	0.0	5.0	0.0
Red 40	0.0	33.3	0.0	0.0	8.3	0.0
Tasha	0.0	0.0	3.9	0.0	1.0	0.0
Mean	2.3	11.7	3.9	1.2	4.6	1.8
CV%	110.3	261.6	512.8	854.6	405.5	134.4
$LSD_{(P \leq 0.05)}G$	4.2	50.8	33.5	15.0	15.1	4.0
$LSD_{(P \leq 0.05)}$ E		6.7^{**}			7.1^{***}	
$LSD_{(P \leq 0.05)}I$		28.2			30.2	

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E= Environment (Location & Planting Time), I= Genotype by Environment Interaction; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

Table 4.13: Percentage incidence of bean common mosaic virus symptoms on common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone															
	UM 1				UM 2-T			UM 2			UM 3-4				LM 2	
	1st	2nd	3rd	Mean	1st	2nd	Mean	1st	2nd	Mean	1st	2nd	3rd	Mean	2nd	3rd	Mean
Cal 194	0.0	0.0	0.0	0.0	2.2	0.0	1.1	0.9	0.0	0.3	0.0	0.0	24.9	8.3	0.0	0.0	0.0
Cal 33	0.0	0.0	1.0	0.3	1.9	0.0	1.0	0.0	2.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Chelalang	0.0	0.0	0.0	0.0	3.8	0.0	1.9	0.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GLP 1127	0.0	0.0	0.0	0.0	1.1	0.0	0.5	3.3	0.0	1.1	3.1	0.0	0.0	1.0	0.0	0.0	0.0
GLP 2	0.0	3.7	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
GLP 585	1.5	0.0	6.4	2.6	5.6	1.7	3.6	2.3	0.0	0.8	0.0	0.0	24.7	8.2	0.0	10.6	3.5
GLP X92	0.0	0.0	6.4	2.1	3.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KAT B9	2.6	0.0	0.0	0.9	1.3	0.0	0.7	0.0	0.0	0.0	0.0	0.0	22.2	7.4	0.0	0.0	0.0
KAT X56	0.0	0.0	0.0	0.0	5.7	0.0	2.8	1.9	0.0	0.6	0.0	0.0	28.7	9.6	0.0	0.0	0.0
KK 071	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.6	0.0	0.0	0.0	0.0	4.4	0.0	1.5
KK 072	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
KK 15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.7	0.0	0.0	25.3	8.4	0.0	4.2	1.4
KK 22	0.0	0.0	0.0	0.0	3.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1	0.0	1.7
KK 8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red 13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Red 16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3	2.8	0.0	0.0	1.0	0.3	0.0	0.0	0.0
Red 40	1.0	0.0	0.0	0.3	16.1	0.0	8.1	6.5	0.0	2.2	2.9	0.0	17.8	6.9	0.0	0.0	0.0
Tasha	3.3	2.0	0.0	1.8	25.6	0.0	12.8	9.6	0.0	3.2	2.3	0.0	0.0	0.8	0.0	2.8	0.9
Mean	0.5	0.3	0.8	0.5	3.9	0.1	2.0	1.6	0.6	0.7	0.5		8.0	2.8	0.5	1.0	0.5
CV%	408.2	55.2	142.6	457.0	113.2	734.8	156.8	154.5	593.8	282.7	425.3		254.4	4.7	528.5	213.1	398.2
$LSD_{(P \leq 0.05)}G$	3.1	2.9	30.1	3.8	7.2	1.1	3.6	4.1	5.9	3.6	3.3		33.9	15.5	4.7	3.5	1.9
$LSD_{(P \leq 0.05)}$ E	1.0^{**}	0.8^{**}	4.5^{**}	0.9^{***}			1.2^{***}			1.2^{***}				5.1^{***}			0.8^{***}
$LSD_{(P \leq 0.05)}I$	4.2	3.5	19.1	3.8			5.0			5.1				21.7			3.2

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E= Environment (Location & Planting Time), I= Genotype by Environment Interaction; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

Table 4.14: Percentage incidence of golden mosaic virus symptoms on common bean genotypes in the second and third planting of different agro-ecological zones of Western Kenya during the 2017 long rains.

Genotypes	Agro-Ecological Zone			
	2nd Planting			3rd Planting
	UM 1	LM 2	UM 3-4	UM 3-4
Cal 33	20.0	3.0	1.2	1.2
Chelalang	3.3	0.0	0.0	0.0
GLP 2	3.9	6.7	2.3	0.0
KK 071	4.8	0.0	0.0	0.0
KK 8	6.3	16.1	1.3	8.2
Red 13	1.1	0.0	0.0	0.0
Tasha	6.5	0.0	28.3	0.0
Red 40	0.0	0.0	0.0	1.8
Mean	2.5	1.4	1.8	0.6
CV%	355.5	330.7	635.3	394.9
$LSD_{(P \leq 0.05)}G$	15.0	7.9	19.4	4.0
$LSD_{(P \leq 0.05)}$ E	3.4			
$LSD_{(P \leq 0.05)}I$	14.5			

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E=Environment, I= Genotype by Environment Interaction.

4.4.5 Grain yield and yield components of different planting dates and environments

The environments showed significant ($P \leq 0.05$) differences between grain yields from different planting dates in the long and short rain seasons. Crops established in the early planting dates had the highest yields with up to 1.9 t/ha in the first plantings in agro-ecological zones UM 1, UM 2 and UM 3-4. Late sowing dates were the worst performing with yields of 0 t ha^{-1} in the fourth planting of genotypes in agro-ecological zone UM 1 and the third and fourth plantings of genotypes in agro-ecological zones UM 2 and LM 2 (Table

4.15). The genotypes showed significant ($P \leq 0.05$) differences in yield in all environments with varieties KK 22 and GLP 1127 being consistently the worst performing genotypes across the season with overall yields of as low as 0.4 t/ha for variety KK 22 in agro-ecological zones UM 1 and UM 2 (Table 4.15).

In the short rains, the highest grain yields were generally observed in the early plantings with as high as 1.5 t/ha in the first planting of genotypes in agro-ecological zone UM 1 whereas late plantings were the worst performers with overall yields of as low as 0.5 t/ha for genotypes in the fourth planting in agro-ecological zone UM 1. Genotypes in crops established as the first planting in agro-ecological zone UM 2 performed worst in the environment with an overall grain yield of 0.6 t/ha. The genotypes had significant ($P \leq 0.05$) differences in their yields in all environments with 1.7 t/ha, for variety Cal 33 in agro-ecological zone UM 1 being the highest overall yield observed in the season. The worst performing genotype in this season and across the environments was consistently variety KK 22 with yield of as low as 0.1 t/ha in agro-ecological zone UM 1 (Table 4.16).

The environments showed significant ($P \leq 0.05$) differences in the seed weight of their bean cropping dates in both the long and short rain seasons. The highest seed weights in the long rain season were observed in early planted genotypes which significantly ($P \leq 0.05$) outperformed the late plantings with 38.0 g in the first planning in agro-ecological zone UM 1 while most late plantings did not seed (Table 4.17). The genotypes had significant ($P \leq 0.05$) differences in seed weight in all environments with variety GLP 2 the overall best performer with seed weight of as high as 44.4 g in agro-ecological zone UM 3-4 while variety KK 22 was the overall worst performer with seed weight of as low as 6.1 g in agro-ecological zone UM 1 (Table 4.17).

Crops established as the early plantings significantly ($P \leq 0.05$) had the highest seed weights in the short rain season. Seeds weights of as high as 29.7 g were observed in the first planting in agro-ecological zone UM 1 whereas genotypes in late sowing dates had the lowest seed weights with 18.5 g in the fourth planting in agro-ecological zone UM 1 (Table 4.18). The genotypes had significant ($P \leq 0.05$) differences in seed weight with variety GLP 2 having the heaviest overall seeds with as much as 36.8 g in agro-ecological zone UM 2 whereas variety KK 22 was the worst performer with seed weight of as low as 4.9 g in agro-ecological zone UM 1 (Table 4.18).

The environments showed significant ($P \leq 0.05$) differences in seed damage between the different planting dates of genotypes in both the long and short rain season. In the long rains, most seed damage was found in late plantings with up to 100% damage observed on genotypes in the fourth planting in agro-ecological zone UM 1 and the third plantings in agro-ecological zones UM 2, UM 3-4 and LM 2. Early planted crops generally had the least damage with as low as 9.3% in the first planting in agro-ecological zone UM 2-T. The genotypes had significantly ($P \leq 0.05$) differing seed damage levels with variety GLP 1127 being overall the worst performer with up to 71.5% damage in agro-ecological zone LM 2 (Table 4.19).

In the short rain season, most seed damage occurred in late planted crops with up to 100% damage in the third planting in agro-ecological zone UM 2 whereas the early plantings had the least damage with as low as 11.4% in agro-ecological zone UM 2 (Table 4.20). The genotypes had significantly ($P \leq 0.05$) different damage levels with variety KK 22 consistently among the worst performing genotype with seed damage of up to 68.1, 73.8 and 51.7% in agro-ecological zones UM 1, UM 2 and UM 4 respectively.

Table 4.15: Grain yield in tons per hectare of common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone																			
	UM 1					UM 2-T			UM 2				UM3-4				LM 2			
	1st	2nd	3rd	4th	Mean	1st	2nd	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Cal 194	2.1	2.2	0.5	0.0	1.2	2.1	0.6	1.4	2.3	1.9	0.0	1.4	1.9	2.3	1.2	1.9	2.2	1.4	0.0	1.2
Cal 33	2.3	2.2	0.7	0.0	1.3	2.1	0.5	1.3	2.0	1.8	0.0	1.3	2.2	2.1	1.2	1.9	2.1	1.2	0.0	1.1
Chelalang	1.7	1.9	0.6	0.0	1.1	1.6	0.4	1.0	1.9	0.5	0.0	0.8	1.9	2.3	1.6	2.0	1.5	0.5	0.0	0.7
GLP 1127	1.8	0.7	0.0	0.0	0.6	1.5	0.1	0.8	2.0	0.1	0.0	0.7	1.7	0.9	0.0	0.9	1.3	0.3	0.0	0.5
GLP 2	1.9	2.1	0.5	0.0	1.1	2.0	1.3	1.7	1.9	1.3	0.0	1.1	2.0	2.2	1.4	1.9	1.9	2.1	0.0	1.3
GLP 585	1.7	1.7	0.8	0.0	1.1	1.6	0.7	1.2	1.5	1.0	0.0	0.8	1.8	2.2	0.7	1.6	1.8	0.7	0.0	0.8
GLP x92	1.6	1.9	0.1	0.0	0.9	1.6	0.9	1.3	1.5	0.9	0.0	0.8	1.7	1.0	1.5	1.4	1.4	0.4	0.0	0.6
KAT B9	1.7	1.3	0.2	0.0	0.8	1.5	0.0	0.8	1.5	0.4	0.0	0.6	1.7	0.7	0.0	0.8	1.7	0.3	0.0	0.7
KAT x56	1.9	1.7	0.0	0.0	0.9	1.7	0.1	0.9	1.8	0.0	0.0	0.6	2.1	2.3	0.4	1.6	1.4	0.3	0.0	0.6
KK 071	1.6	2.2	0.1	0.0	1.0	1.6	0.3	1.0	1.9	0.2	0.0	0.7	1.7	1.5	0.3	1.2	1.8	1.5	0.0	1.1
KK 072	1.9	2.2	0.0	0.0	1.0	1.9	0.9	1.4	1.8	0.7	0.0	0.8	2.1	1.2	0.5	1.3	1.9	1.3	0.0	1.1
KK 15	1.9	2.2	1.0	0.0	1.3	1.8	0.9	1.4	1.9	0.9	0.0	0.9	1.7	2.2	0.8	1.6	1.7	0.6	0.0	0.8
KK 22	1.2	0.4	0.0	0.0	0.4	1.0	0.0	0.5	1.2	0.0	0.0	0.4	0.8	0.6	0.0	0.5	2.0	0.3	0.0	0.8
KK 8	1.9	1.8	0.5	0.0	1.0	2.1	0.5	1.3	1.8	0.4	0.0	0.7	1.8	1.8	1.2	1.6	2.0	1.1	0.0	1.0
Red 13	2.2	2.0	0.7	0.0	1.2	2.1	0.7	1.4	2.2	1.6	0.0	1.2	2.0	2.2	0.7	1.6	2.0	1.9	0.0	1.3
Red 16	2.2	2.2	0.4	0.0	1.2	2.2	0.9	1.6	2.5	1.7	0.0	1.4	2.2	2.2	1.0	1.8	2.2	1.1	0.0	1.1
Red 40	2.0	2.0	0.4	0.0	1.1	1.5	0.4	1.0	1.8	0.8	0.0	0.9	2.0	1.4	0.3	1.2	2.0	0.7	0.0	0.9
Tasha	2.1	1.5	0.5	0.0	1.0	1.6	0.1	0.9	2.0	0.7	0.0	0.9	2.3	1.8	1.0	1.7	1.9	0.7	0.0	0.9
Mean	1.9	1.8	0.4	0.0	1.0	1.7	0.5	1.1	1.9	0.8	0.0	0.9	1.9	1.7	0.8	1.5	1.8	0.9	0.0	0.9
CV%	22.5	33.6	52.9		38.6	21.6	63.9	37.9	17.3	76.4		45.0	28.8	55.4	95.8	50.7	25.7	64.4		58.3
$LSD_{(P \leq 0.05)}G$	0.7	1.0	0.3		0.3	0.6	0.6	0.5	2.5	1.0		0.4	0.9	1.6	1.2	0.7	0.8	0.9		0.5
$LSD_{(P \leq 0.05)}$ E	0.2^{**}	0.3^{**}	0.1^{**}		0.2^{***}			0.2^{***}				0.2^{***}				0.3^{***}				0.9^{***}
$LSD_{(P \leq 0.05)}$I	0.7	1.1	0.5		0.6			0.7				0.7				1.2				0.2

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype, E= Environment (Location & Planting Time), I= Genotype by Environment Interaction; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

Table 4.16: Grain yield in tons per hectare of common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone												
	UM 1					UM 2				UM 4			
	1st	2nd	3rd	4th	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Cal 194	2.1	1.7	1.2	0.8	1.4	0.8	0.8	0.9	0.8	1.0	0.8	0.4	0.7
Cal 33	2.1	2.3	1.8	0.8	1.7	0.6	0.7	0.7	0.7	1.0	0.8	0.4	0.7
Chelalang	1.4	1.2	1.3	0.4	1.1	0.7	0.3	0.1	0.4	0.8	1.3	0.4	0.8
GLP 1127	1.1	0.5	0.4	0.1	0.5	0.6	0.6	0.7	0.6	1.2	1.0	0.8	1.0
GLP 2	1.8	1.5	1.5	0.5	1.3	0.7	1.1	1.7	1.2	1.3	0.9	0.5	0.9
GLP 585	1.2	1.1	0.8	0.2	0.8	0.3	0.3	0.4	0.3	0.6	0.8	0.1	0.5
GLP x92	1.5	0.7	0.8	0.5	0.9	0.3	0.7	0.6	0.5	1.0	1.0	0.9	0.9
KAT B9	1.5	0.9	0.8	0.6	0.9	0.5	1.1	0.9	0.9	1.2	0.9	0.7	0.9
KAT x56	1.5	1.7	1.1	0.6	1.2	0.8	1.1	1.2	1.1	1.0	0.9	1.0	0.9
KK 071	1.4	0.4	0.3	0.2	0.6	0.6	1.5	0.4	0.8	0.8	0.6	0.5	0.6
KK 072	0.8	0.5	0.2	0.0	0.4	0.6	0.7	0.4	0.6	0.8	0.7	0.4	0.6
KK 15	1.0	1.3	0.6	0.2	0.8	0.2	0.2	1.0	0.5	1.0	0.5	0.4	0.7
KK 22	0.3	0.2	0.0	0.0	0.1	*	0.6	0.1	0.3	*	0.8	0.4	0.7
KK 8	1.8	1.0	1.0	0.9	1.2	0.6	1.3	0.9	0.9	1.0	0.7	0.4	0.7
Red 13	2.2	1.4	1.3	0.8	1.4	0.6	1.3	0.4	0.8	1.0	0.4	0.6	0.7
Red 16	2.1	2.0	1.7	0.9	1.7	1.0	1.0	1.4	1.1	0.8	0.6	0.4	0.6
Red 40	1.5	1.2	0.8	0.5	1.0	0.8	1.0	0.8	0.9	1.1	0.5	0.7	0.8
Tasha	1.7	1.3	0.9	0.5	1.2	0.6	0.7	1.2	0.8	0.7	0.8	0.5	0.7
Mean	1.5	1.2	0.9	0.5	1.0	0.6	0.8	0.8	0.7	1.0	0.8	0.5	0.8
CV%	21.2	35.6	32.2	50.1	35.3	50.6	46.0	70.7	58.7	34.1	25.9	49.8	36.2
$LSD_{(P \leq 0.05)}G$	0.5	0.7	0.5	0.4	0.3	0.5	0.6	1.4	0.4	0.5	0.3	0.4	0.3
$LSD_{(P \leq 0.05)}E$	0.1^{**}	0.2^{**}	0.2^{**}		0.1^{***}				0.2^{***}				0.1^{***}
$LSD_{(P \leq 0.05)}I.$	0.6	0.7	0.7		0.6				0.7				0.4

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype; E= Environment (Location & Planting Time); I= Genotype by Environment Interaction; *=Missing data; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

Table 4.17: Weight in grams of seeds of common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone																
	UM 1				UM 2-T			UM 2			UM 3-4				LM 2		
	1st	2nd	3rd	Mean	1st	2nd	Mean	1st	2nd	Mean	1st	2nd	3rd	Mean	1st	2nd	Mean
Cal 194	37.5	26.6	19.1	20.8	35.9	14.3	24.6	34.2	27.0	20.4	31.1	37.5	23.4	30.6	37.8	20.3	19.4
Cal 33	45.3	43.3	16.7	26.3	39.2	17.9	28.6	40.9	32.4	24.6	44.0	45.3	42.1	43.8	43.4	14.1	19.2
Chelalang	36.9	34.1	14.3	21.3	42.9	14.1	29.3	38.8	20.7	19.8	37.4	37.1	36.8	37.1	43.4	10.1	17.8
GLP 1127	38.5	13.7	0.0	13.1	38.1	10.9	24.5	40.1	13.0	17.7	37.9	26.6	0.0	21.4	38.8	0.0	12.9
GLP 2	46.7	37.6	27.2	27.9	42.4	24.7	33.6	47.1	20.0	22.4	37.4	60.7	35.1	44.4	49.6	38.5	29.4
GLP 585	33.2	26.1	12.5	17.9	19.1	13.4	16.2	23.1	16.1	13.1	15.4	19.9	16.1	17.2	24.3	10.4	11.6
GLP X92	38.5	25.9	0.2	16.1	30.5	20.3	25.4	38.3	7.7	15.3	26.9	14.5	20.9	20.8	20.2	8.5	10.2
KAT B9	43.1	23.7	14.9	20.4	38.7	0.0	20.3	36.2	7.4	14.5	33.4	50.0	0.0	27.8	17.0	9.3	9.4
KAT X56	36.9	17.3	0.0	13.6	34.8	5.7	20.3	34.3	0.0	11.4	33.1	30.4	12.9	25.5	20.9	9.1	10.0
KK 071	44.4	28.3	6.2	19.7	40.6	15.0	27.8	39.8	5.6	15.1	31.2	11.7	0.0	14.3	37.9	25.6	21.2
KK 072	42.4	28.3	0.0	17.7	37.6	21.5	29.5	44.2	29.5	24.5	37.9	29.8	9.0	25.5	36.4	18.5	18.3
KK 15	31.7	27.4	17.5	19.2	30.4	13.8	22.1	34.8	18.3	17.7	23.1	35.8	20.4	26.4	34.7	14.2	16.3
KK 22	19.4	5.4	0.0	6.1	21.1	0.0	11.5	29.2	0.0	9.7	15.1	16.1	0.0	10.3	25.1	5.2	10.1
KK 8	39.6	34.0	20.3	23.5	39.9	12.8	26.4	44.7	11.9	18.9	32.7	31.5	43.1	35.8	42.2	27.0	23.1
Red 13	35.9	30.0	17.6	20.9	31.9	12.1	22.0	36.1	23.6	19.9	31.0	49.3	15.0	31.7	31.2	20.4	17.2
Red 16	38.0	27.5	17.9	20.8	32.2	19.2	25.7	36.7	24.7	20.5	30.0	48.4	20.3	32.9	33.5	17.6	17.0
Red 40	31.4	29.1	15.9	19.1	28.6	10.7	19.7	30.1	18.1	16.1	24.1	21.6	10.1	18.6	27.8	13.1	13.6
Tasha	44.6	21.9	15.0	20.4	41.2	13.4	27.3	41.7	33.7	25.2	37.1	34.6	12.9	28.2	37.5	10.2	15.9
Mean	38.0	26.7	12.0	19.2	34.7	13.3	24.5	37.2	17.2	18.2	31.0	33.4	17.6	27.4	33.4	15.1	16.3
CV%	12.8	12.5	57.2	27.5	8.4	83.6	36.4	12.9	64.1	38.1	11.8	31.9	59.2	30.2	27.3	59.8	53.2
$LSD_{(p\leq 0.05)}G$	8.1	11.0	11.4	4.3	4.9	18.5	10.1	8.0	18.3	6.5	6.1	18.1	17.7	7.8	15.2	14.7	8.0
$LSD_{(p\leq 0.05)}E$	1.1^{**}	4.1^{**}	2.2^{**}	2.0^{***}			3.4^{***}			2.6^{***}				3.2^{***}			3.2^{***}
$LSD_{(p\leq 0.05)}I$	4.5	17.4	9.2	8.5			14.3			11.2				13.4			13.8

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p\leq 0.05$); G=Genotype, E= Environment (Location & Planting Time); I= Genotype by Environment Interaction; **=LSD for comparing similar plantings across different environments; ***=LSD for comparing different plantings within an environment.

Table 4.18: Weight in grams of seeds of common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone												
	UM 1					UM 2				UM 4			
	1st	2nd	3rd	4th	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Cal 194	34.4	28.0	24.8	26.5	28.4	29.7	31.2	17.1	26.5	26.4	25.9	13.3	21.8
Cal 33	38.2	35.5	28.2	28.5	32.6	34.6	38.3	31.6	35.1	33.1	28.7	23.6	28.5
Chelalang	34.8	36.5	26.4	24.3	30.5	34.0	25.2	34.9	31.6	31.4	25.1	22.1	26.2
GLP 1127	31.2	24.1	24.3	17.1	24.2	27.6	33.5	25.3	30.3	31.7	28.7	28.4	29.6
GLP 2	36.7	33.0	28.5	16.3	28.6	37.0	34.5	38.0	36.8	32.6	28.1	24.4	28.3
GLP 585	16.6	16.9	15.8	10.0	14.8	18.3	21.5	10.6	17.9	19.3	16.8	5.4	13.8
GLP x92	28.5	22.5	25.7	14.8	22.9	24.1	26.3	24.5	23.4	28.8	25.4	20.3	24.8
KAT B9	27.9	30.1	27.3	24.8	27.5	28.0	28.1	32.2	31.2	27.2	24.9	22.1	24.7
KAT x56	27.3	29.6	23.5	23.4	25.9	27.1	27.8	23.6	26.5	29.4	23.6	21.3	24.8
KK 071	32.9	10.0	17.3	23.7	21.0	30.9	34.1	1.3	23.6	33.7	26.0	36.6	32.1
KK 072	36.4	24.4	14.1	0.2	18.0	29.9	31.3	1.4	22.3	31.6	28.3	15.4	25.1
KK 15	27.0	28.5	22.9	13.3	22.9	20.2	15.5	25.2	21.8	26.0	22.1	20.6	22.9
KK 22	13.0	6.5	0.0	0.0	4.9	*	16.2	0.6	9.5	*	16.0	11.1	15.6
KK 8	31.1	30.8	27.7	24.9	28.6	29.5	29.0	30.7	30.0	32.4	27.9	14.8	25.0
Red 13	30.1	25.3	23.4	23.5	25.6	26.3	27.8	1.4	20.0	24.3	22.1	17.5	21.3
Red 16	28.3	24.8	24.3	20.9	24.6	26.5	26.5	27.0	26.7	24.8	21.3	15.9	20.7
Red 40	25.0	23.2	17.2	16.6	20.5	22.0	25.1	23.6	23.8	21.6	15.4	13.8	17.0
Tasha	34.8	31.7	27.8	24.1	29.6	35.9	33.9	15.5	30.4	33.7	31.8	20.9	28.8
Mean	29.7	25.6	22.2	18.5	24.0	27.6	28.1	20.3	26.0	27.7	24.3	19.3	24.0
CV%	10.9	19.5	24.4	41.7	22.8	12.7	23.3	57.7	30.8	7.7	10.8	66.7	31.5
$LSD_{(P \leq 0.05)}G$	5.4	8.3	8.8	12.6	4.4	6.0	10.9	32.3	7.5	3.7	4.4	21.4	7.0
$LSD_{(P \leq 0.05)}$ E	1.4^{**}	2.1^{**}	4.4^{**}		2.1^{***}				3.1^{***}				2.9^{***}
$LSD_{(P \leq 0.05)}I$	6.1	9.1	18.7		8.8				13.0				12.2

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p \leq 0.05$); G=Genotype; E= Environment (Location & Planting Time); I= Genotype by Environment Interaction; *=Missing data; **=LSD for comparing similar plantings across different environments;***=LSD for comparing different plantings within an environment.

Table 4.19: Percentage yield loss due to damaged seeds of common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2017 long rains.

Genotype	Agro-Ecological Zone																			
	UM 1					UM 2-T			UM 2				UM3-4				LM 2			
	1st	2nd	3rd	4th	Mean	1st	2nd	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean	1st	2nd	3rd	Mean
Cal 194	13.8	6.6	25.0	100	36.3	15.7	13.0	14.3	9.1	14.1	100	41.1	5.3	61.4	68.1	44.9	17.5	13.4	100	43.6
Cal 33	31.6	13.8	47.8	100	48.3	11.4	19.3	15.4	17.1	17.4	100	44.7	16.5	48.5	62.9	42.6	20.7	49.4	100	56.7
Chelalang	18.6	11.6	28.7	100	39.7	7.9	8.9	8.4	10.5	10.8	100	40.4	12.0	31.3	57.4	33.6	15.2	3.0	100	39.4
GLP 1127	34.6	49.6	100	100	71.0	14.0	71.8	42.9	9.9	83.9	100	64.6	14.5	50.9	98.9	54.8	19.9	94.6	100	71.5
GLP 2	12.9	10.8	27.4	100	37.8	8.9	23.6	16.3	17.8	30.9	100	49.6	6.8	31.2	51.6	29.9	11.8	16.5	100	42.8
GLP 585	5.4	10.3	12.4	100	32.1	5.9	19.8	12.9	7.1	16.4	100	41.2	12.0	37.6	56.4	35.3	14.2	11.5	100	41.9
GLP x92	18.5	18.1	80.7	100	54.3	15.0	22.3	18.6	7.2	6.1	100	37.8	5.4	34.0	75.0	38.2	17.5	4.2	100	40.6
KAT B9	17.7	20.3	39.1	100	44.3	9.9	0.0	5.0	26.6	5.3	100	44.0	8.8	78.1	*	43.5	18.6	9.3	100	42.6
KAT x56	26.6	55.4	100	100	70.5	10.9	3.4	7.1	20.9	0.0	100	40.3	17.5	59.0	37.5	38.0	11.1	17.6	100	42.9
KK 071	25.4	24.6	74.7	100	56.2	13.7	13.6	13.7	23.2	11.8	100	45.0	11.5	20.4	21.3	17.7	20.6	15.5	100	45.4
KK 072	37.3	27.1	100	100	66.1	9.3	11.7	10.5	23.5	16.4	100	46.6	11.7	55.2	27.0	31.3	16.6	6.5	100	41.0
KK 15	9.2	5.7	21.7	100	34.2	4.2	10.3	7.3	4.7	25.6	100	43.4	12.7	23.2	68.6	34.8	6.8	20.1	100	42.3
KK 22	33.6	44.9	100	100	69.6	6.5	0.0	3.7	4.2	0.0	100	34.7	21.7	54.8	*	38.2	37.8	9.3	100	49.0
KK 8	13.3	13.3	26.4	100	38.3	9.4	20.5	14.9	17.8	10.3	100	42.7	9.8	38.8	37.5	28.7	13.6	28.5	100	47.4
Red 13	26.3	15.0	25.3	100	41.6	4.2	13.8	9.0	7.3	21.2	100	42.8	6.7	54.1	41.3	34.1	32.2	16.3	100	49.5
Red 16	9.9	8.4	44.3	100	40.7	4.2	30.6	17.4	5.6	13.5	100	39.7	14.7	91.1	62.6	56.1	9.8	25.6	100	45.1
Red 40	18.1	8.2	6.7	100	33.3	5.9	21.6	13.8	11.6	11.2	100	40.9	8.9	38.7	21.5	23.0	33.3	12.0	100	48.4
Tasha	14.1	12.1	35.5	100	40.4	9.3	13.2	11.3	7.5	20.6	100	42.7	10.8	36.0	23.3	23.4	15.1	5.1	100	40.1
Mean	20.4	19.8	49.7	100	47.5	9.3	17.6	13.5	12.9	17.5	100	43.5	11.5	46.9	44.9	34.4	18.5	19.9	100	46.1
CV%	50.5	98.9	63.6	0.0	39.8	50.1	100.5	96.9	49.8	86.8	0.0	21.7	50.5	45.1	66.0	55.8	90.8	85.0	0.0	30.0
$LSD_{(P\leq0.05)}G$	17.1	32.4	52.5	0.0	15.2	7.7	28.4	15.0	10.6	25.3	0.0	8.8	9.6	35.8	48.4	18.0	27.8	28.0	0.0	12.9
$LSD_{(P\leq0.05)}E$	3.9^{**}	6.8^{**}	7.7^{**}		7.2^{***}			5.0^{***}				15.3^{***}				7.4^{***}				5.3^{***}
$LSD_{(P\leq0.05)}I$	16.6	28.8	32.5		30.5			21.2				3.596				31.2				22.4

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p\leq0.05$); G=Genotype, E= Environment (Location & Planting Time); I= Genotype by Environment Interaction; *=Missing data; **=LSD for comparing similar plantings across different environments;***=LSD for comparing different plantings within an environment.

Table 4.20: Percentage yield loss due to damaged seeds of common bean genotypes planted in different agro-ecological zones over multiple planting dates in Western Kenya during the 2016 short rains.

Genotype	Agro-Ecological Zone									
	UM 1				UM 2			UM 4		
	2nd	3rd	4th	Mean	2nd	3rd	Mean	2nd	3rd	Mean
Cal 194	5.8	7.4	9.7	7.6	20.7	100	60.4	60.4	65.7	63.1
Cal 33	10.6	35.0	13.2	19.6	13.4	100	57.2	43.9	77.0	60.5
Chelalang	8.5	19.8	15.5	14.6	8.6	100	54.8	87.6	67.0	77.3
GLP 1127	20.8	33.4	64.8	39.7	13.7	100	57.9	55.0	50.7	52.8
GLP 2	12.1	17.0	41.5	23.5	12.4	100	56.7	22.9	40.6	31.8
GLP 585	8.9	28.0	46.1	27.6	17.4	100	56.4	52.9	89.7	71.3
GLP X92	13.6	16.6	44.1	24.8	14.8	100	53.9	23.3	87.5	55.4
Kat B9	9.8	17.9	27.3	18.3	22.3	100	61.4	35.2	61.0	48.1
Kat X56	13.3	16.1	15.2	14.9	28.2	100	64.6	30.3	79.7	55.0
KK 071	1.1	56.3	26.3	28.5	26.9	100	64.5	60.7	86.7	73.7
KK 072	44.8	55.3	72.7	57.6	27.2	100	64.7	36.5	40.7	38.6
KK 15	9.2	15.8	39.4	21.5	42.3	100	72.2	18.6	36.6	27.6
KK 22	2.5	100	100	68.1	46.5	100	73.8	38.6	64.8	51.7
KK 8	14.4	11.9	5.8	10.7	16.0	100	58.5	50.1	45.6	47.9
Red 13	3.7	10.7	16.0	10.1	24.5	100	62.8	57.6	59.8	58.7
Red 16	5.4	8.8	6.1	6.8	28.2	100	64.6	38.0	71.8	54.9
Red 40	6.6	15.1	11.7	11.2	22.8	100	61.9	43.2	76.6	59.9
Tasha	14.0	*	32.7	26.2	14.2	100	57.6	46.3	78.4	62.4
Mean	11.4	27.4	32.7	24	22.2	100	61.6	44.5	65.6	55.0
CV%	56.1	73.5	87.0	84.9	88.2	0.0	27.8	38.2	32.5	35.3
$LSD_{(P\leq0.05)}G$	10.7	33.4	47.3	19	32.5	0.0	19.9	28.2	35.3	22.4
$LSD_{(P\leq0.05)}E$	6.0**	7.4**		7.8***			6.6***			7.5***
$LSD_{(P\leq0.05)}I$	25.3	31.4		33			28.1			31.6

UM=Upper Midland zone, LM= Lower Midland zone; CV%=Coefficient of variation; LSD=Least Significant difference at ($p\leq0.05$); G=Genotype; E= Environment (Location & Planting Time); I= Genotype by Environment Interaction *=Missing data;**=LSD for comparing similar plantings across different environments;***=LSD for comparing different plantings within an environment.

4.5 Discussion

4.5.1. Bacterial diseases affecting beans across different planting dates and environments

This is the first study on the effect of sowing dates on common bean diseases in Western Kenya and while studies have been done in other regions, they are not of good reference due to differences in factors such as how seasons are defined. Up to 11 different diseases were observed in this study (Appendix I). Among these, bacterial diseases were common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli*), halo blight (*Pseudomonas savastanoi* pv. *phaseolicola*) and bacterial brown spot (*Pseudomonas syringae* pv. *syringae*). The genotypes, environment and sowing dates all had significant effects on the occurrence and intensity of bacterial diseases. The genotypes showed varied reactions to bacterial diseases across planting dates and environment. Generally, the early planted genotypes and those planted in agro-ecological zone UM 1 had had the highest CBB and bacterial brown spot intensity.

Fininsa and Tefera (2006) observed that variances in altitude, relative humidity and precipitation influence the occurrence of bacterial diseases. Mpayo (2010) and Wortmann *et al.* (1998) also stressed the importance of the environment on occurrence of bacterial diseases in their experimental results. Variations in disease intensity across plantings could be primarily due to favorable micro- and macro-environmental conditions (Mani *et al.,* 2017). Further, different dates of sowing could also have produce different disease incidences and severity despite experiencing similar weather condition due to difference in growth stages of the plants at the time of exposure to the pathogen (Mahapatra and Das, 2015).

High relative humidity may be the reason for the high bacterial disease intensity early in the season as this is when most of the precipitation was received (Kenya Meteorological Department, 2016 and 2017) (Appendix III and IV). Environments of high rainfall and strong

winds favor bacterial diseases with common blight and bacterial brown spot further favored by cloudy damp weather and relatively high air temperatures of 28 to 32^0C (University of Illinois, 2000), conditions which fall early in the season. Increased temperatures due to reduction in altitude and lateness of the planting may be the reason for the high CBB intensity observed in the fourth planting of genotypes in agro-ecological zone UM 4. Hailu *et al.* (2017) observed that in mid-altitudes and highland areas, an increase in temperature may trigger the development of common bacterial blight epidemics. Variations in genotypic reactions to bacterial diseases across sowing dates could have been as a result of the genotypes diverse genetic backgrounds and their interactions with the environments.

4.5.2. Fungal diseases affecting beans across different planting dates and environments

Fungal diseases observed in this study were scab (*Elsinoë phaseoli*), anthracnose (*Colletotrichum lindemuthianum*), angular leaf spot (*Pseudocercospora griseola*), rust (*Uromyces appendiculatus*), floury leaf spot (*Mycovellosiella phaseoli*) and Cercospora leaf spots. The genotypes, environments and sowing dates all reacted variably to the diseases. The clearest pattern was observed in bean scab in the long rains where it gradually increased in intensity from the early to late sowing dates so that most late plantings were completely destroyed by the disease. The genotypes performed variably with some, such as variety Glp X92 in agro-ecological zone UM 2 in the long rain season, consistently showing high ALS intensities in across sowing dates. Others such as varieties KK 22, KK 15 and GLP 585 showed effect of planting date in their disease reactions by having low levels of scab in early sowing dates but succumbing to the disease in later dates when pressure increased.

All fungal diseases observed in this study have been reported to occur in the Western Kenya (Allen *et al*., 1996: Mwang'ombe *et al*., 2007). Hagan *et al*. (2015) demonstrated the effect of planting time on leaf spots of peanuts by observing a reduction in disease intensity on early

sown peanuts compared to late ones while Gupta *et al.* (2003) also observed that Altanaria blight increased on potatoes with advancement in date of sowing. The variations in disease reaction between different sowing dates could be a result of differences in the environmental conditions across sowing dates.

Diseases have been observed to occur with varying intensities across sowing dates due to varying environmental conditions that affect pathogens (Kone *et al.*, 2017). Since disease onset and intensity is affected by the period that the susceptible host, virulent pathogen and right environment are aligned (Moore *et al.*, 2016), a disease may exist in an environment but fail to appear on one date but appear in another when the environmental conditions are conducive. The environment has an important role in the development of fungal diseases including ALS, scab and anthracnose (Mutitu, 1979; Wortmann *et al.*, 1998; Leitich *et al.*, 2016).

The gradual increase of scab to an epidemic proportion may have been due to inoculum build up in early crops and subsequent secondary spread of the disease to the late plantings (Nelson, 1994; Indiaagronet, 2018). In Western Kenya most farms are small and close to each other (Tittonell *et al*. 2008) making it easy for the pathogen to disperse across crops of different growth stages. Early planting might have resulted in reduced fungal disease intensity even in susceptible cultivars. In addition, even with use of resistant cultivars, disease intensity might still increase probably due to greater inoculum potential in delayed planting dates.

Variations in the genotypes reactions to fungal diseases across sowing dates could be a result of the genotypes diverse genetic background and their interactions with the environments. Genotype GLP 1127 had relatively high reactions to rust in all sowing dates in agro-ecological zone UM 1 during the short rains despite being listed as tolerant to the pathogen

while Red 13 and Red 16, which are listed as resistant to ALS, showed relatively high reactions to the pathogen in different planting and environments. Increased stresses in the environment in the late planting coupled with possible build-up of pathogen inoculum from the previous plantings, in the case of Red 16 in the third planting in agro-ecological zone UM 1, may be the reason for the breakdown in resistance to ALS.

Barros *et al*. (1958) in Columbia reported that ALS increased dramatically when several bean crops occur in the same environment within a short period. Further, the presence of an abiotic stress can have an effect of increasing a plants susceptibility to a pathogen (Atkinson and Urwin, 2012). Red 13 is not an officially released variety and therefore the level of its resistance to ALS may not be fully understood. Bean rust (*Uromyces appendiculatus*), has one of the highest pathogenic variability among fungal pathogens (Arunga *et al*., 2012) therefore variety GLP 1127 reactions to rust in all planting dates in agro-ecological zone UM 1 during the short rains may be as a result of the genotypes being exposed to a different pathogen race to that which its resistance was developed.

Within-host competitive exclusion among diseases could be why both ALS and rust levels were low when there was high bean scab pressure and high when scab pressure was low. Gold *et al*. (2009) observed that a resident infection on a host frequently exclude other pathogen genotypes that may later challenge the host. This was more evident among the genotypes where varieties KK 15, GLP X92 and GLP 585 had relatively low scab intensities across environments but more rust compared to other varieties. Abdullah et al. (2017) have also reported possible antagonistic interactions between pathogens in the same host. Anthracnose symptoms can be easily overlooked in a field as its most striking symptoms usually develop on the pods (Seebold, 2014 and Greenlife, 2018). Because this study concentrated on foliar symptoms, anthracnose may have appeared at a higher intensity than observed.

4.5.3 Viral diseases affecting beans across different planting dates and environments

Viral diseases that appeared at relatively high incidence in this study were BCMV and BCMNV. The diseases appeared with significant differences in the genotypes, environments and sowing dates in at least one season. Bean common mosaic necrosis virus generally appeared at a lower incidence in the early plantings compared to late plantings across the environments. The genotypes showed variations in their reactions to both BCMV and BCMNV with varieties KK 22 and KK 072 consistently having the highest necrosis reactions across seasons, environments and planting dates.

Both BCMNV and BCMV have been reported in Western Kenya (Mangeni *et al.,* 2014; Leitich *et al.,* 2016). Mangeni *et al.* (2014) also observed BCMNV on KK 072 while Otsyula (2016), the developer of variety KK 22, confirmed the genotypes necrosis reaction to BCMNV strains. Studies on the effect of planting time on viral diseases of beans in Western Kenya have not been conducted. However, Buruchara *et al*. (2010) states the importance of early planting as a disease avoidance strategy for the control of viral diseases providing support to this study in which early plantings were generally observed to have more virus disease presence.

Variations virus incidences in the genotypes, environments and sowing dates could be due to genetic, biotic and abiotic factors. Mangeni *et al.* (2014) support the importance of cultivar genetics in manifestation of viral diseases while Cadle-Davidson (2005) and Mvile (2015) observed that temperature has an influence on the occurrence of both BCMV and BCMNV. Variations in viral incidences may also be influenced by the interaction between vectors such as aphids with the environment. Buruchara *et al.* (2010) states the importance of early planting as a disease avoidance strategy for the control of viral diseases as vector pressure is relatively low at the onset of the season. Kone *et al.* (2017) observed that sowing dates that

coincide with moderate rainfall together with warm weather had high disease pressure as it favored the development and spread of potential pathogen vectors.

4.5.4 Grain yield, seed weight and seed damage in different planting dates and environments

The genotypes, environments and planting dates showed significant effects on yields and seed weight across the seasons with bean crops established in agro-ecological zone UM 1 being generally the best performing environment for all sowing dates. Generally, genotypes in early sowing dates performed significantly better than the late planted ones in yield and seed weight as seen in the long rains where there was no yield for genotypes in the third planting in agro-ecological zones UM 2, LM 2 and genotypes in the fourth planting of UM 1 as all the genotypes died before attaining physiological maturity.

The genotypes yielded variably across the environments as seen with KK 15 which led in performance in agro-ecological zone UM 1, varieties GLP 2 and Red 16 which led in agro-ecological zone UM 2-T and Red 16 and Cal 194 which led in agro-ecological zone UM 2. Variability in the seed weight was also observed where large seeded varieties such as GLP 2 and Cal 194 generally outweighed small seeded varieties such as KK 22 across seasons, environments or planting dates. Elhag and Hussein (2014), Moosavi *et al*. (2014) and Nwadike and Terkimbi (2015), also observed significant positive effects of early planting on both quantitative and qualitative traits of common beans whereas Shiringani (2007) reported the same on cowpea.

Variations in disease intensity across the environments, planting dates and genotypes may have had an effect on grain yields. Low disease pressure in the early plantings could be the reason for better grain yields compared to the late plantings which had high disease pressure especially of scab which has been reported to cause yield losses of up to 70% (Schwartz,

1991). Moosavi *et al.* (2014) observed that early bean plantings performed well as the plants benefited from prevailing optimal growth conditions of a full growing season, cool temperatures, high relative humidity and better solar radiation compared to late plantings. Kenya Meteorological Department (2016 and 2017) recorded generally poor and erratic rainfall and higher than normal temperatures in Western Kenya across the seasons.

In the short rains of 2016, for example, there were frequent dry spells that may have caused the generally poor performance of genotypes in this season and especially in the late plantings when dry spells were more frequent. According to Gross and Kigel (1994), Ngueguim *et al*. (2011) and Tom (2014) the timing, length and degree of stress plays an important role in yield. Stress during flowering, pod filling and root formation results in a reduced number of pods, seeds and consequently yield of the genotypes. High temperatures may also cause a reduction in yield possibly due to flower abortion or failure of fertilization (Tom, 2014).

There was more seed damage by discoloration and shriveling or wrinkling in the late planted crops compared to the early planted ones in all seasons and agro-ecological zones. Date of planting may have influenced seed quality through the action of both diseases and abiotic factors such as temperature and humidity. The genotypes showed significant variations in seed damage across the environments and date of planting. Icishahayo *et al.* (2009) observed that presence of a seed borne pathogen inoculum on the surface of the seed causes seed damage while Makelo (2010) linked variations in seed damage between environments to a higher prevalence of bean diseases in a particular zone, compared to others, due to weather conditions favoring the disease.

Genotypes such as GLP 1127 and KK 22 had high seed damage likely because of BCMNV which was observed at a high incidence in them and is known to cause seed damage (Otsyula,

2016). High moisture levels in the environment even after plants had attained maturity could be the reason for the higher seed damage on genotypes such as Kat B9 and Kat X56 which were developed for their earliness (Karanja *et al*., 2008). Abiotic environmental factors such as temperature and rainfall also have an effect on seed quality. Muasya *et al*. (2008) noted that when temperatures are high and rainfall is little, seed quality is negatively affected. Since the short rain season of 2016 experienced periodic dry spell especially in the late plantings (Kenya Meteorological Department, 2016), the high seed damage is highly likely a result of water stress especially since in this season seed damage was high even when both disease incidences and intensity were relatively low.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Disease severity was affected by cultivar genetics, the environments and planting date. Diseases had an effect on the yield, seed weight and seed damage of genotypes in all environments and sowing dates. There was more disease diversity and pressure in higher-lying agro-ecological zones UM 1 and UM 2 compared to low-lying agro-ecological zones UM 4 and LM 2. The genotypes are variably adapted to the different environments as they ranked variably. Genotypes generally yielded highest in agro-ecological zone UM 1 whereas they generally had their lowest yields in low-lying environments such as agro-ecological zones LM 2 and UM 4.

Individual genotypes performed best in environments where diseases they were susceptible to did not occur. For example KK 22, which is susceptible to BCMNV, had relatively low yields in upper-lying agro-ecological zone UM 1 where BCMNV pressure was high compared to low-lying agro-ecological zone LM 2 where the disease did not occur. Tasha also had high yields in agro-ecological zone UM 3-4 where it had some of the lowest overall disease reactions but had low yield in agro-ecological zone UM 2-T where it had the highest overall BCMV incidence in the long rain season. Diseases were observed to appear in complexes of two or more and rarely singly in both the environments and on individual genotypes. For example, ALS and rust frequently occurred in the same environments and affected similar genotypes such as Glp x92 and Glp 585 in agro-ecological zone UM 2 in the short rain season.

Whereas bacterial diseases occurred mostly in early planting dates, fungal and viral disease development was observed to reduce in early compared to late planting dates. Genotypes in

late planting dates in all environments suffered from a combination of high disease pressure and fluctuating weather conditions that negatively affected their yield. Early planting dates had more disease diversity but severity and incidence of individual fungal and viral diseases appeared to increase in late sowing dates. High scab intensity was the reason most late-planted crops died before attaining physiological maturity. No genotype performed exceptionally well in the late planting dates as all eighteen genotype succumbed to extreme scab pressure.

5.2 Recommendations

i) Agro-ecological zone UM 1 generally provides the best environment to grow beans. Where farmers do not know or lack access to varieties best suited to their environments, they should plant varieties such as Red 16, Red 13 and Cal 194 that are high yielding, have a wide adaptation to diseases and are stable across different environments to improve their chances of a good harvest.

ii) Synchronized early planting between farms in the same areas is essential to prevent secondary spread of diseases from older crops to new ones especially for small-scale farmers whose farms are usually adjacent to each other with crops of different growth stages. In addition, partially resistant genotypes can be integrated with early sowing date to further reduce yield losses caused by a disease.

iii) Disease hot spots should be mapped-out based on the understanding of the relative importance of different diseases in the environments. Such information will help address the requirements of farmers in a specific environment when developing disease resistance varieties.

iv) While symptoms of a single disease observed independently may appear negligible, when diseases occur in complexes the plant is adversely affected. This highlights the importance of developing genotypes with multiple disease resistances through techniques such as gene pyramiding.

v) Bean Scab symptoms were the most prevalent in this study. This was the first study of scab in Western Kenya. It is therefore mandatory that the disease be studied in detail for better understanding of its epidemiology and occurrence and development of resistant cultivars.

REFERENCES

Abdullah A. S., Moffat C. S., Lopez-Ruiz F. J., Gibberd M.R., Hamblin J. and Zerihun A. (2017). Host–Multi-Pathogen Warfare: Pathogen Interactions in Co-infected Plants. *Frontiers in Plant Science* 8: 1-12.

Ahmad J., Choudhery M. H., Salah-ud-Din S. and Ali M. A. (2001). Stability for grain yield in wheat. *Pakistan Journal of Botany* 28: 61-65.

Allen D. J., Ampofo J. K. and Wortmann C. S. (1996). Pest, diseases, and nutritional disorders of the common bean in Africa: A field guide. International Center for Tropical Agriculture (CIAT), Cali, Colombia.

Allen T. (2012). The principles of plant pathology: The disease triangle and influence of the environment. Mississippi State University extension. http:www.mississippi-crops.com, Accessed 28th May, 2017.

Allorent D. and Savary S. (2005). Epidemiological Characteristic of Angular Leaf Spot of Beans: A system Analysis. *European Journal of Plant Pathology* 113: 329-341.

Apeyuan K. D., Nwankiti A. O., Oluma O. H. and Ekefan E. J. (2017). Effect of Different Sowing Dates on Disease Initiation and Development of Roselle (*Hibiscus sabdariffa* L.) Leaf Spot Disease Caused by *Coniella musaiensis* Var. *hibisci* in Makurdi, Central Nigeria. *Journal of Geoscience and Environment Protection* 5: 94-101.

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

Atkinson N. J. and Urwin P. E. (2012). The interaction of plant biotic and abiotic stresses: from genes to the field. *Journal of Experimental Botany* 63: 3523–3543.

Ayoub Z. E. and Abdalla H. M. (2014). Effects of sowing date and plant population on snap

bean (*Phaseolus vulgaris* L.) growth and pod yield. *Universal Journal of Agricultural Science* 2: 115-118.

Baker R. J. (1988). Tests for crossover genotype x environment interactions. *Canadian Journal of Crop Science* 68: 405-410.

Bardas G. A., Koutita O. and Tzavella-Klonari K. (2007). Geographical distribution, pathotype characterization, and molecular diversity of *Colletotrichum lindemuthianum* in Greece and resistance of Greek bean cultivars. *The American Phytopathological Society Journal* 91: 1379-1385.

Barros O. R., Cardona O. C., Cardenosa R. and Skiles R. L. (1958). The control of angular leaf spot in Colombia. F.AO. *Plant Protection Bulletin* 6: 97-101.

Bastas K. K. and Sahin F. (2017). Evaluation of seed borne bacterial pathogens on common bean cultivars grown in central Anatolia region, Turkey. *European Journal of Plant Pathology* 147: 239–253.

Boersma J.G., Conner R,L., Balasubramanian P.M., Navabi A., Yu K., Hou A. (2014). Combining resistance to common bacterial blight, anthracnose, and bean common mosaic virus into Manitoba-adapted dry bean (*Phaseolus vulgaris* L.) cultivars. *Canadian Journal of Plant Science* 94: 405-415.

Boersma J.G., Hou A., Gillard C. L., McRae K. B., Conner R. L. Conner R,L., (2015). Impact of common bacterial blight on yield, seed weight and seed discoloration of different market classes of dry beans (*Phaseolus vulgaris* L.). *Canadian Journal of Plant Science* 95: 703-710.

Buruchara R. (2007). Background information on Common Beans (*Phaseolus vulgaris* L). Biotechnology, Breeding and Seed Systems for African Crops. The Rockefeller Foundation, Nairobi.

Buruchara R. A., Mukakusi C. and Ampofo K. (2010). Bean disease and pest identification

and management. Centro Internacional de Agricultura Tropical (CIAT), Kampala.

Bruner S. C. and Jenkins A. E. (1933). Identity and host relation of the Elsinoë of Lima bean. *Journal of Agricultural Research* 47:783-789.

Cabi.org. (2015). *Xanthomonas axonopodis* pv. *phaseoli* (bean blight). http:www.cabi.org, Accessed 24th August, 2016.

Cadle-Davidson M. M. (2005). Mechanism of resistance to bean common mosaic virus conferred by the "I" locus in *Phaseolus vulgaris* L. Cornell university, New York, USA. p. 98.

Carlson J. D. (2008). Intercropping with maize in sub-arid regions. Community planning and analysis. Technical Brief, 25: 1-6.

Chatterton S., Balasubramanian P. M., Ericlson R. S., Hou A., Mclaren D. L., Henriquez M. A. and Conner R. L. (2016). Identification of bacterial pathogens and races of *Pseudomonas syringae* pv. *phaseolicola* from dry bean fields in western Canada. *Canadian Journal of Plant Pathology* 38: 41-54.

Chilagane L. A., Tryphone M. G., Protas D., Kweka E., Kusolwa P. M. and Nchimbi-Msolla S. (2013). Incorporation of resistance to angular leaf spot and bean common mosaic necrosis virus diseases into adapted common bean (*Phaseolus vulgaris* L.) genotype in Tanzania. *Academic Journals* 12: 4343 – 4350.

Chirwa R., Buruchara R., Sperling L., Mukankusi C., Rubyogo J. C. and Muthoni R. (2011). Development and delivery of bean varieties in Africa: The Pan- Africa Bean Research Alliance (PABRA) model. *Africa Crop Science Journal* 19: 227 - 245.

Coffman W. R., Sorrels M. E. and Brown K. D. (1983). A method for classification and evaluation of testing environments. *Journal of Crop Science* 23: 889-893.

Conner R. L., Gillard C. L., Mcrae K. B., Hwang S.-F., Chen Y. Y., Hou A., *et al*. (2019).

Survival of the bean anthracnose fungus (*Colletotrichum lindemuthianum*) on crop debris in Canada. *Canadian Journal of Plant Pathology* 41: 209-217.

CGIAR (2012). Leveraging legumes to combat poverty, hunger, malnutrition and environmental degradation. https://cgspace.cgiar.org/handle/10947//5316, Accessed 24th August, 2016.

Corrales M. P. (2006). Breeding better beans: Increasing disease resistance in common beans.https://agresearchmag.ars.usda.gov/ar/archive/2006/jun/beans0606.pdf&sa=U&ved=2ahUKEwiq6fW-5MbdAhVOLBoKHe5-BO4QFjAAegQIABAC&usg=AOvVaw3W59VWPVmi_oNIb5XZSIZv, Accessed 1st February, 2015.

Ddamulira G., Mukankusi C., Ochwo-Ssemakula M., Edema R., Sseruwagi P. and Gepts P. (2014). Distribution and Variability of *Pseudocercospora griseola* in Uganda. *Journal of Agricultural Science* 6: 16-29.

Direk M., Bayranoglu Z. and Paksoy M. (2002). Problems encountered in the production of beans in Konya province. Faculty of Agriculture Magazine, Selcuk University, Turkey. 16: 21-27.

Drijfhout E. 1978. Genetic interaction between *Phaseolus vulgaris* and Bean common mosaic virus with implications for strain identification and breeding for resistance. Agricultural Research Reports 872, Centre for Agricultural Publishing and Documentation, Wageningen. p. 98.

e-Krishi Shiksha (2011). Effect of environmental factors on disease development. Fundamentals of Plant Pathology**.** http://ecoursesonline.iasri.res.in/mod/page/view.php?id=101365, Accessed 1st October, 2018.

El-Aal H. A., El-Hwat N., El-Hefnawy N. and Medany M. (2011). Effects of sowing dates,

irrigation levels and climate change on yield of common bean (*Phaseolus vulgaris* L.). *American-Eurasian Journal of Agriculture and Natural Science* 11: 79-86.

Elhag A. Z. and Hussein A. M. (2014). Effects of sowing date and plant population on snap bean (*Phaseolus vulgaris* L.) growth and pod yield in Khartoum state. *Universal Journal of Agricultural Research* 2: 115-118.

Fajinmi A. A., Odebode C. A., and Fajinmi O. B. (2011). The effect of agro-Ecological zones on the incidence and distribution of aphid vectors of pepper veinal mottle virus, on cultivated pepper (*Capsicum annuum* L.) in Nigeria. *Journal of Central European Agriculture* 12: 528-542.

Fan X. L., Barreto R. W., Groenewald J. Z., Bezerra J. D., Pereira O. L., Cheewangkoon R., *et al*. (2017). Phylogeny and taxonomy of the scab and spot anthracnose fungus *Elsinoë* (Myriangiales, Dothideomycetes). *Studies in Mycology* 87: 1-41.

Feng X., Poplawsky A. R., Nikolaeva O. V., Myers J. R. and Karasev A. V. (2014). Recombinants of BCMV and genetic determinants of BCMV involved in over-coming resistance in common beans. *Journal of Phytopathology* 104: 786-793.

Fininsa C. and Tefera T. (2006). Multiple disease resistance in common bean genotypes and their agronomic performance in Eastern Ethiopia. *International Journal of Pest Management* 52: 291–296.

Flores-Estevez N., Acosta-Gallegos J. and Silva-Rosales L. (2003). Bean common mosaic virus and Bean common mosaic necrosis virus in Mexico. *Plant Disease* 87: 21-25.

Food and Agriculture Organization (1995). Farming systems approach development and appropriate technology generation. http://www.fao.org/docrep/v5330e/V5330e00.htm#Contents, Accessed 20th May, 2016.

Food and Agriculture Organization. (2015). Crop Water Information. Bean. Food and

Agriculture Organization of the United Nations. http:www.fao.org, Accessed 1st April, 2016.

Food and Agriculture Organization. (2017). FAOSTAT. Food and Agriculture Organization. http:www.fao.org, Accessed 1st April, 2018.

Fotiadis S., Koutroubas S. D. and Damalas C. A. (2017). Sowing Date and Cultivar Effects on Assimilate Translocation in Spring Mediterranean Chickpea. *Crop Ecology & Physiology* 109: 2011–2024.

Fourie D. (2011). Susceptibility of South African dry bean cultivars to bacterial diseases. *African Crop Science Journal* 19:387-392.

Franzon R. C., Goncalves-Vidigal M. C., Lacanallo G. F., Caixeta, M. P. and Vidigal P. S. (2015). Application of mixed models to evaluate genotype and environment interaction in common bean. *Bean Improvement Cooperative* 58: 133-134.

Getachew E., Mohammed A. and Tesfaye A. (2015). Impact of sowing date and plant spacing on yield, quality and disease incidence of Snap bean (*Phaseolus vulgaris* L.) varieties at Jimma Southwestern. *Advanced Research Journal* 45: 081-089.

Gold A., Giraud T. and Hood M. E. (2009). Within-host competitive exclusion among species of anther smut pathogen. *Bio Medical Central Ecology* 9: 11.

Greenlife (2018). Bean anthracnose. Greenlife: Crop Protection Africa. https://www.greenlife.co.ke/bean-anthracnose, Accessed 7th April, 2018.

Gross Y. and Kigel J. (1994). Differential sensitivity to high temperature of stages in the reproduction development of common beans (*Phaseolus vulgaris* L.). *Journal of Field Crops Research* 36: 201-212.

Gupta R., Awashthi R. P. and Kolte S. J. (2003). Influence of sowing dates and weather factors on development of Alternaria blight on rapeseed-mustard. *Indian Phytopathology Journal* 56: 398-402.

Hagan K. A., Campbell H. L. and Bowen K. L. (2015). Seeding rate and planting date impacts stand density, diseases, and yield of irrigated peanuts. *Plant Health Progress Journal* 16: 63-70.

Hagedorn D. J. and Inglis D. A. (1986). Handbook of bean diseases. Wisconsin: University of Wisconsin-Extension. http://learningstore.uwex.edu/assets/pdfs/A3374.pdf, Accessed on 24th February, 2017.

Hailu N., Fininsa C., Tana T. and Mamo G. (2017). Effect of temperature and moisture on growth of common bean and its resistance reaction against common bacterial blight (*Xanthomonas axonopodis* pv. *phaseoli* strains). *Journal of Plant Pathology and Microbiology* 8: 419. doi: 10.4172/2157-7471.1000419

Hardner C. (2017). Exploring opportunities for reducing complexity of genotype-by-environment interaction models. *International Journal of Plant Breeding* 213: 248. https://doi.org/10.1007/s10681-017-2023-0

Harveson R. M. (2009). Common Bacterial Blight of Dry Beans in Nebraska. University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources. http://ianrpubs.unl.edu/live/g1562/build/g1562.pdf, Accessed on 24th January 2017.

Icishahayo D., Sibiya J., Dimbi S., Madakadze I., Manyangarrwa and Chipindu B. (2009). Assessment of quality and health of field bean seeds home saved by smallholder farmers. *Africa Crop Science* 9: 609–615.

Icishahayo D. (2014). Management of common bean (*Phaseolus vulgaris*) angular leaf spot (*Pseudocercospora griseola*) using cultural practices and development of disease-weather models for prediction of the disease and host characteristics. Ph.D. Thesis, University of Zimbabwe, Harare, Zimbabwe.

Indiaagronet (2018). Transmission of plant diseases. IndiaAgroNet.Com.

https://www.indiaagronet.com/indiaagronet/Disease_management/content/transmission_of_plant_diseases.htm., Accessed 15th May, 2018.

International Center for Tropical Agriculture (2004). Impact of improved bean varieties in Western Kenya. Centro Internacional de Agricultural Tropical, Cali, Colombia.

Jaetzold R., Schmidt H., Hornetz B., Shisanya C. (2005). Farm management handbook of Kenya Volume II. Natural conditions and farm management information. 2nd Edition, part A West Kenya, subpart A1 Western Province. Ministry of Agriculture, Nairobi, Kenya.

Jochua C., Amane M. I., Steadman J. R., Xue X. and Eskridge K. M. (2008). Virulence Diversity of the common bean rust pathogen within and among individual bean fields and development of sampling strategies. *Plant Disease* 92: 401-408.

Jones, M.P. 1999. Food security and major technological challenges: The case of rice in Sub Saharan Africa. *World Food Security Conference*, Kyoto, Japan.

Joshi S. and Rahevar H. (2014). Effect of dates of sowing, row spacing and varieties on growth attributing characters of rabi Indian bean (*Dolichos lablab* L.). *Trends in Biosciences* 7: 3717-3721.

Juroszek P. and Tiedemann A. V. (2011). Potential strategies and future requirements for plant disease management under a changing climate. *Plant Pathology* 60: 100-112.

Karanja D. R., Mulwa D. M., Ragwa L. and Rubyogo J. (2008). Grow improved beans for food and income. Information brochure, Kenya Agricultural Research Institute (KARI), Katumani, Kenya.

Karavina C., Mandumbu R., Parwada C. and Tibugari H. (2011). A review of the occurrence, biology and management of common bacterial blight. *Journal of Agricultural Technology* 7: 1459-1474.

Katungi, E., Farrow, A., Chianu, J., Sperling, L., & Beebe, S. (2009). Common bean in

Eastern and Southern Africa: a situation and outlook analysis. *CIAT*.

Katungi E., Sperling L., Karanja D., Farrow A. and Beebe, S. (2011). Relative importance of common bean attributes and variety demand in the drought areas of Kenya. *Journal of Development and Agricultural Economics* 3:411-422.

KALRO (2016). A brochure on bean varieties Released from KALRO Kakamega. Kenya Agricultural and Livestock Organization, Non-Ruminant Research Institute, Kakamega, Kenya.

Kenya Meteorological Department (2016). Review of rainfall during the "Long rains", March to May (MAM) 2016 and June-July-August (JJA) 2016 seasons and the outlook for October-November-December (OND) 2016 Season. Ministry of Environment and Natural Resources, State Department of Environment, Nairobi, Kenya.

Kenya Meteorological Department (2017). Review of rainfall during the 2017 "Long rains" (March to May Season) and the outlook for June-July-August (JJA) 2017. Ministry of Environment and Natural Resources, State Department of Environment, Nairobi, Kenya.

Kenya Plant Health Inspectorate Service (2016). National Crop Variety List, Kenya. http://www.kephis.org/#, Accessed 23rd May, 2016.

Khan M. H. and Tyagi S. D. (2010). Genotype x environment interaction and stability analysis for yield and its components in soybean [*Glycine max* (L.) Merrill]. *Journal of Agricultural Science* 1: 93-101.

Kimiti J. M., Odee D. W. and Vanlauwe B. (2009). Areas under grain legume cultivation and problems faced by small holder farmers in legume production in the semi-arid Eastern Kenya. *Journal of Sustainable Development* 11: 101-118.

Kiryowa M. J., Ebinu A., Kyaligonza V., Nkalubo S. T., Paparu P., Mukankusi C., *et al*.

(2016). Pathogenic variation of *Colletotrichum Lindemuthianum* causing anthracnose of beans (*Phaseolus vulgaris*) in Uganda. *International Journal of Phytopathology* 89-98.

Kone N., Asare-Bediako E., Silue S., Kone D., Koita O. and Menzel W. (2017). Influence of planting date on incidence and severity of viral disease on cucurbits under field condition. *Annals of Agricultural Science* 62: 99-104.

Konsens I., Ofir M., and Kigel J. (1991). The effect of temperature on the production and abscission of flowers and pod in snap bean (*Phaseolus vulgaris* L.). *Annals of Botany* 67: 391-399.

Kulkarni H. Y. (1973). Notes on East African plant virus diseases. Bean common mosaic virus. *East African Agricultural and Forestry Journal* 39: 72-76.

Laghari S., Kandhro M.M., Ahmed H.M., Sial M.A. and Shad M.Z. (2015).Genotype X Environment (GXE) Interaction in Cotton (*Gossypium hirsutum* L.) Genotypes. *Asian Journal of Plant Science* 2: 480-482.

Leitich R. K., Omayio D. O., Mukoye B., Wosula D. W., Otsyula R. M. and Were H. K. (2016). Pathogenic variability of angular leaf spot disease of common bean in Western Kenya. *International Journal of Applied Agricultural Sciences* 2: 92-98.

Liebenberg M.M. and Pretorius Z.A. (2004). Proposal for designation of a rust resistance gene in the large-seeded cultivar Kranskop. *Bean Improvement Cooperative* 47: 255-256.

Lima E. R., Santiago A. S., Araujo A. P. and Teixeira M. G. (2005). Effects of size of sown seed on growth and yield of common bean cultivars of different seed sizes. *Brazilian Journal of Plant Physiology* 17: 273-281.

Lin C. S. and Binns M. R. (1991). Genetic properties of four types of stability parameter. *Theory of Applied Genetics* 82: 505-509.

Lourenço V. J., Takaki R. K., Nunes M. V., Borsato L. C., Moita A. W., Foloni J. S., *et al.* (2017). Effect of the sowing date and cultivar reaction on the gray mold progress on castor bean cultivars. *Crop Protection* 110: 214-220.

Mahapatra S. and Das S. (2015). Effect of sowing dates, varieties and weather factors on the occurrence and severity of Alternaria leaf blight and yield of Indian mustard. *African Journal of Agricultural Research* 10: 579-587.

Mahuku G. S., Jara C. E., César C. and Beebe S. (2002). Sources of resistance to *Colletotrichum lindemuthianum* in the secondary gene pool of *Phaseolus vulgaris* and in crosses of primary and secondary gene pools. *Euphytica* 130: 303–313.

Makelo M. N. (2010). Assessment of seed-borne pathogens for some important crops in western Kenya. *KARI Scientific Conference*, Nairobi, Kenya.

Mangeni B. C., Abang M. M., Awale H., Omuse C. N., Leitch R. and Arinaitwe W. (2014). Distribution and pathogenic characterization of bean common mosaic virus (BCMV) and bean common mosaic necrosis virus (BCMNV) In Western Kenya. *Journal of Agri-Food and Applied Sciences* 2:308-316.

Mani K. K., Hollier C. A. and Groth D. E. (2017). Effect of cultivar susceptibility and planting date on narrow brown leaf spot progression in rice. *Crop Protection* 102: 88-93.

Mauyo L. W., Chianu J. N., Nassiuma B. K. and Musebe R. O. (2010). Cross border bean market performance in Western Kenya and Eastern Uganda. *Journal of Service Science and Management* 3: 501-511.

Mavrič I., and Šuštar-Vozlič J. (2005). Virus diseases and resistance to Bean common mosaic and Bean common mosaic necrosis potyvirus in common bean (*Phaseolus vulgaris* L.). *Acta Agriculturae Slovenica* 83: 181-190.

Mbugua B. W. (2016). Effect of intercropping and legume diversification on intensity of

fungal and bacterial diseases of common bean. M.Sc. Thesis, University of Nairobi, Nairobi, Kenya.

McKinney (1923). A new system of grading plant disease. *Journal of Agricultural Research* 26: 195-218.

Medvecky B.A., Ketterings Q.M, and Nelson E.B. (2007). Relationships among soil borne bean seedling diseases, *Lablab purpureus* L. and maize stover residue management, bean insect pests, and soil characteristics in Trans Nzoia district, Kenya. *Applied Soil Ecology* 35: 107-119.

Miklas P., Hart J., Porch T. and Beaver J. (2015). Breeding for resistance to BCMV and BCMNV.http://arsftfbean.uprm.edu/bean/wp-content/uploads/2015/09/BDW-Day4-BCMV_Phillip-Miklas.pdf, Accessed 24th May, 2016.

Mirzaienasab M. and Mojaddam M. (2014). The effect of planting date on yield and yield components of two red bean cultivars in Anza weather conditions. *Indian Journal of Fundamental and Applied Life Sciences* 4: 2231- 3345.

Monda E. O., Sanders F. E. and Hick A. (2001). Infection and colonization of bean leaf by *Phaeoisariopsis griseola*. *Plant Pathology* 50: 103–110.

Monneveux P.P., Sanchez C., Beck D. and Edmeades G. O. (2006). Drought tolerance improvement in tropical maize source populations: evidence of progress. *Crop Science* 46: 180-191.

Moore D., Robson G. D. and Trinci A. P. (2016). 21st Century Guidebook to Fungi. http://www.davidmoor.org.uk, Accessed 24th May, 2017.

Moosavi S. G., Seghatoleslami M. J. and Delarami M. R. (2014). Effect of sowing date and plant density on yield and yield components of lentil (*lens culinaris cv. sistan*). *Annual Research & Review in Biology* 4: 296-305.

Mpayo E. P. (2010). Effect of the environment on growth and yield performance of ten

common bean genotypes. M.Sc. Thesis, Sokoine University of Agriculture, Morogoro, Tanzania.

Muasya R. M., Lommen W. J., Muui C. W. and Struik, P. C. (2008). How weather during development of common bean (*Phaseolus vulgaris* L.) affects the crop's maximum attainable seed quality. *Wageningen Journal of Life Sciences* 56: 85-100.

Muthomi J. W., Otieno P. E., Chemining'wa G. N., Nderitu J. H. and Wagacha J. M. (2007). Effects of legume root rot pathogens and fungicide seed treatment on nodulation and biomass accumulation. *Journal of Biological Sciences* 7: 1163-1170.

Muthomi J. W., Fulano A., Wagacha J., Mwang'ombe A. (2017). Management of Snap Bean Insect Pests and Diseases by Use of Antagonistic Fungi and Plant Extracts. *Sustainable Agriculture Research* 6: 52-63.

Mutitu E. W. (1979). Etiology, epidemiology and control of bean scab caused by *Elsinoë phaseoli Jenkins F.sp. vulgare* in Kenya. M.Sc. Thesis, University of Nairobi, Nairobi, Kenya.

Mvile B. (2015). Genotype x environment interaction of common bean (*Phaseolus vulgaris* L.) genotypes on reaction to four bean diseases. M.Sc. Dissertation, Sokoine University of Agriculture, Morogoro, Tanzania.

Mwang'ombe A. W., Wagara I. N., Kimenju J. W. and Buruchara R. A. (2007). Occurrence and severity of angular leaf spot of common bean in Kenya as influenced by geographical location, altitude and agro ecological zones. *Journal of Plant Pathology* 6: 235-241.

Namugwanya M., Tenywa J. S., Otabbong E., Mubiru D. N. and Basamba T. A. (2014). Development of common bean (*Phaseolus vulgaris* L.) production under low soil phosphorus and drought in Sub-Saharan Africa: A Review. *Journal of Sustainable Development* 7: 128-139.

Nelson E. B. (1994). The disease triangle and the disease cycle. http://archive.lib.msu.edu/tic/tgtre/article/1994aug8a.pdf&sa=U&ved=2ahUKEwiO9ozd7sbdAhULCxoKHR-eA5EQFjAAegQICBAC&usg=AOvVaw2VAKPCmvHE9RQ6rtaU_7EZ, Accessed 19th April, 2017.

Ngueguim M., Mekontchou T., Fobasso M. and Nounamo L. (2011). Influence of time of planting on yield and grain quality of bean genotypes grown on an andosol in the Western highlands of Cameroon. *African Crop Science Journal* 19: 247-254.

Nunes W. M., Corazza M. J., Souza C. D., Tsai , S. M. and Kuramae E. E. (2008). Characterization of *Xanthomonas axonopodis* pv. *phaseoli* isolates. *Phytopathology* 34: 228-231.

Nwadike C. and Terkimbi V. (2015). Effects of planting date on performance of common bean (*Phaseolus vulgaris* L) landraces of the Jos Plateau: A preliminary studies. *International Journal of Current Research and Academic Review* 3: 309-324.

Nyang'au E. K., Nyangeri J. B. and Makatiani, J. (2016). Identification of Bean Rust (*Uromyces appendiculatus*) Races on Isolates Collected from Nyamira County and Narok South Sub County, Kenya. *Annual Research & Review in Biology* 9: 1-7.

One Acre Fund (2013). Common bean trial-long rain season. Kakamega, Kenya.

Odhiambo G.D. and Ariga E.S. (2001). Effect of intercropping maize and beans on striga incidence and grain yield. *Seventh Eastern and Southern Africa Regional Maize Conference* 7: 183-186.

Opio F., Kimani P. M., Musaana S. M. and Buruchara R. (2002). Research on common bacterial blight and halo blight of common bean in East and Central Africa. *Bean Improvement Cooperative* 45: 160-161.

Otsyula R. M. (2016). Kenya Agricultural and Livestock Research Institute Communication.

Non-ruminant Research Institute, Kakamega, Kenya.

Öztürka M. and Aksoy H. M. (2018). Isolation and identification of *Xanthomonas axonopodis* pv. *phaseoli* and *Pseudomonas savastanoi* pv. *phaseolicola* causing disease in common bean producing areas in Samsun province of Turkey. *Anadolu Journal of Agricultural Sciences* 33: 105-115.

Pacheco A., Vargas M., Alvarado G., Rodrigues F., Lopez M. and Crossa J. (2016). GEA-R (genotype × environment analysis with R for Windows). Version 4.0. CIMMYT. http://hdl.handle.net/11529/10203, Accessed June 2017.

Padder B. A., Sharma P. N., Awale H. E. and Kelly J. K. (2017). *Colletotrichum lindemuthianum*, the causal agent of bean anthracnose. *Journal of Plant Pathology* 99: 317-330.

Pamela P., Mawejje D. and Ugen M. (2014). Severity of angular leaf spot and rust diseases on common beans in Central Uganda. *Ugandan Journal of Agricultural Sciences* 15: 63-72.

Pettigrew W. T. (2004). Physiological consequences of moisture deficit stress in cotton. *Journal of Crop Science* 44:1265-1272.

Phillips A. J. L. (1994). Occurrence of scab of Phaseolus vulgaris caused by *Elsinoë phaseoli* in South Africa. *Plant Pathology* 43: 417-419.

Phillips A. J. L. (1996). Evaluation of some cultivars of Phaseolus vulgaris in the greenhouse and in the field for resistance to *Elsinoë phaseoli*. *African Plant Protection* 1: 59-62.

Piepho H. P. (1998). Methods of comparing the yield stability of crop systems. *Journal of Agronomy Crop and Science* 180: 193-213.

Porch T. G. and Jahn M. (2001). Effects of high-temperature stress on microsporogenesis in heat-sensitive and heat-tolerant genotypes of *Phaseolus vulgaris*. *Plant Cell Environment* 24: 723-731.

Prior R., Mittelbach M. and Begerow D. (2017). Impact of three different fungicides on fungal epi- and endophytic communities of common bean (*Phaseolus vulgaris*) and broad bean (*Vicia faba*). *Journal of Environmental Science and Health* 52: 376-386.

Rezene Y., Tesfaye K., Makankusi C. and Gepts P. (2018). Pathotypes Characterization and Virulence Diversity of *Pseudocercospora griseola* the Causal Agent of Angular Leaf Spot Disease Collected from Major Common Bean (*Phaseolus vulgaris* L.) Growing Areas of Ethiopia. *Journal of Plant Pathology and Microbiology* 9: 445-451.

Rheneen H.A., Hasselbach O.E. and Muigai S.G.N. (1981). Effect of growing beans together with maize on the incidence of bean diseases and pests. *Plant Pathology* 87:193-199.

Sallam N. M. (2011). Biological control of common blight of beans caused by *Xanthomonas axanopodis* pv. *phaseoli* by using the bacterium *Rahnella aquatilis*. *Archives of Phytopathology and Plant Protection* 44: 1966-1975.

Schwartz H. F. (1991). Compendium of bean diseases. The American Phytopathological Society, St. Paul, Minnesota, USA. p. 25.

Schwartz, Pastor-Corrales M.P., and Marcial Antonio (1989). Bean production problems in the tropics. Centro Internacional de Agricultural Tropical, Cali, Colombia. p. 655-725.

Seebold K. W. (2014). Bean Diseases: Plant Pathology Fact Sheet. Cooperative Extension Service, College of Agriculture, University of Kentucky, Kentucky, USA.

Shiringani R. P. (2007). Effects of planting date and location on phenology yield and yield components among selected cowpea varieties. M.Sc. Dissertation, University of Limpopo, South Africa.

Sindhan G. S. and Bose S. K. (1979). Perpetuation of *Phaeoisariopsis griseola* causing angular leaf spot of French beans. *Indian Phytopathology* 32: 252-252.

Stenglein S. A., Ploper D., Vizgarra O. and Balatti P. (2003). Angular leaf spot: A disease

caused by the fungus *Phaeoisariopsis griseola* (Sacc.) Ferraris on *Phaseolus vulgaris* L. *Advances in Applied Microbiology* 52: 209-243.

Tittonell P, Shepherd K, Vanlauwe B, Giller K (2008). Unraveling the effects of soil and crop management on maize productivity in smallholder agricultural systems of western Kenya—An application of classification and regression tree analysis. *Agriculture, Ecosystems and Environment* 123: 137–150.

Tom W. (2014). Planting date effects on growth, development and yield of selected agronomic crops at Makhathini irrigation scheme. M.Sc. Dissertation, University of KwaZulu-Natal, South Africa.

University of Illinois (2000). Bacterial Diseases of Beans. Department of Crop Sciences. https:www.extension.illinois.edu, Accessed 1st April, 2018.

University of Illinois Extension (2018). Focus on plant problems. University of Illinois Extension:https:www.extension.illinois.edu/focus/index.cfm?problem=bacterial-diseases-of-beans, Accessed 1st April, 2018.

Vange T. and Obi I. U. (2006). Effect of planting date on some agronomic traits and grain yield of upland rice varieties at Makurdi, Benue state, Nigeria. *Journal of Sustainable Development of Agriculture and Environment* 2: 1-9.

Verma B. R. and Sharma S. L. (1984). Variability in *Phaeoisariopsis griseola* the causal agent of angular leaf spot of beans. *Indian Phytopathology* 37: 580-581.

Wachenje C. W., 2002. Bean production constraints, bean seed quality and effects of intercropping on floury leaf spot disease and yields in Taita Taveta district, Kenya. M.Sc. Thesis, University of Nairobi, Nairobi, Kenya.

Wagacha J. M., Muthomi J. W., Mutitu, E. W. and Mwaura F. B. (2007). Control of Bean

Rust using Antibiotics Produced by *Bacillus* and *Streptomyces* species - Translocation and Persistence in Snap Beans. *Journal of Applied Sciences and Environmental Management* 11: 165-168.

Wagara I. N., Mwang'ombe A. W., Kimenju J. W., Buruchara R. A. and Kimani P. M. (2011). Reaction of selected common bean genotypes to physiological races of *Phaeoisariopsis griseola* occurring in Kenya. *African Crop Science Journal* 19: 343 - 355.

Webber M., Barnett J., Finlayson B. and Wang M. (2006). Pricing China's irrigation water. Working paper. School of Anthropology, Geography and Environmental Studies, University of Melbourne, Victoria, Australia.

Wortmann C. S., Kirkby R. A., Eledu C. A. and Allen D. J. (1998). Atlas of common bean (*Phaseolus vulgaris* L.) production in Africa. International Center for Tropical Agriculture (CIAT), Cali, Colombia.

Yordanov L., Velikova V. and Tsonev T. (2003). Plant response to draught and stress tolerance. *Journal of Plant Physiology* 1: 187-206.

Zitter T. A. and Provvidenti R. (1984). Vegetable crops virus diseases of snap and dry beans. Vegetable MD online: http://vegetablemdonline.ppath.cornell.edu/cropindex.htm, Accessed 24th August, 2016.

APPENDIX

Appendix I: Disease symptoms observed on common bean genotypes planted in different agro-ecological zones of Western Kenya during the 2016 short rain and 2017 long rain seasons.

Season	Agro-ecological zone				
	LM 2	UM 4	UM 3-4	UM 2	UM 1
Short Rains 2016	1. CBB* 2. Systemic necrosis* 3. Rust* 4. Scab*	1. CBB 2. Systemic necrosis 3. Mosaic 4. Yellow mosaic 5. Rust 6. Scab 7. Angular leaf spot	1. Rust* 2. CBB*	1. CBB 2. Halo blight 2. Systemic necrosis 3. Mosaic 5. Rust 6. Scab 7. Angular leaf spot	1. CBB 2. Halo blight 3. Systemic necrosis 4. Mosaic 5. Yellow mosaic 6. Rust 7. Scab 8. Angular leaf spot
Long Rains 2017	1. CBB 2. Halo blight 3. Systemic necrosis 4. Common mosaic 5. Rust 6. Scab	1. CBB 2. Halo blight 3. Systemic necrosis 4. Mosaic 5. Golden mosaic 6. Rust 7. Scab 8. Angular leaf spot 9. Cercospora leaf spot	1. CBB 2. Halo blight 3. Systemic necrosis 4. Rust 5. Scab 6. Anthracnose	1. CBB 2. Halo blight 3. Bacterial brown spot 4. Systemic necrosis 5. Common mosaic 6. Rust 7. Scab 8. Angular leaf spot 9. Anthracnose	1. CBB 2. Halo blight 3. Bacterial brown spot 4. Systemic necrosis 5. Common mosaic 6. Golden mosaic 7. Rust 8. Scab 9. Angular leaf spot 10. Anthracnose 11. Floury leaf spot

CBB= Common Bacterial Blight

*=Missing yield data therefore not analyzed with the rest

Appendix II: ANOVA table for comparison of the Yields of bean genotypes grown in different agro-ecological zones in the long rain season of 2017 in Western Kenya

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	2	0.4675	0.2337	1.21	
Reps.*Units* stratum					
AEZ	5	0.6581	0.1316	0.68	0.639
Genotype	17	15.4955	0.9115	4.71	<.001
AEZ x Genotype	85	8.6379	0.1016	0.53	1
Residual	214	41.4041	0.1935		
Total	323	66.6631			

P≤0.05

Appendix III: Monthly precipitation (mm) data recorded by the Bungoma County Government Metrological Department for the year 2017.

Month	Total Precipitation	
	UM 4 (Tongaren)	LM 1 (Kanduyi)
January	47.3	63.0
February	168.0	180.1
March	250.5	162.5
April	154.7	133.5
May	293.1	262.9
June	137.3	141.6
July	73.8	100.7
August	247.0	124.0
September	221.9	81.3
October	271.4	206.0
November	45.0	144.1
December	22.1	135.4

(mm)=Millimeters; UM= Upper Midland zone; LM= Lower Midland zone.

Source: County Government of Bungoma, Metrological Department, Bungoma County

Appendix IV: Monthly precipitation (mm), temperature (°C) data recorded at Kakamega Meteorological Weather Station for the year 2016.

Month	Precipitation	Minimum av. Temp	Maximum av. Temp
January	118.4	15.9	28.7
February	16.6	15.7	31.1
March	118.6	16.3	31.8
April	291.5	16.8	28.3
May	391.7	15.5	27.9
June	130.6	15.0	28.3
July	127.3	14.8	*
August	116.4	14.5	*
September	127.0	14.5	*
October	147.3	14.9	*
November	92.1	15.6	*
December	7.4	15.6	*

av.= Average; Temp= Temperature

*Data Unavailable