EFFECT OF CROP MANAGEMENT PRACTISES, TEMPERATURE AND RAINFALL ON DEVELOPMENT OF ANGULAR LEAF SPOT AND ANTHRACNOSE ON COMMON BEANS IN TRANS NZOIA COUNTY, KENYA

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This thesis is my original work and has not been submitted for award of degree in any other university.

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This thesis is dedicated to my parents Mr. Wyckliffe Odunga and Mrs. Beatrice Oyaa, my sister Ms. Terry Odunga and brother Mr. Byron Odunga.

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ABBREVIATIONS AND ACRONYMS

AEZ	Agroecological zone
Als	Angular leaf spot
ANOVA	Analysis of Variance
AUDPC	Area under disease progress curve
BCMV	Bean Common Mosaic Virus
C	Carbon
CABI	Centre for Agriculture and Bioscience International
CBB	Common Bacterial Blight
CIAT	Centre for International Tropical Agriculture
CV	Coefficient of Variation
DAP	Di-Ammoninium Phosphate
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
GLP 2	Grain Legume Program Two
HA	Hacter
ILRI	International Livestock Research Institute
KALRO	Kenya Agriculture and Livestock Research Institute
KEPHIS	Kenya Plant Health Inspectorate Service
Kg	Kilograms
LH1	Lower Highland 1
LSD	Least Significant Difference
Ml	Millilitres
MOA	Ministry of Agriculture
MRT	Multiple Range Test
pH	Potential of Hydrogen
Ppm	Parts per million
RCBD	Randomized complete block design
UM 3	Upper midland 3
UM 4	Upper midland 4
USA	United States of America

ABSTRACT

Plant disease is a major constraint in common bean (*Phaseolus vulgaris* L.) production in Kenya. Angular bean leaf spot (als) (*Pseudocercospora griseola)* and anthracnose of bean (*Colletotrichum lindemuthianum)* are foliar fungal diseases that affect common beans in Trans Nzoia County. Development of plant diseases are influenced by weather parameters including temperature, humidity, rainfall and farm cultural practices such seed selection, planting time, field sanitation practices and disease control methods. The overall objective of the study was to determine how crop management practices, rainfall and temperature affect the temporal development of angular leaf spot and anthracnose on common beans under diverse agro-climatic zones in Trans Nzoia County, Kenya.

Farmers' perception on seed access approaches to disease management practice for angular bean leaf spot and anthracnose of bean was determined through a survey carried out on 100 randomly selected common bean farmers in Trans Nzoia County by administering a semi structured questionnaire. Data was collected on the sources of seeds, preferred bean varieties, disease knowledge and management methods used by the farmers. A survey was done on six major breeding institutions which were KEPHIS, KALRO, CIAT, Egerton University, Simlaw and Seedco Groups of companies to understand bean breeding and availability of certified seeds to farmers. Purposive sampling method was used to select the key breeders for survey using a semi structured questionnaire which was done virtually. Field experiments were conducted in Kitale, Trans Nzoia County over two cropping seasons that was during the short rains in 2020 and during the long rains in 2021. The experimental treatments were in three plots that was KALRO Research centre (UM 4), Kitale Airstrip (UM 3) and Kibomet (LH 1) with a size of 0.5 hectares each and bean variety Rosecoco GLP 2 was planted in a Randomized Complete Block Design (RCBD). Temperature data was collected using a HoboMobile app while the rainfall measurements were recorded using a rain gauge installed 2m away from the plants within the field. Data on phenological stages of crop, plant height, disease incidence and severity collected two times a week during the cropping season. Samples of diseased plant materials were collected and the disease causing fungi isolated for identification.

The survey showed that most farmers (82%) sourced their seeds from local markets and their own saved seeds from the previous harvest which they grow for household consumption. The most preferred bean variety was Rosecoco (GLP 2) because of its early maturity, high yielding and adaptability characteristics. Information on good agricultural practices was accessed through the extension officers by majority of the farmers (55%) on how to manage pests and diseases which was a major (51%) challenge on bean production. The major diseases observed on 78% of the farms were angular leaf spot and anthracnose of which most farmers used cultural methods to manage the diseases. Majority of breeders (33%) preferred to breed Rosecoco GLP2 since it had high intake in agroshops which they bred against disease tolerance and resistance. Majority (67%) had bred beans for disease resistance against angular leaf spot and anthracnose. The main challenge was pathogen variability among 50% of the breeders which occurred after the crops have been exposed to the environment. Majority of the breeders (60%) knew about common beans diseases in specific regions through the farm visit reports by extension officers.

Results from the field experiments showed that increase in temperature and rainfall caused an increase in disease development. The disease severity was highly significantly ($p \leq 0.05$) affected by increase in temperature. The development of the disease on the three AEZs was attributed to the varying environmental conditions. However, there was no significant difference in the temperature records on UM4, UM3 and LH1 during the long rains as the AEZs bordered each other hence the close climatic condition. During the short rains, there was a positive significant correlation of 0.031 between temperature and anthracnose severity. There was a significant difference ($P \leq 0.05$) in temperature means between UM4 and UM3 during the short rains however there was no significant difference ($P \leq 0.05$) in the different AEZs during the long rains. The study showed that farmer's cultural practices such as choice of bean varieties and weather elements including temperature and rainfall increase disease development in the cropping system which later affects the expected yields. Breeders concentrated more on early maturity characteristics so that their variety could be accepted by farmers. Alternating periods of high and low rainfall with long periods of high humidity caused increase in both diseases across the three AEZs.

Key words: *Pseudocercospora griseola*, *Colletotrichum lindemuthianum*, *Phaseolus vulgaris*, disease models, disease management

CHAPTER ONE: INTRODUCTION

1.1 Background Information

Common bean (*Phaseolus vulgaris)* is a key food security and nutrition crop contributing to about 300 million daily diet intake (Odendo *et al*., 2011; Steenson *et al*., 2020). Latin America is by far the world's leading common bean producer contributing 50% of the total bean production globally (Barnes *et al*., 2021). The crop is popularly grown and frequently consumed legume in Kenya and ranked second after maize (Duku *et al*., 2020). The major producers and consumers of common beans in African continent are the countries within Eastern and Central, since it supplies around 45% of dietary protein and 25% caloric intake which makes it the greatest contributor of proteins worldwide (Makunja,2020; Semba *et al*., 2021). Uganda, Kenya and Tanzania are the leading producers in Africa (Nchanji *et al*., 2021). Total production of common bean in Kenya was 728,160 metric tons (MT) in 2016 and 846,000MT in 2017, an improvement from the previous year (Food and Agriculture Organization, 2017).

Common beans can be produced in diverse agroecological zones in Sub Saharan Countries (Duku *et al*.,2020). The environmental conditions that support growth of beans include temperature ranges of 16 - 25°C, the soil has to be loam, high organic matter levels and neutral soils pH of about 6.5-7.5 (Mondo *et al*., 2019), rainfall from 400 and 1600 mm annually. Crop development takes about 70-200 days, however, this depends on variety and the agroecological zone. The yield potential ranges al from 400-5000 kg ha−1 (Kimani *et al*., 2009; Duku *et al*., 2020). The short maturity rate of about 3 months exhibited by most available common bean varieties and the high yield potential in most cropping system makes it of great significance in enhancing food security in Kenya (Otieno *et al*., 2020). In addition to protein, beans have trace elements of iron and zinc key elements for nutrition (Dumoulin *et al*., 2021) and a lower level of glycemic index (Gao *et al*., 2019).

Most small-scale farmers cultivate common beans for family food security and nutrition then sell surplus for family income and livelihood (Mangeni *et al*., 2020). Consumption of beans is high amongst rural families with low income and some in urban areas, however utilization of common beans varies depending on the region and the countries where they are popularly grown (Mutungi *et al*., 2020; Wachira, 2020). There are a number of bean types for example, determinate bush, indeterminate bush and the climbing type beans with are the bush type (Kimani *et al*., 2019) the most commonly cultivated. Bean varieties include; large red kidney, small red, black, sugars, red mottled, black, navy and purple beans are the commonly consumed types of beans (Katungi *et al*., 2009; Glahn *et al.*, 2020). Most farmers, especially in Western region of Kenya prefer Rose coco Grain Legume Program Two (GLP2) due to high demand and prices at the local market with a good taste in meals. GLP 2 is susceptible to most bean diseases like angular leaf spot, anthracnose and common bacterial blight (Wagara and Kimani,2007; Fritsche-Neto *et al*., 2019).

Farmers employ different methods of controlling these diseases ranging from cultural control, chemical control and use of diseases resistance varieties like Canadian wonder GLP 24 beans. Poor cultural practices like use of farmers own saved seeds is a common practice leading to disease build up (Fritsche-Neto *et al*., 2019). It is difficult to know the cause of yield reduction and the exact management measures to employ since pathogens have similar hosts and there are other underlying factors in the field that encourage disease development (Strauss *et al*., 2019). For better growth and yield, important nutrients are Nitrogen (N) and phosphorus (P) (Opala *et al.*, 2020). Due to continual ploughing, these nutrients lack in most soils across most agro-ecological zones in the country including western Kenya region. For example, phosphorus is lost during nutrient fixation (Han *et al*., 2021). In addition, most farmers apply fertilizers or manure to beans during growth (Otieno *et al*.,2009). In the study area, farmers do not practice crop rotation thus these practices reduce the fertility of soils and increases pathogens buildup in the field (De Corato, 2020). Bean production farmers face several challenges such as pests and diseases, unreliable rainfall, poor soil fertility and high cost of farm inputs.

1.2 Statement of problem

Common bean production in Trans Nzoia County has been on the decline due to several constraints (Ogecha *et al*., 2019). Plant diseases causing both quantitative and qualitative losses in common beans (Chepkemboi *et al*., 2020). Losses can range from 20% to 100% if no control measures are put in place (Mangeni *et al*., 2020). Most common beans being produced in the fields are susceptible to many fungal and bacterial diseases (Fernandes *et al*., 2021). Angular leaf spot and anthracnose are the most important fungal diseases, they are widely distributed and inoculum have been found in all AEZ with potential to grow common beans are grown within the country (Otieno *et al*., 2020). *Pseudocercospora griseola* and *Colletotrichum lindemuthianum* pathogens are highly variable and endemic in various agro ecological zones in Kenya thus making the disease difficult to control (Papias *et al*., 2020; Degu *et al.*, 2020). These pathogens are seedborne, therefore trading of infected seeds cause introduction and spread of the diseases to new regions. In regions with strict quarantine measures, there is reduced trade of bean seeds.

There is increase in production cost as the farmers try to control the diseases and they also cause reduction in the expected yields. In fields where the diseases are not controlled, there can be total crop loss. Total bean productivity in the country has been on the decline cannot meet the market demand of the increasing human population. There is gap in research as information on the relationship among weather variables, angular leaf spot and anthracnose development and agronomic practices for various bean production regions in Kenya has not be determined. Angular leaf spot and anthracnose severity has not been documented in all bean production regions in the country.

1.3 Justification

Bean cultivation has many challenges including diseases (Mangeni *et al*.,2020) which makes the production process costly and unprofitable (Caproni *et al*., 2020). While farmers may recycle own saved seeds, buildup of seedborne diseases leads to poor yield (Kan *et al*., 2019). Most of the available bean varieties are highly susceptible to angular leaf spot and anthracnose. Disease severity is high due to the conducive environment in the tropics, for instance high humidity and high temperature that favor the development of the pathogens (Gupta *et al*., 2020). Recent reports have indicated that common beans can be attacked by more than one pathogen giving synergistic reactions with severe impact on crop yield (Osdaghi *et al.*, 2020). Farmers lack knowledge on pest identification, its development during bean crop growth, timing of pest management decisions to maximize on the value of fungicide used during the disease development.

The use of resistant varieties has been reported as one way for angular leaf spot and anthracnose management while they are not accessible or affordable to small scale farmers. The research was used to collect data on angular leaf spot and anthracnose development on common beans in Trans Nzoia County and identified the key weather parameters driving their development. In this study, small scale farmer knowledge on foliar fungal diseases, management options employed and the challenges they encountered were documented. The information obtained was used in assessing the risk factors and developed a system for early warning for further sharing with small scale common bean farmers that was used to guide rational decisions for timing of applying disease management options to reduce yield loss in beans (Asgharipour *et al*., 2019).

1.4 Objectives

The overall objective was to determine how crop management practices, rainfall and temperature affect the temporal development of angular leaf spot (*Pseudocercospora griseola*) and anthracnose (*Colletotrichum lindemuthianum*) on common beans under diverse agro-climatic zones in Trans Nzoia County, Kenya

The specific objectives of the study were:

i. To determine farmers' and breeders' perception on production constraints, seed access and approaches to management of angular leaf spot and anthracnose on common beans in Trans Nzoia County
ii. To evaluate the effect of temperature and rainfall on the development of angular leaf spot and anthracnose on common beans in Trans Nzoia County

1.5 Hypotheses

i. Farmers and breeders perception on approaches to management of angular leaf spot and anthracnose in common bean is influenced by preference for specific variety and source of seeds which causes an increase in disease development.
ii. Temperature and rainfall variations significantly affect development of angular leaf and anthracnose of common beans by causing an increase in the development of the pathogens.

CHAPTER TWO: LITERATURE REVIEW

2.1 Economic importance of common beans (*Phaseoulus vulgaris* L.)

Common beans (*Phaseolus vulgaris* L.) have a high nutrient capacity providing about 45% of proteins that is nationally consumed (Wagara, 1996; Mangeni *et al*., 2020). Compared to other sources of protein diet such as meat and chicken, cost of beans is affordable to most families (Mangeni *et al*., 2020). Beans can also be eaten as accompanying meal with cooked rice, chapati or mixed with maize to make a common meal referred to as ‘githeri, ‘nyoyo’ in Kikuyu and Luo dialects respectively (Katungi *et al*.,2009). It is also blended with cereals for example maize, sorghum to make weaning foods for children or those with compromised immunity. Consumption rates also vary depending on different regions within the continent. Most varieties mature within 3 months and this makes it a good crop for enhancing food security in Kenya. It can grow well in different regions and cropping systems (Fritsche-Neto *et al*., 2019). It can be intercropped or rotated with other non-legumes like maize. There is limited crop rotation due to high land fragmentation (Nassary *et al*., 2020).

Sub Saharan Africa is the leading consumer of common beans with production of about 3.5MT (Nchanji *et al*., 2021). In Kenya, the total production of common beans is around 600,000 MT per year while the total consumption rate is around 755,000 MT per year. In Rwanda and Western, Kenya around 60 kilograms per capita of common beans is consumed annually. This ratio is very high and requires high production rate in order to meet the nutritional needs of the increasing number of inhabitants in the country (Ngigi *et al*., 2019). This huge deficit is filled through importation from neighboring countries like Ethiopia, Tanzania and Uganda (Warinda *et al*., 2020). Common bean is also a source of income and some small-scale farmers sell their season’s surpluses to earn income (Justino *et al*., 2019). The countries with the highest common bean production are Brazil, India, China, Myanmar, Mexico, USA then Kenya is the seventh greatest producer (Basavaraja *et al.*, 2020). In the Eastern African region of Kenya, Tanzania, Rwanda, Uganda, Ethiopia and Democratic Republic of Congo are the regions where common beans are intensively cultivated. This makes about 62% of common bean production in East Africa (Nchanji *et al*., 2021).

2.2 Production constraints of common beans in Kenya

Common bean production in Kenya cannot attain the optimal yield measure due to biotic and abiotic elements (Kosgei, 2016; Degu *et al.*, 2020). Most production is on subsistence level such as intercrop with maize, sorghum or other crops such as sugarcane, low access and use of inputs such as fertilizers and poor farming practices contribute to the low production. (Mutari *et al.*, 2021). In other bean growing regions in Africa, farmers obtain seeds through the informal channels which include saving their own seeds from previous harvests, local exchanges and purchase of non-certified seeds from local markets. Use of own farm saved seeds is common with small scale bean growers due to high cost and limited access to certified seeds (Njonjo *et al*., 2019) leading to high disease build up in farms (Tugume *et al*.,2019). These seeds lack the desired traits of tolerance to biotic and abiotic stresses and are likely infected with fungal, viral or bacterial diseases. Despite, production of hybrid certified high yielding varieties and tolerant to diseases (Geda *et al*., 2021). Their adoption by farmers remains low due to high costs (Kidudu *et al*., 2019). Some varieties also have varietal purity and poor adaptation of introduced varieties to local conditions (Voss, 2020). Due to lack of uniformity of own saved seeds, harvests are of mixed varieties, thereby fetching low prices at the local markets.

Land is highly fragmented due to increasing human population and diverse alternatives for land use. Cultural practices like crop rotation cannot take place since there is no land for rotation. In Kenya most agro ecological zones have warm and wet climatic conditions (Wawuda *et al*., 2021). This is the ideal condition for the establishment and development of most common beans pathogens. When the host crop is susceptible the pathogens are able to reproduce and destroy the crop within a short period. Disease management options are influenced by cropping practices and environmental factors like rainfall and temperature that favor the disease development (Papias *et al.*, 2020). Irregular or unreliable rainfall results in drought in most regions and this reduces the yields since most farmers in Kenya rely on rain-fed agriculture (Do *et al*., 2021). Installation of irrigation schemes is very expensive especially in small scale farms. Some parts of Rift valley and Eastern Kenya are drought endemic regions. In Kenya farmers depend on the long and short rains seasons to grow the common beans.

In the recent years the short rains have failed causing drought in most parts of the country and this is a major challenge to common bean cultivation (Duku *et al*., 2020). Other abiotic factors like soil nutrients can decrease crop production if not controlled (Meng *et al*., 2021). Common beans have their optimal requirement of each of the essential nutrients. When there is excess or limited nutrients the soil becomes infertile and unbearable for common beans production. High or very low pH causes decline in production (Meng *et al*., 2021). Together, these constraints may cause production instability, decline in market, increase production cost thus also affecting food security (Zanella *et al*., 2019). Preharvest and postharvest losses are as a result of pests and diseases (Nay *et al*., 2019). Pathogens have survival mechanisms where they have increased their host range and diversification such that wherever a plant is growing there is a pathogen that affects it. Common beans diseases are of national concern due to the direct and indirect losses that they cause to the common beans. There are high qualitative losses as a result of seed discoloration and pod malformation especially when the weather is warm and humid (Ellis *et al*., 2020). It is during this period that control measures should be intensified. Bean stem maggot is a key pest in Western, Kenya. Most farmers rarely manage pests and diseases of common beans. If you plant susceptible common bean cultivar and the environmental factors are conducive for the development of a particular pathogen, there can be disease epidemic causing total crop losses of around 80 to 100% (Gaur *et al*., 2020).

2.3 Foliar diseases affecting common beans and major management practises

In most parts of the world and particularly in the tropics wherever beans are grown there are pathogens in the fields (Fernandes *et al*., 2021). There are several diseases that infect common beans. They include angular leaf spot which is caused by *Pseudocercospora griseola* (Binagwa *et al*., 2020), common bacterial blight caused by *Xanthomonas axonopodis* pv. *phaseoli* (Costa *et al*., 2020). Bean common mosaic virus, bean anthracnose caused by *Colletotrichum lindemuthianum* (Costa *et al*., 2020), bean rust (*Uromyces appendiculatus*) and halo blight *Pseudomonas savastanoi pv. phaseolicola* (Cooper *et al*., 2021). Most of common beans production regions in Kenya have reported incidence of angular leaf spot (Mahdi *et al*., 2019) and anthracnose. The output from bean production in Western Kenya has however been on the decline due to several constraints (Ogecha *et al*., 2019). Diseases are one of the major challenges in common bean production (Chepkemboi *et al*., 2020). Common beans being produced in the fields are susceptible to many fungal and bacterial diseases (Fernandes *et al*., 2021). They are grown in different altitudes and agro ecological zone for example the Coastal, Eastern, Western and even Central parts of Kenya. These foliar diseases damage the above ground parts of common beans therefore reducing their market quality and expected yields.

Management measures aim to reduce the level of inoculum in the field and reduce crop loss. The disease is spread through infected seeds, therefore the best method to avoid introduction of disease causing organism to the farm is through the use of certified seeds. Clean seed programs can be set up in farm levels especially in areas where the disease pressure is low (Misganaw *et al*., 2019). Rotation of crops with non-legumes and removal of crop residues on the farm which would otherwise act as alternative hosts will help reduce the spread of the disease (Mota *et al.,* 2021). Varietal mixture will help reduce losses in cases where the one variety is susceptible to the disease. Intercropping of beans with maize is a common practice especially in Western, Kenya (Ziaie-Juybari *et al*., 2021).

Use of resistant varieties is highly recommended as it is cost effective especially at small scale level (Mungalu *et al.,* 2020). However, it takes a long time for resistant varieties to establish for example breeding for resistance for angular leaf spot takes upto 10 years. Fungicides for example metalaxyl and mancozeb are commonly used to control the disease since they are efficient especially in highly infested fields (Xavier *et al.,* 2019). When the factors that influence occurrence of disease coincide especially when there is high humidity, warm temperatures and the host is susceptible, there are high chances that the crop will suffer total loss (Mangeni *et al*., 2020). Use of integrated disease management method is the most appropriate as it involves incorporation of cultural, physical and chemical control methods.

2.4 Economic importance of angular leaf spot and anthracnose on common beans

Angular leaf spot and anthracnose are very important diseases in subtropical and tropical countries particular in regions where common beans are consumed by majority of the households and are grown by many small scale farmers (Assefa *et al*., 2019). Yearly quantitative losses in Kenya due to diseases are around 374800 tones (MoA, 2019). Premature and severe defoliation of leaves reduce the quantity and quality of expected harvest (Halvorson *et al*., 2021). Farmers also incur monetary losses from the increased cost of production while trying to control the diseases (Rezene *et al*., (2019). Screening common bean germplasm for resistance against angular leaf spot and anthracnose under field conditions can help reduce disease impact. The diseases attack the leaves, pods and stem of the crops thereby reducing the expected yield of the crop and also damaged pods lower market value of common beans (Gupta *et al*., 2020). Angular leaf spot and anthracnose are of great significance because they occur in all regions growing beans, spread really fast through seed transmission and can cause total losses when the incidence is high (Gonçalves-Vidigal *et al*., 2020). The causal agents for these diseases are highly variable and have been spread in different regions in the country through exchange of seeds in the informal seed systems. This has led to outbreak of the foliar diseases in new areas thereby reducing bean productivity. Climate change, especially increase in humidity and temperature cause increase in disease development thereby accelerating the rate of yield losses.

2.5 Angular leaf spot on common beans

2.5.1 Distribution and occurrence of the disease

Most common bean production regions in Kenya have reported incidence of angular leaf spot (Mukhwana *et al*.,2021). It is one of the most damaging and widely distributed diseases as it occurs in most fields growing beans. The pathogen is common in areas with warm and wet weather conditions (Degu *et al*., 2020). It affects a variety of legume crops including *Phaseolus vulgaris*, whether wild or cultivated, dry or green snap beans, lima beans, scarlet runner or large white kidney beans, tepary bean, soyabeans, and hyacinth bean, *Desmodium* species and Dolichos lablab, adzuki beans and cowpea (Mukhwana *et al*., 2021). In Western parts of Kenya, the information on the variability and distribution of pathogen is limited which limits the breeding for disease resistance (De-Almeida *et al*., 2021).

2.5.2 Etiology of *Pseudocercospora griseola*

Angular leaf spot disease in common beans is caused by an imperfect hemibiotrophic fungal pathogen, *Pseudocercospora griseola* (De Almeida *et al*., 2020) which are symptomologically diagnosed through appearance of angular necrotic spots on pods and plant leaves. This fungus belongs to the class Dithideomycete (Silva *et al*., 2020), order Moniliales and family Stibaceae. *Pseudocercospora griseola*, is a hemibiotroph. It starts as a biotroph where it establishes infection in a living host then becomes necrotrophic where it kills the cells by secreting toxins. It can be isolated from the host and grown in artificial media like potato dextrose agar (PDA), cornmeal, water agar, bean leaf decoction media and malt extract agar for disease diagnosis. The pathogen sporulates faster in cornmeal and malt extract agar however the media inhibits mycelial growth. In potato dextrose agar the mycelia are well exhibited.

The conidia of *Pseudocercospora griseola* are borne at the tip of conidiophores and synnemata is formed from organized bundles. They are brownish in colour. Their shape is cylindrical to spindle with a slight curve and not constricted. They are septate and smooth and vary in size and number depending on species. In culture the fungus growth is fluffy and greyish brown in colour for the first two weeks and then it changes to brown and dark. The culture also has white fluffy to grey sections (Rezene *et al*., 2019).

2.5.3 Signs and symptoms on common beans

Angular leaf spot symptoms on common beans can be seen on all the above ground tissue of the crop with pronounced symptoms on the leaves and pods (Misganaw *et al*., 2019) which can cause yield losses of upto 80% (Mongi *et al*., 2018). On the leaves, the lesions are dark grey to brown, and are often delimited by veins, giving them the characteristic angular appearance which resulted in the name angular leaf spot. The surrounding tissue may become chlorotic. Under conditions of severe infection, lesions coalesce and premature defoliation occurs (Pereira *et al*., 2019). Leaves have abnormal colours, leaf fall and discoloration of the bark. Lesions initially are gray or brown, may be surrounded with a chlorotic halo, and have indefinite margins. On the underside of the leaf, are lesions which look like brown spots and their expansion is limited by the veins. They appear slightly paler than those on the upper side. Stem lesions are oval or circular initially superficial with margins that are almost black to reddish brown centres which are sharply defined (Rezene *et al*., 2018).

Dark brown elongate lesions appear on petiole and stems. The spots vary in size and coalesce completely covering the pod in severe infections (Pereira *et al*., 2019). The lower part of the leaf will reveal dark tiny tuft (synnemata) protruding from lesions (Andrianova, 2020). Dark stromata are produced on the lesions, and in humid weather, many synnemata may develop bearing conidia. If control is not put in place in good time, total loss of the crops can be incurred by the farmer. Qualitative and quantitative losses occur after symptom are fully expressed on the plant. The angular lesions on bean pods reduce their market value and also reduce the quality of seeds (Gupta *et al*., 2020).

2.5.4 Infection process and disease development

Entry of the pathogen is by use of direct penetration mode. This needs the fungus to be adhesive to the plant surface and degrade the cuticle and cell wall. The pathogen infects the leaf tissue by entering the stomata and advancing intracellularly in the mesophyll and palisade parenchyma (Renan *et al*., 2020). The hyphae use the appressorium to penetrate the cell wall. The leaf has to be wet to enhance the movement of the pathogen into the leaf. Other conditions necessary are high moisture, temperature, light and nutrients availability. The pathogen can remain latent if the conditions for infection are not favorable. Development of disease is favored by optimal temperatures of 28^0 C, high humidity that alternates with dry periods and susceptibility of the host. Infection will not take place if the host is resistant to the pathogen. Sprinkler irrigation also favors disease development since this method of irrigation allows water to settle on plant leaves and also increase humidity within the farm. Lesion establishment and spore germination in *Pseudocercospora griseola* is strongly dependent on moisture (Renan *et al*., 2020). The pathogen has to create a relationship with the host. In the disease cycle the incubation period is of importance and refers to appearance of lesions and not necessarily the start of sporulation. Within 9 days after infection, the fungus develops intracellularly through necrotic lesions. By 9-12 days, stromata develop in the substomatal cavity and sporulation during periods (24-48hours) of continuous moisture (Rodríguez *et al*., 2019) Lesions will be the first symptoms of infection. The wet period favors production and germination of spores which are wind dispersed in the dry period and this can cause epidemics since wind moves very fast.

2.5.5 Transmission and survival and of the pathogen

There are several dispersal methods for plant diseases. The main mode of dispersal for *Pseudocercospora griseola* is through seed transmission especially when the seed is not certified and movement of water. The spores can travel long distance in windy seasons (Degu *et al*., 2020). Movement of people and animals in infected fields also help to disseminate the pathogen. The disease can spread within the fields during farm cultural practices like irrigation, during weeding or training when farms tools have not been disinfected and also through rain splashes from infected to non-infected farms (Mahdi *et al*., 2019). Dissemination by wind can allow spores to travel a very long distance and infect many plants. This can cause disease epidemics in areas where the pathogen did not exist before. Human activities especially during cultural practices also increase the spread of the disease. The pathogen has survival mechanisms that enables it to remain dormant during unfavorable weather or when the host is not available (Degu *et al*., 2020). The pathogen however cannot survive for a long time in bare soils with no vegetation cover that is why it is recommended to remove crop debris from the fields after harvesting.

2.6 Anthracnose on common beans

2.6.1 Distribution and occurrence of the disease

Anthracnose is an economically important disease that affects common beans (Banoo *et al*., 2020). It is caused by a hemibiotrophic fungal pathogen called *Colletotrichum lindemuthianum (*Conner *et al.* 2019). It was first reported in Germany in 1875. Since then it has been reported in all countries in Europe, Japan, Taiwan, India, South America and East African countries. The disease is widely distributed throughout the region's growing beans. This is a seed borne pathogen which is a major challenge to small scale producers who prefer to use own saved seeds. The pathogen is highly variable which makes management process ineffective limiting crop production (Amalou *et al*., 2021). Anthracnose is a major disease of beans in regions with high humidity and 100% losses can occur when the environmental conditions favor the development of the disease (Kiptoo, 2020). Beans market quality is reduced due to infection by anthracnose as the sunken and spotted seeds do not fetch good market price.

2.6.2 Etiology of *Colletotrichum lindemuthianum*

Colletotrichum lindemuthianum, the causal agent for anthracnose produces setae in some bean species. This fungus is in the class of deuteromycetes, order moniliales and sub division hyalosporae. The fruiting body produced is acervulli which is saucer shaped. The pathogen's cells are joined to each other perforations and are multinucleated. The mycelium is branched and the filament is septate. The hyaline changes colour and becomes darker as the mycelium reaches maturity. In culture medium the colonies appear as slow glowing, darkish brown, immersed mycelium that is brown and the margins are regular. Filiform setae of 2-4 septate which are sparse are produced along the conidiophores. Setae have varying length of pointed stiff brown hairs which are simple. The conidia are non-septate, hyaline, well rounded with a slight constricted middle and are closely packed in the arcevulus which occur in light pink massses. They are kidney, sigmoid or cylindrical in shape. The vacuole bodies are present at centre or the end of the conidium

(Gaudencia *et al*., 2020).

2.6.3 Signs and symptoms of anthracnose

Symptoms of anthracnose start when the plant is on the fourth week from the date of planting. They are distinctive on the leaves, then stem and on pods when the plant is about to reach maturity stage. They appear as regular dark brown sunken lesions with light grey centre on the cotyledons, on the underside of the leaf symptoms appear on the veins as linear brick red lesions (Shams *et al*., 2020). Freshly colored pink fruiting bodies can be seen sporulating on the surface of the necrotic spots. The lesions will then expand and cause the leaf to flag and wilt which makes the tissue chlorotic. They can also be diagnosed by the presence dark brown to black sunken lesions on cotyledons and stems. A clear understanding of its seed-borne nature, survival mechanism and its host's most susceptible stage of growth is a step in managing the disease.

2.6.4 Infection process and disease development

Cool temperatures of 18℃ and high humidity range of 70-100% increase the rate infection and disease development. Increase in moisture favors development, germination and spread of spores as well as infection of the disease. Free water on the foliage and young pods also promote the development of anthracnose. Infected plants will produce infected seeds and this is the major source of inoculum for the pathogen. The disease occurs in the early developmental stage when the crop is at the 3rd trifoliate stage (Opio *et al*., 2001). When temperature and humidity conditions are favorable, the pathogen causes death of the plant (Kiryowa *et al.*, 2016). The wet period should be prolonged to facilitate the infection process. The period from infection to when the plant can show visible symptoms ranges between 4-10 days depending on the age of tissue, bean variety and atmospheric temperature. Disease development is successful when the pathogen is virulent and the host is susceptible. Disease occurrence and severity is favored by frequent rainy weather.

2.6.5 Transmission and survival and of the pathogen

The pathogen is spread through the seed and can survive for three to five years therefore spreading the disease to other fields (Ferreira *et al.,* 2013). It is also passively spread by wind, rain water and animals moving from infected farm to healthy plants. People moving machinery through the infected fields during wet period also facilitate the movement of the disease causing fungus.

Survival of *Colletotrichum lindemuthianum* is influenced by temperatures. This pathogen can be dormant in mycelium form in the seed and also survive a spores. It has a wide range of hosts including vegetables and legumes which enhances their survival in the absence of their main host. In the absence of the main host, it will form sclerotia and survive on crop debris for atleast two years (Conner *et al*., 2019). Survival of the pathogen is reduced when the materials infected are buried deep in the ground and then come into contact with rain water. When wet and dry cycles alternate in the diseased soils the survival rate of the fungus is reduced

2.7 Factors that affect development of diseases on common beans

2.7.1 Effect of temperature on disease development

Environmental conditions especially the temperature play a major role in the development of disease causing organism (Singh *et al*., 2019). Every pathogen has their optimal level of temperature where they can grow and reproduce maximally. The different developmental stages of the disease cycle, for example spore production, germination, penetration, infection and colonization of the susceptible host are favored by different temperatures (Mwang'ombe, 2018). For example, in angular leaf spot development the disease is favored by optimal temperatures of 28 ℃ (Singh and Gupta, 2019). Infection and sporulation are optimal at 21℃. Survival of pathogen can take place in plant debris or infected seeds in the fields at temperature ranges of 25℃ to 35℃° (Dubey *et al*., 2019). Anthracnose development is favored by temperature range of 13℃-26℃, free moisture and a high relative humidity of 92%. The diseases can be very destructive in extended periods of warm and humid weather where losses can occur both in the field reducing seed quality (Suárez *et al.*, 2020).

2.7.2 Effect of rainfall on disease development

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 (Singh *et al*., 2019). *Pseudocercospora griseola* requires high humidity that alternates with dry periods and susceptibility of the host (Berny *et al*., 2019). Sprinkler irrigation also favors disease development since this method of irrigation allows water to settle on plant leaves and also increase humidity within the farm. Lesion establishment and spore germination in *Pseudocercospora griseola* strongly dependent on moisture (Degu *et al.,* 2020). High moisture levels favor spore germination in anthracnose (Gupta *et al*., 2020). Rain splash in the fields act as agents of dispersal for the pathogens (Mahdi *et al*., 2019). Rainfall also act as a major mode of dispersal for the pathogens through rain splash and moving water. In dry conditions the stomatal opening is reduced to prevent excessive transpiration and this prevents entry of pathogens (Driesen *et al*., 2020). Moisture stress is a major production constraint since most regions within Kenya receive insufficient rainfall at the same time installation of irrigation systems is expensive in small scale farms (ESONU, 2021). Plants that are environmentally stressed are susceptible to disease causing pathogens.

2.7.3 Effect of cultural practices on disease occurrence

Agronomic practices that are common in bean fields include selection of planting site, choice of bean varieties, use of certified or non-certified seeds, planting dates, intercropping, weeding and rotation of crops. These activities influence the introduction and spread of the disease-causing organisms (Sanyang *et al*., 2019). Early planting may result in reduction of vector transmitted viral diseases as it coincides with high rainfall that negatively affects the mobility of vectors (Mangeni *et al*., 2020). Mixed cropping or planting pure lines could increase or decrease the disease pressure on the farm (Reinprecht *et al*., 2020) as some pathogens have a wide host range. Appropriate spacing of the bean crop stand makes the environment less conducive to the pathogen as it reduces the effect of microclimate. The use of mulching cushions the fall of raindrops preventing spread of the inoculum by splashing the inoculum to other plants or fields (Nyawade *et al.*, 2019). In Western Kenya, smallholder farmers mainly intercrop maize and beans to produce enough food on their small pieces of land (Koomson *et al*., 2020). Intercropping reduces the spread of diseases and also reduces losses in case of susceptibility of hosts from monoculture. Weeds on the farm reduce the expected yields since they compete with the crops for essential nutrients and also act as an alternative host to diseases. Proper weed management in farms tends to improve crop yields (Laizer *et al.,* 2019).

2.7.4 Effect of host susceptibility on disease occurrence

Susceptibility or resistance of the host is determined by the crops genetics (Xue *et al*., 2015). Genes for resistance appear and accumulate first in hosts through evolution and that coexist with nonspecific genes for pathogenicity which evolve in pathogens while genes for pathogenicity exist in pathogens against all host plants that lack specific resistance. The crop has to be susceptible to the causal organism for the disease to develop. Resistant varieties are able to tolerate or even escape the effects of the disease. Most bean varieties are susceptible to angular leaf spot and this limits management options. There are different genotypes which confer to resistance such as improved Rosecoco and Canadian wonder which have already been identified (Mondo *et al*., 2019). The damage by the diseases is more severe where a susceptible host is cultivated during the warm and humid weather (De Ron *et al*., 2019). Disease may cause yield losses ranging between 10% and 40% depending on susceptibility of different varieties and environmental conditions. The farmers are advised to plant resistant varieties since there will be no management measure needed to control the diseases (Rezene *et al*.,2019).

2.7.5 Effect of soil characteristics on disease development

Soils have a variety of characteristics such as moisture content, pH, fertility level and structure that vary depending on the different agroecological zones (Willy *et al*., 2019). Fertile soils increase plants resistance to the diseases. Soils with high organic matter have low disease incidence (Dignam *et al*., 2019). Cropping practices that involve continuous ploughing of the same field causes land degradation that lowers soil fertility (Singh, 2021). Warm and moist soils provide favorable environment for the soil borne pathogen to develop and this makes the plant susceptible to other foliar pathogens to attack the plants with low resistance. Production of common beans can also be limited when there is an excess or shortage of essential mineral salts, lower pH and low soil fertility, which will render the crop to be susceptible to diseases (Głowacka *et al*., 2019).

2.8 Management of angular leaf spot and anthracnose on common bean diseases

There can be two or more diseases on the same plant at the same time and this limits the management options (Paulino *et al*., 2021). When a farmer intends to make a decision on which management method to employ, they need to have prior knowledge about the crop, growing season, disease tolerance level, sources of disease inocula, types of diseases affecting beans, diagnosis of the disease, management options available and optimal yield of common beans. Angular leaf spot and anthracnose are difficult to control since they spread really fast. Management measures that can be used include cultural practices, host resistance, chemical control and integrated approaches (Gupta *et al*., 2021).

2.8.1 Cultural methods of plant disease management

The farmer has to know the amount of losses as a result of disease infection by angular leaf spot and anthracnose in common beans before they make a decision on which management method should be used if the disease pressure is above the economic threshold (Nay *et al*., 2019). Scientist and breeders of beans have been trying to come up with solutions to the constraints faced in bean production (Voss, 2020). The primary causes of these disease problems are contaminated seed and infested crop debris (Jacobs *et al*., 2019). Use of pathogen free certified seeds is the first step towards avoidance of the inoculum especially when the pathogen is seed borne. Using farmers' own recycled seeds should be discouraged. Bean debris can remain a source of inoculum on the soil surface for 18 months in the temperate regions while in the tropics 6-8 months is maximal for survival of the pathogen. Also, the cost and availability of improved seed often force many small landholders to reuse some of their own seed or obtain seed from a neighbor.

In other instances, the absence or poor management of seed certification programs leads to contaminated seed (Osdaghi *et al*., 2020). Crop rotation with non-host crops like maize and other cereals for at least two years this will interfere with the survival mechanism of the pathogen ((Sanyang *et al*., 2019; Gonçalves *et al*., 2021), planting in well-drained soil as water logging encourages the development of the pathogen, removal of infected crop debris so as to avoid the survival of the pathogen in the absence of the main host, planting using pathogen free seed (Rai *et al*., 2020). Proper site selection as one needs to avoid regions that have been previously infected with diseases so as to reduce the negative effects on quantity and quality of common beans (Oladzad *et al*., 2019). Practice field sanitation from land preparation, during planting, weeding, watering and harvesting of the beans. Disinfection of farm tools, use of drip irrigation, spacing of beans to avoid the plants from overlapping each other and avoidance of injury to plants during farm operations (Sanyang *et al*., 2019) helps to reduce disease spread.

2.8.2 Host resistance in plant disease management

The use of host resistance as a method of disease management is very significant because it is cheap for a farmer to buy a resistant variety since it will require no additional costs to control the disease (Mahuku *et al*., 2004). This method is also safe to the environment and can be easily adopted by small scale farmers (Rezene *et al*., 2019). Use of common bean varieties that are resistant to angular leaf spot and anthracnose disease will provide cross protection to the plant

(Oladzad *et al*., 2019). Breeders are trying to come up with varieties that are able to tolerate diseases. This will result in improved yields and little or no use of chemical control. *Pseudocercospora griseola* and *Colletotrichum lindemuthianum* keep changing their variability and new pathogen races are formed that are able to infect the current resistant varieties. Therefore, the resistance which results from breeding is not long term and will breakdown easily when the pathogen is highly virulent (Kiryowa *et al*., 2021). Use of resistant varieties has been very effective in the control of angular leaf spot.

2.8.3 Use of chemicals to manage common bean diseases

Chemicals are used to control diseases when there is high disease pressure and instant control measure is needed or when other methods of control have not been successful. In commercial bean production, chemicals are frequently used to control diseases (Harveson, 2019) however, small holder farmers do not use fungicides frequently due to the high costs. The use of fungicides is a popular method in most farming schemes as it is effective and prevents total loss in common beans when there is high disease incidence (Teixeira *et al*., 2019). Commonly used fungicides are triazole, metalaxyl, tebuconazole which help to improve yields as they instantly reduce the effect of the pathogen (Teixeira *et al*., 2019). The farmer should follow manufacturers' instructions before fungicide application to enhance its efficacy. The use of fungicides should be intensified when the common beans are vulnerable to pathogen attack especially at flowering stage and when the flower blooming coincides with the pathogen's favorable environment for the disease. Second fungicide application can be done in late bloom that is if the disease persists. Application of fungicides should be avoided when the disease pressure is below economic threshold (Ons *et al*., 2020). When the factors that influence occurrence of disease coincide especially when there is high humidity, warm temperatures and the host is susceptible, there are high chances that the crop will suffer total loss (Singh *et al*., 2019). However, these management methods do not usually give maximum protection (CABI, 2019). This information will help the farmer to decide on the most effective management method that is highly effective and less costly. Fungicides are expensive, not compatible with environmental sustainability and are limited to protectants in many countries (Baibakova *et al*., 2019).

2.8.4 Challenges in management of diseases in common beans

Use of cultural control method alone is not convenient for management of ALS and anthracnose because certified planting materials are expensive to purchase at the same time not locally available (Haq *et al*.,2020). Most farmers lack knowledge on how to implement proper field sanitation, disinfection of tools after every use is not practical in large scale farms. Crop rotation cannot be maintained because there is not enough land for rotation due to high land fragmentation. Drip irrigation system is expensive to install and maintain especially in small scale fields so most farmers still use sprinkler method which otherwise create a micro climate for development of pathogens. It is also difficult to control movement of farm workers in large scale farms so they are able to carry diseases causing organisms from one plant to another.

Although the use of biocontrol agents is desirable from an environmental perspective, their limitation include inconsistent performance related to lack of stable formulations, a narrow spectrum of activity and a heavy dependence on locally available strains for local applications (Kagot *et al*., 2019). Use of resistant varieties is a time consuming process, it takes time for trials to be done and approved for control. Plant breeders are continuously developing resistant bean varieties but pathogens rapidly mutate, attacking formerly resistant cultivars (Gonçalves-Vidigal *et al*., 2020). The pathogen, *Pseudocercospora griseola* keeps changing rendering control of angular leaf spot a major challenge (Pereira *et al*., 2019). The pathogens develop new races and pathovars that are able to overcome plant resistance (Gonçalves-Vidigal *et al*., 2020). Therefore, breeders have to continuously come up with new varieties.

Chemical control is being discouraged because of environmental and health issues (Mpumi *et al*., 2016). Extensive use of fungicides is environmentally not safe. Chemical residues find their way into water sources making water unsafe for use. Some farmers apply pesticides then sell their produce without observing the recommended pre-harvest interval time which makes the produce unsafe for human consumption. Increased consumer awareness of the detrimental effects of synthetic chemical fungicides threaten their continued use (Meena *et al*., 2020). Fungicides are also expensive to buy especially in small scale farms and at the same tiem continuous use of fungicicdes makes the pathogen to be resistant.

2.9 Modelling of foliage diseases on common beans

General disease modelling considers all the factors that affect the pathosystem including the host and environmental conditions. Disease research topics use the potential distribution models to show the future distribution of species in a specific environment. In most cases the environmental factors have a direct effect on occurrence and distribution of diseases on common beans. Spatial projections of the pathogen's favorability can be assessed when environmental conditions are modelled (Fritsche-Neto *et al*., 2019). Foliage disease models can be parameterized using the ecological data derived from the field experiments for angular leaf spot and anthracnose (Sache and Zodak, 1995). The area under disease progress curve (AUDPC) is used to show the relationship between the disease severity and yield loss which relates the quantitative disease intensity over a period of time (Pereira *et al*., 2019). Statistical model was used to predict the level of disease threat at a particular. It will help to forecast outbreaks and impact of the disease.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Description of study sites

The experiment was carried at the Kenya Agricultural and Livestock Research Organization (KALRO) Kitale an Industrial Crop Research Center and neighbouring farms in Saboti sub-county, Trans Nzoia County which is 3 kilometers from Kitale town. The KALRO Centre is located 70 kilometers from Eldoret and 400 kilometers from Nairobi. The area is 1900 meters above sea level and located on latitude 1° 0′ 6.6´´N and longitude 34° 59´ 10´´E (Larnyo and Atitsogbui, 2020). The dominant soils are humic acrisols that are deficient in nitrogen and phosphorus (Jones *et al.*, 2013). The site has an annual mean precipitation of about 1000-2100 mm unimodal rainfall that occurs from March to November with peaks in May and August with a distinct dry spell from December to March (Kenduiywo *et al*., 2020) while the daily means for rainfall amount was 6.4mm in the year 2020 and 3.1mm in 2021. The research centre lies in upper midland 4 (UM4) agroecological zone (Owiny *et al*., 2019). Rainfed agriculture is the dominant source of food in the region as crops, for example common beans, are grown during the short and long rain seasons. Sowing time is determined by the onset of rains by most farmers. Intercropping/ mixed cropping and crop rotation of cereals with legumes is a common cropping practice in Trans Nzoia County (Kirungu *et al*., 2002).

The region is generally cool with average temperatures that range between 14℃ and 25℃. In 2020 the average daily temperature was 19.7℃ and it slightly increased to 20.2℃ in 2021 (Table 3.1) The second site was located at Kiminini constituency on latitude $1^0$0′N and longitude $35^0$7′ E. It lies in Upper midland 3 (UM3) between altitudes of 1,700 and 2000metres above the sea level. The zone had well drained deep red- brown clays and sandy clays derived from the basement complex. The third site is located at Cherangany constituency on latitude 1.022^0 1N and longitude 35^0 036^0E. It was on the lower highland zone (LH1) with an altitude ranging from 1800-2400m above the sea level. The soil in LH1 were brown and red clay soils which have been derived from the volcanic ash. The soils had high content of clay mineral which gave the beans continuous supply of nutrients.

Table 3.1 Daily means for temperature, rainfall and relative humidity (RH) for Trans Nzoia County, Kenya in 2020 and 2021

	2020			2021		
Month	Temp (^{0}C)	Rainfall(mm)	RH(%)	Temp (^{0}C)	Rainfall(mm)	RH(%)
January	19.6	5.4	66	19.7	1.1	57
February	20.1	1.5	64	20.5	0.7	56
March	20.7	12.5	69	21	1	52
April	20.3	6.9	71	20.4	4.9	70
May	20.3	7.3	76	19.7	4.6	73
June	19.3	10.5	79	19.2	1.9	69
July	19	6.8	79	18.7	4.8	75
August	19.3	9.8	80	19	3.8	70
September	19.5	6	73.6	19.3	6.1	74.6
October	19.8	5.2	72	19.6	6.8	71
November	19.6	5	67	19.7	1.5	60
December	19.2	0.3	54	25.4	0.3	55
Means	19.7	6.4	70.9	20.2	3.1	65.2

Source: Kenya Meteorological Department, Trans Nzoia County.

3.2 Determination of farmers' and breeders' perception on approaches to management bean diseases

3.2.1 Determination of farmers' perception on approaches to management of angular leaf spot and anthracnose

Farmers' perception on management of angular leaf spot and anthracnose was determined by use of an open ended questionnaire and direct observation of the small holder farmers' plots (Muoni *et al*., 2019) during the short rains 2020. Using systematic random sampling method, 100 common bean farmers were sampled within Trans Nzoia County for the survey. Farmers sampled for the survey were selected with the help of the County's extension officers. The regions covered were Saboti, Kiminini and Cherangany constituencies due to their importance in common bean production and the favorable environmental conditions that favour the crop development. Knowledge of common bean diseases by the farmers was determined using a semi structured questionnaire method. The farmers gave the names of the diseases on common beans that they know and the symptoms that they saw on their farms (Kosgei *et al*., 2021) and their knowledge of the diseases was scored through the display of the pictorial guides which showed the different and their damages to help in disease identification.

Bean varieties grown by the farmers were assessed through direct observation and by asking them questions about the bean varieties that they had been planting and why they preferred those varieties (Abtew *et al*., 2016). In some cases, the farmers sampled identified the varieties they had grown by showing the remnants of seed samples and seed packets available. From the questionnaire, the most popular bean varieties in the region was identified and the reasons why it was the most preferred variety documented (Mutari *et al*., 2021). The farmers also provided details of where they sourced their seeds for planting. The farmers were also asked about the management measures that they used on their farms (Emongor *et al*., 2019). This was documented on the questionnaire. The importance of t*he disease was evaluated from the different management options put in place by farmers and they gave the challenges they faced from each management option that they had adopted (Antony *et al*., 2021) and that was used to rate the different management methods.

3.2.2 Evaluation of breeders' perception on approaches to the management of angular leaf spot and anthracnose of beans

Determination of breeders' perception on approaches to management of angular leaf spot and anthracnose was done by interviewing common bean breeders. Six companies and/ or institutions within the country were purposively sampled for the survey due to their experience in common bean breeding (Table 3.1). The survey was done virtually by administering an open ended questionnaire and doing interviews online. It involved researchers from bean producing or breeding organizations. The organizations sampled for the survey were CIAT, KEPHIS, KALRO, Egerton University, SeedCo and Simlaw Seeds. The questionnaire's aim was for the researcher understand bean breeding, multiplication and access of certified seeds to farmers to be able to upscale bean production in Western Kenya. The survey provided information that was used by breeders to know what aspects of crop characteristics that are desired by farmers since they directly influence the uptake of a particular variety. Details of commonly bred bean varieties and reasons for specific growth traits was documented from the survey. The questionnaire also gave information on the type of breeding methods, approaches adopted to increase uptake of new varieties and sources of germplasm.

Table 3.2 Breeding institutions interviewed and their role in bean production

	Organization	Role in common bean breeding
1	KEPHIS	Phytosanitary inspections, testing, seed certification, quarantine control, plant variety protection variety testing and descriptors of seeds and plant materials.
2	KALRO	To establish suitable legal and institutional framework for coordination of agricultural research in Kenya with the following goals: Promote, streamline, co-ordinate and regulate research livestock, genetic
3	CIAT	Provides all plant materials (as seeds or plantlets in test tubes) free of charge to any individual or organization anywhere in the world for the purposes of research, breeding, or training for food and agriculture, development of better bean varieties that are high yielding, nutritionally improved, resistant to pests and diseases, tolerant to low soil fertility, drought, suited in terms of seed colour and size to meet market demands
4	Simlaw	Research on seeds, import, process and market superior and certified seed varieties for regional and domestic use
5	Seedco	Do hybrid research, production, and commercial availability of hybrid seeds to both small- and large scale farmers in Kenya and the regions.
6	Egerton University	Institution for learning, advancement of knowledge, scientific investigation and scholarly research.

3.3 Evaluation of the effect of temperature and rainfall on the development of angular leaf spot and anthracnose

3.3.1 Experimental design and layout

The field experiment was conducted in three different agroecological zones; upper midland 4 (KALRO Research Centre, Kitale), upper midland 3 (Kitale Airstrip) (Wawuda *et al*., 2021) and upper highland zone 1 (Kibomet) over two cropping seasons. The short rain season was from October 2020 to February 2021 and the long rain season was from April to June, 2021. The smallholder farmer setup was replicated and common farm practices of crop systems, seeds, input and spacing were maintained. The experiment was a representative of the area so that the results could be used by the small holder farmers in Kitale. The plot was weeded at the same frequency will local farmers. Rosecoco GLP2 common bean which is commonly susceptible to angular leaf spot and anthracnose was used in order to maximize chances of infestation in the plot (Wagara and Kimani, 2007). There were 3 plots and each had a minimum size of 0.5 acres where the experiment was laid out in a randomized complete block design (RCBD). One seed was planted per hole at a spacing of 10 cm between plants and 50 cm between rows. No chemicals were used during the research as that would have affected the outcome of the experiment. Selected secured areas near the research station were used to install the raingauge and data loggers.

The plot was given a unique coding according to the name of the research station and pest being studied for ease in identification. The first general survey on the plot and crop characteristics conducted during the experiment were done one week before planting where the first weather data was collected. The general survey of plot and crop characteristics was done twice a week before planting. Photos of the plot were taken, rainfall measurement were recorded, data loggers were downloaded and plot details were recorded. Surveys were continued immediately after bean emergence. Data that were recorded included rainfall measurements, temperature, crop phenology, plant height, disease incidence, severity and yields.

3.3.2 Collection of rainfall and temperature data

Measurement of amount of rainfall was done using a rain gauge installed in each of the plots (Kazai *et al*., 2019). The rain gauge was installed in an open area at least 2meters from the edge of the bean plot to avoid wind disruption (Kazai *et al.,* 2019). The rain gauge was attached to a wooden pole at a height of 1 meter from the ground. The top of the rain gauge was more than 5cm over the top of the pole to avoid splashing. The level of water in the rain gauge was checked every day from week 0-12 during the plant growth. The quantity of rainfall was recorded on data recording sheets in cubic centimeters (cm^3). The inner cylinder was used to measure the total volume where rain water overflow into the outer vessel.

Temperature data was collected using data loggers (Fawcett *et al*., 2019). One data logger was installed at the main research station while two data loggers (HOBO MX2201) were installed in the field. One logger was placed at the crop canopy height which is the bean top while the second logger was placed just above the ground within the bean crop. The loggers were installed with their radiation shields, on a 2meter wooden pole in the centre of the plot. At the beginning of the experiment, both loggers were positioned just above the ground level. Over the course of the experiment the bean top logger was repositioned every two weeks to follow canopy height of the crop. During configuration of the loggers, each of them was allocated a unique identification code according to location, pest and position of the pole. The logger identification (ID) was written on the radiation shield of each individual logger using a permanent marker in order to identify it correctly during data collection. The data loggers recorded and stored the temperature data automatically every 10 minutes (Fawcett *et al*., 2019). Loggers were Bluetooth enabled using an Android phone with HOBO App and the data was downloaded without removing the loggers from the radiation shields. The downloaded data was then uploaded automatically to the HOBOlink cloud.

3.3.3 Assessment of plant growth parameters

The surveys that were carried out in the experiments were on crop phenological stages were assessed from emergence until maturity stage. Plot and crop characteristics that were recorded on first visit included plot identification, plot size and dimensions, GPS Coordinates, planting date, watering method, crop variety and details of previous crop planted on the farm. The sampling date, maximum height of the crop (Laizer *et al*., 2019), maximum number of leaves per plant infected, cultural practices on the crops were also recorded. Phenological stages were recorded from emergence to maturity (Cavalcante *et al.*, 2020) and codding was done to identify these stages (Table 3.3). Bean emergence was assessed on the 7th day after planting and the plant stand count was assessed on the 7^{th}, 14^{th}, 21^{st}, 28^{th} and 35^{th} day after sowing. This was done by counting the number of emerged plants. It was then expressed as a percentage of the seeds that were planted in each treatment plot (Mutahi *et al.*, 2019). The height of each plant was determined by dividing the plot in three sections each with ten check points. Then 5 plants were randomly sampled per check point in a zigzag movement (Figure 3.1).

Table 3.3 Common beans phenological stages and their codes

Crop phenological stage	Code
Emergence	1A
Unifoliate leaves	1B
1-2 Trifoliate leaves	1C
3 or more trifoliate leaves	2A
Bud emergence	2B
Popcorn bloom	2C
Pod development	2D
Pod filling	2E
Maturity	2F

Source: CABI, PRISE 2020

3.3.4 Assessment of angular leaf spot and anthracnose incidence

Disease was sampled by use of random sampling method (De Almeida *et al*., 2020). The bean plants throughout the plot were sampled following a series of three zigzag surveys consisting of 30 check points. Each of the three sections (Blocks) had 10 check points each with 5 plants (Table 3.1). Data was collected from a total of 150 plants per site, on the level of angular leaf spot and anthracnose on bean plants was estimated by the incidence and severity. Data was collected for 12 weeks after emergence on symptomatic plants. Incidence of disease was calculated as the sampled number of plants in the plot that had disease symptoms expressed as a percentage of the total number of sampled plants (Mwang'ombe *et al*., 2007; Rezene *et al*., 2018).

$$\text{Incidence} = \frac{\text{Total number of sampled diseased plants}}{\text{Total no. of sampled plants in the field}} \times 100\%$$

3.3.5 Assessment of severity of angular leaf spot and anthracnose

Severity was assessed as proportion of plant showing disease symptoms (Sharma *et al*., 2008). Each experimental site was divided into 3 blocks which had 10 check points each (Figure 3.1). Severity was done by randomly sampling bean plants throughout the plot, following a series of three zigzag surveys consisting of 30 check points (Ochichi, 2015). Two plants with symptoms were randomly selected at each check point on all the 3 blocks. A total of 60 plants were sampled per site for severity. Then three trifoliate leaves from each plant that is the upper, middle and lower leaves were scored for severity using modified severity scale 0-3 (Pereira *et al.*, 2019). The next check points were at least 5 meters at a random angle through the plot. Angular leaf spot and anthracnose severity were estimated on a scale of 0 to 3 where 0 = 0 per cent disease free that is no disease, 1 = 1–33 per cent showed mild severity with presence of a few small non sporulating lesions that cover approximately 10% of the leaf surface area, 2 = 34–66 per cent moderate severity evidenced by the presence of several, generally small lesions with limited sporulation that cover approximately 20% of the leaf surface area and 3 = 67-100 percent of the surface area of the shoot with severe symptoms of generally large sporulating lesions that covers more than 30% of the leaf. (Maldonado-Mota *et al*., 2020).

The trapezoidal method was used approximating the AUDPC, and also it was also used to discretize the time variable in addition to computing the average disease strength amidst each sets of adjoining time points Ddamulira, 2019). The example time points were contemplated in a series $\{t_i\}$, wherever the time interlude between two time points was constant and was similarly related procedures of the disease level $\{y_i\}$. Outline $y(0) = y_0$ as the original infection or the disease level at $t = 0$ (i.e. was the primary disease severity observation in the study). $A(t_k)$, the AUDPC at $t = t_k$, was the total accrued disease until $t = t_k$, given by (Muengula-Manyi, *et al*., 2013):

$$A_k = \sum_{i=1}^{N_i-1} \frac{(y_i + y_{i+1})}{2}(t_{i+1} - t_i)$$

Angular leaf spot % severity was calculated as follows (Kolkam and Kelly, 2000)

$$\frac{\text{Rating number of each sampled plants}}{\text{Total no. of sampled plants in the field * Highest rating}} \times 100\%$$

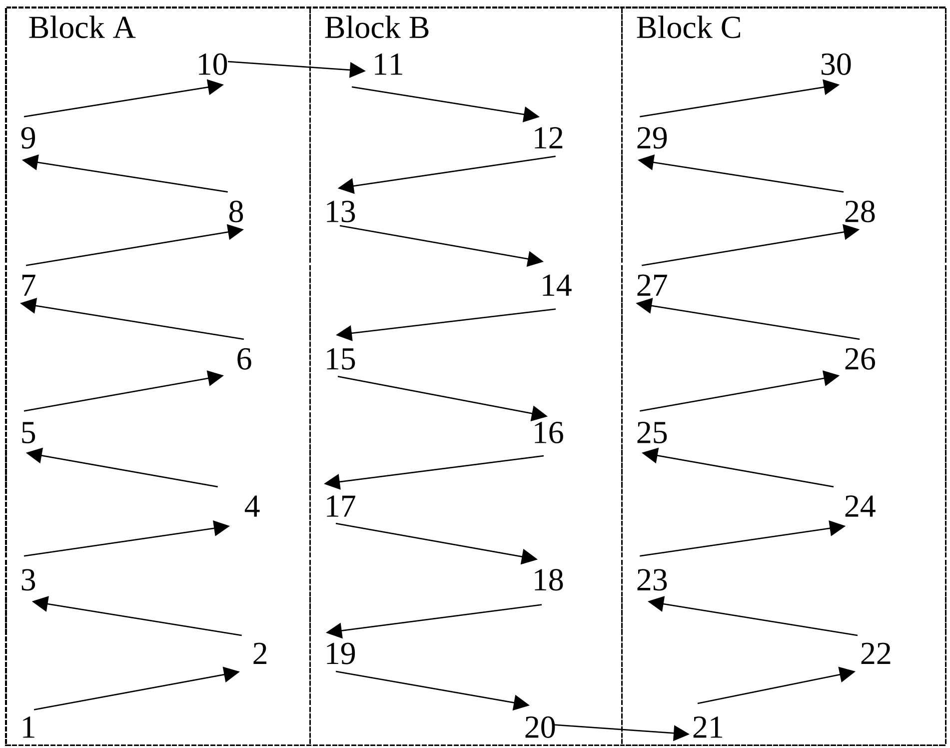

Figure 3.1 Random zigzag sampling on level of infestation of angular leaf spot and anthracnose

3.3.6. Determination of yield and yield components

The number of pods per plant, seeds per pod and the yield of grain was determined during the final crop harvest (Langat *et al*., 2019). The grain yield was determined after counting the number of plants per treatment plot (Langat *et al*., 2019). All plants in the three plot were harvested by hand, threshed, cleaned then weighed to determine the grain yield (Nassary *et al*., 2020). Moisture content of 10% was attained from one kilogram of beans that was air dried and the weight was converted to kilogram per hacter (Liton *et al*., 2019).

$$\text{Yield (kg/hac)} = \frac{\text{Harvested weight per plot}}{\text{Area of plot}} \text{ X } 10{,}000\text{m}^2$$

3.4 Development of models to relate weather conditions to development of angular leaf spot and anthracnose

Disease models were created to show the relationship between disease severity, weather parameter and plant growth stages on common beans across the three AEZs (Calonnec *et al*.,2013). Analysis was done using R 4.1.1 software to show the relation between disease development over time as influenced by rainfall and temperature. Single point and multiple-point models were used to relate yield to disease severity at a single growth stage of the crop or at multiple growth stages, respectively. Integral models were used to relate yield to the area under the disease progress curve (AUDPC) (Ddamulira, 2019). Negative binomial regression model was used in this experiment. This model was used since the data is highly overdispersed. Data was collected for rainfall and temperature throughout the cropping season. It was then analysed to get the equation showing the relationship and it was used to predict the disease threshold in the next cropping season. The pearsons correlation was also be determined from the modelling with a general equation of Y=mx+c. Relationship between temperature, rainfall, disease intensity and crop phenological stages was shown through the following modelling equations. Angular leaf spot modelling was described as Y= 55.85 (% Severity)- 1.304 (UM3)- 4.832 (UM4)+ 2.184 (Weeks) -3.419 (Temperature) +5.646 (Season 2) + 7.066 (Emergence)+ 24.120 (Pod Development) +57.78 (Pod filling) + 5.99 (Unifoliate leaves). The formular for short rains disease modelling was described as Y=0.022 (Weeks) -0.065(Temperature)-0.017 (Rainfall)-0.28 (UM4)-0.072 (UM3) while the long rains model prediction was Y= 0.29(Weeks) -0.18(Temperature)- 0.17 (UM3). While for anthracnose disease modelling was described as follows Y= 0.31 (Seasons) – 0.5 (weeks) -0.22 (temperature) + 0.04 (rainfall)+ 0.17 (UM4) +0.7 (UM 3). The short rains 2020 disease model prediction was described as Y= -0.29 (weeks) +0.13(temperature)+ 0.12 (UM4)+ 0.12 (UM3) while the long rains 2021 disease model prediction was Y= -0.2884(weeks)+0.1286 (temperature)+0.1189 (UM4)+0.1197 (UM3).

3.5 Isolation and identification of causal agents of angular leaf spot and anthracnose

3.5.1 Collection of diseased plant samples

Isolation, characterization and identification of fungi causing angular leaf spot and anthracnose as well as pathogenicity test were conducted in the Plant Pathology Laboratory of University of Nairobi from January 2021 to March 2021. The isolates of *Pseudocercospora griseola* and *Colletotrichum lindemuthianum* that were used had been collected from the experimental bean fields that have been naturally infected by the diseases at the KALRO Research site (UM4) and two of farmers' fields in Kitale Airstrip (UM 3) and Kibomet (LH 1) in the short rains of 0ctober-February 2020 and long rains of April-June 2021. Bean plants showing symptoms of angular leaf and anthracnose were collected in brown paper sampling bags. The bags were clearly labelled to indicate date of collection and location. The samples were then put in a cooler box and transported to the laboratory. Storage of samples was done in the refrigerator at 4℃ before pathogen isolation was done. The two sets of experiment were conducted in growth chambers.

3.5.2 Isolation and morphological identification of *Pseudocercospora griseola*

Leaves that were infected with *Pseudocercospora griseola* had signs of lesions which were dark grey to brown delimited by veins and the surrounding tissue were chlorotic (Serrato-Diaz *et al*., 2020). Isolation of the pathogen was done from the symptomatic lesions of the beans that had been naturally infected and showing fungal sporulation (Lima *et al*., 2010). Media was prepared as shown on appendix 3. Fungus was induced to sporulate by incubation of the infected tissues. The working area was sterilized with alcohol 70%. Glass slide was sterilized and laid on the tile and then 2 drops of sterile distilled water were placed at the central part of the slide. The infected plant material which was showing fungal sporulation was placed on the stage of dissecting microscope and conidia on the synnemata was touched with the tip of a moistened mounting needle without touching the host material. The conidia were collected and aseptically transferred onto the water drop let on the glass slide then was stirred using a wire loop to form spore suspension. The film of spore suspension was captured by withdrawing the wire loop after stirring (Lima *et al*., 2010). It was streaked on the surface of bean leaf dextrose agar medium plates by using four streaks to uniformly distribute the spores. The plates were incubated at 25℃ and pathogen germination monitored using compound microscope. On the 14th day, the mycelia were transferred to modified V8 juice to allow for production of conidia.

3.5.3 Isolation and morphological identification of *Colletotrichum lindemuthianum*

Bean seeds were also isolated then the fungal infection was determined by agar plate method (Serrato-Diaz *et al*., 2020) as shown on appendix 3. The potato dextrose agar (PDA) (39g PDA per 1000g distilled water) was modified by adding 13.45g/L sodium chloride and 0.05g/L of streptomycin sulphate which prevented the germination and growth of bacteria (Westphal *et al*., 2021). The seeds were randomly sampled from the field. 50 grams of seeds were washed in distilled water to remove any soil particles, then they were surface sterilized using 1% Sodium hypochlorite for 30-60 seconds. The seeds were rinsed in sterile distilled water three times then dried on bloating papers (McElhiney *et al*., 2001). Five seeds were aseptically placed in each petri dish with agar therefore 20 seeds were plated from each seed sample. The plates were incubated for 7 days at room temperature of 25°C. The plates were observed for fungal growth from the fifth day of incubation and fungal growth characteristics and the number of infected seeds were recorded as a percentage of the total number of seeds that were plated (McElhiney *et al*., 2001). Each of the fungi isolated was subcultured and identification was done using morphological and cultural characteristics. A sterile needle was used to puncture seedlings after one week of germination which were infected with the inoculum for anthracnose then pathogenicity test was conducted on bean seedlings that are susceptible to confirm Koch's postulate (Wagara, 1996).

3.5.4 Proof of pathogenicity of the isolated *Pseudocercospora griseola* and *Colletotrichum lindemuthianum*

Bean seeds of Rosecoco GLP 2 were surface sterilized using 1% Sodium hypochlorite and rinsed four times with sterile distilled water. Seeds were sown in 48 plastic tins with sterilized soil (Kosgei *et al*., 2016) The seedlings were allowed to grow until the first trifoliate leaves were fully formed. The plates with 14 days old culture with isolates of *Pseudocercospora griseola* were flooded with sterile distilled water and inocula was prepared (Pereira *et al.,* 2019). A bent sterile glass rod was used to scrap off the conidia from the surface of the culture. The obtained suspension was filtered through a cheese cloth with a double layer. The spore concentration was obtained using a Neubauer improved haemocytometer. The conidial concentration was adjusted to 1×10^3 conidia ml^{-1}. Three weeks old seedlings of Rosecoco GLP -2 were covered with transparent polythene bags 24 hours before inoculation. The trifoliate leaves were inoculated using a sterile needle and the control plants were injected using sterile distilled water. Polythene bags were returned and then they were removed after 24 hours. Plants were incubated and examined daily for angular leaf spot symptom development (Ragagnin *et al*., 2005). *Pseudocercospora griseola* was re-isolated from the infected leaf tissue to fulfill Koch's postulate. *Colletotrichum lindemuthianum* cultures were also used to inoculate 2 weeks old seeds and the plants were covered and observed for two weeks. Anthracnose infected plants were re- isolated to fulfill Koch's postulate (Fernandez *et al*., 2000).

3.6 Data analysis

Survey data was analyzed using the Statistical Package for Social Sciences version 20 (SPSS) (Buthelezi-Dube *et al*., 2020) through computation of percentages, means and the frequencies. The weather, plant and disease data was analyzed through Analysis of variance (ANOVA) which was carried out from the two cropping seasons using GenStat 15th Edition software (Lawes Agricultural Trust, Rothamsted Experimental Station, UK). The data was tested for significance using F-test at 95% level of significance (Muthomi *et al*., 2018). The average treatment was compared using the least significant difference (LSD) test at P=0.05 where the F-test was significant (Ogecha *et al*., 2019). Means were separated using Fisher's LSD. Analysis of correlation among disease incidence and severity, rainfall, temperature and plant yield was done by GenStat 15th edition.

CHAPTER FOUR: RESULTS

4.1 Perception of farmers and bean breeders on approaches to management of angular leaf spot and anthracnose

4.1.1 Socio-demographic characteristics of bean farmers and production practices

Survey results show that most of the farmers were male (61%) in the four constituencies. Kiminini had the highest number of males while Saboti had more females than male farmers. Majority of the respondents were farm owners (51%) where they produced common beans in small acreage of land of less than 3 acres (Table 4.1). A few farmers (2%) owned more than 10 acres from which they produced various varieties of beans. Farmers reported different sources of bean seed (Table 4.2). Majority of farmers (44%) interviewed used their own saved seeds and also from the local markets since were cheaper and readily available. Few farmers (8%) buy seeds from agroshops since the certified seeds are of good quality according to them. Majority of farmer's have been cultivating beans for less than 3 years. Most of them (61%) grow for household since it is produced on small acreage of land and only few farmers (39%) have surplus beans to sell (Table 4.1).

There are many challenges faced by common bean farmers which affect the actual yield of the crops. Pests and diseases are the major challenge which cause yield loss in majority of the regions in Trans Nzoia (Table 4.1). Unreliable rainfall and soil infertility are among other problems that farmers face. Among the bean diseases, angular leaf spot and anthracnose are the main diseases that affect beans and can cause total yield loss when there is no control measure. Powdery mildew is the disease that is of minor importance to bean growers. The most common pest is bean stem fly that attacks the plant at the root-stem junction and makes the plant to stop developing. However, red spider mites found in 1% of the farms surveyed were of minor importance since they did not cause major destruction on the farms Farmers use different management methods to manage diseases on common beans. Few farmers (21%) use certified seeds from the agro-shops so that they reduce introduction of pests and diseases to their farms (Table 4.1). Majority of farmers do not use certified seeds because they still get infected despite the seeds being treated. A few farmers (19%) practice crop rotation with cereals being the most commonly used crop.

Table 4.1 Sociodemographic characteristics, seed sources and production experience of bean farmers in Trans Nzoia County.

Sociodemographic characteristics	Modalities	Percentage	Characteristics	Categories
Gender	Male	61	Seed source	Own saved seeds
	Female	39		Local Market
Relation to farm	Owner	51		Neighbours
	Manager	23		Agro-shops
	Employer	19	Production reason	Household
	Others	7		Selling
Total land size	0-3acres	70	Production challenges	Pests and diseases
	4-6acres	26		Unreliable rainfall
	7-10acres	2		Infertile soil
	>10acres	2		High cost labour
Acreage on beans	0-3acres	80		Hailstone
	4-6acres	10		High cost of farm inputs
	7-10acres	6	Practice Crop rotation	Do rotation
	>10acres	4		No crop rotation
Bean diseases	ALS	50	Bean pests	Bean Stem Fly
	Anthracnose	29		Pod borer
	Fusarium wilt	6		Aphids
	Halo Blight	4		Leafminers
	Powdery mildew	2		Red spider mites
	Blight	9		Beetle

4.1.2 Common bean varieties preferred by farmers and sources of information on disease management methods

Famers in Trans Nzoia plant different varieties of beans. The most preferred variety is Rosecoco GLP2 and Canadian wonder. The choice of bean variety to plant is influenced by different factors. Most farmers prefer Rosecoco because it is high yielding and matures early (Figure 4.1). It takes two and half months to reach maturity stage. This variety is susceptible to angular leaf spot and anthracnose (Masheti,2019) but very few farmers (6%) make their variety preference based on the ability of a variety to tolerate diseases. Most farmers have access to information on good agricultural practices from the extension officers (55%) who do field visits and advise farmers on production practices. Few farmers (5%) have no access to information on bean production (Figure 4.1).

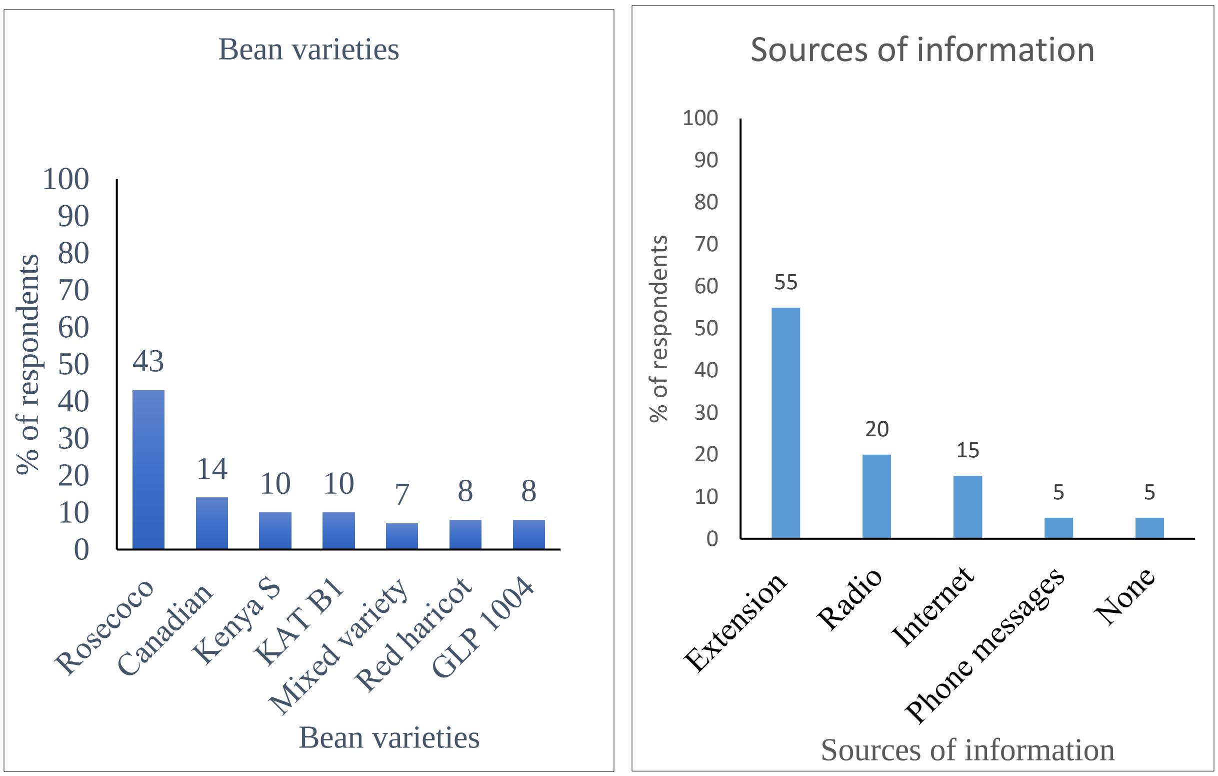

Figure 4.1 Bean varieties commonly grown and sources of information on disease management in Trans Nzoia County

4.1.3 Awareness on angular leaf spot and anthracnose of beans

Angular leaf spot and anthracnose were present in 78% of the farms surveyed where the diseases occurred together. Farmers were able to identify the diseases from the photos of plants with symptoms. In most farms the diseases have been a challenge for more than 10 years causing high yield loss (Table 4.2). However, there were few farms (6%) which did not have ALS and anthracnose diseases. Most of the farmers (70%) reported that serious disease outbreaks have been experienced in the last three years. Pest warning information can be passed to farmers using different methods. Majority of farmers (40%) prefer to listen to radio early in the morning to get the pest warning updates. However, 70% of them are not willing to pay for the information if messages on good agricultural practices can be directly sent to their phones depending on their needs. The farmers willing to make payments can only pay upto 20 shillings per message in order to be updated on pest early warning signs by the relevant authorities (Table 4.2).

4.1.4 Susceptible varieties and commonly preferred control methods by farmers

Among the varieties planted by farmers in Trans Nzoia county, Rosecoco GLP2 is the most susceptible at 62%, followed by Kenya sugar and red haricot beans. Canadian wonder is the least susceptible variety. Farmers had different methods of managing pests and diseases. Most farmers (55%) use cultural practices such as early planting as their main management since it is affordable and environmentally safe. The few farmers (16%) who used chemicals showed packets of remaining chemicals that they had used. Less than 10% of the farmers do not in-cooperate any management method during the crop growth since they are growing the beans for house hold use and preferred to use less inputs on management. Angular leaf spot and anthracnose cause yield loss of 81-100 % in most of the surveyed farms especially when the two diseases occur together (Figure 4.2).

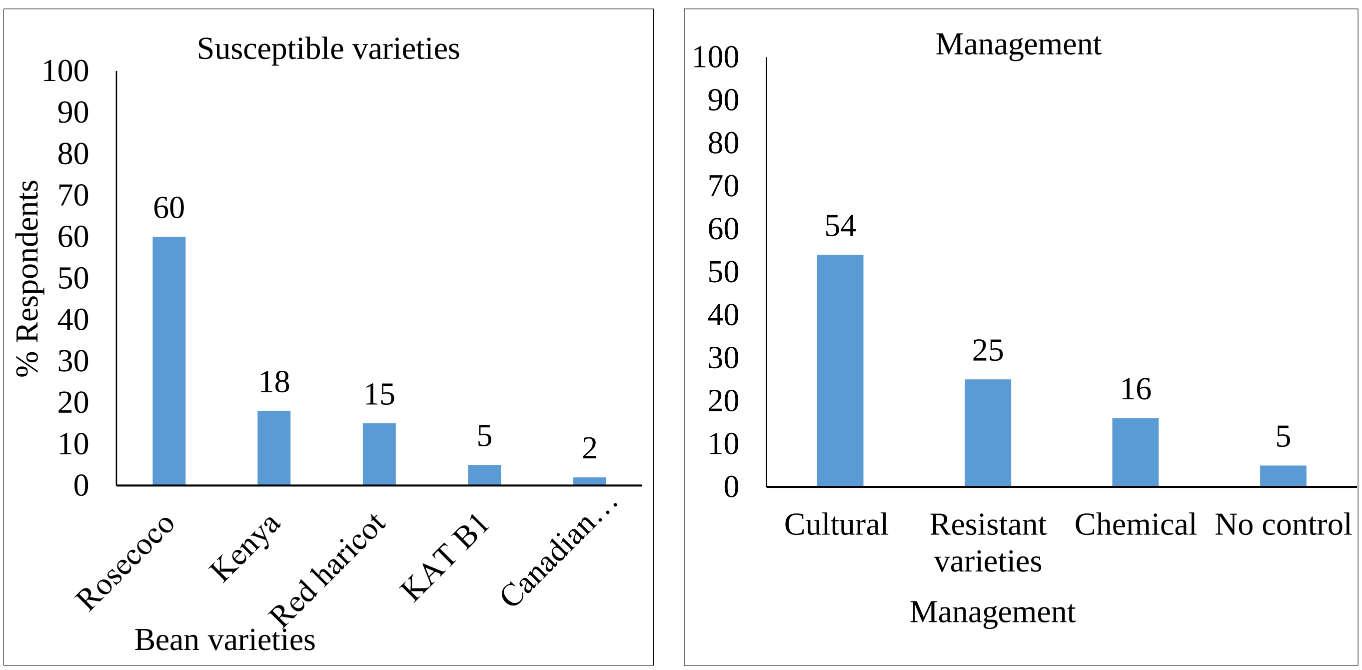

Figure 4.2 Bean varieties that are susceptible to angular leaf spot and anthracnose and common disease management methods.

Table 4.2 Angular leaf spot and anthracnose knowledge and pest warning information

Angular leaf spot and anthracnose	Modalities	Percentage	Pest warning information	Modalities	Percentage
Disease knowledge	Known	78	Time for Radio information	Morning	40
	Not aware	22		Mid Day	26
Duration of diseases as challenges	0-3years	70		Evening	34
	4-6years	6	Willingness to pay for pest warning messages	Yes	40
	7-10years	6		Not willing to pay	60
	>10years	2	Amount willing to pay	0-20 shillings	12
	No disease	16		21-40 shillings	12
Last disease outbreak	0-3years	70		41-60 shillings	7
	4-6years	6		61-80 shillings	3
	7-10years	6		81-100 shillings	9
	>10years	2		None	57
	No disease	16	Reason for payment	Updated on Pest risk warnings	24
				Control time knowledge	20
				Avoid yield loss	18
				Others	38

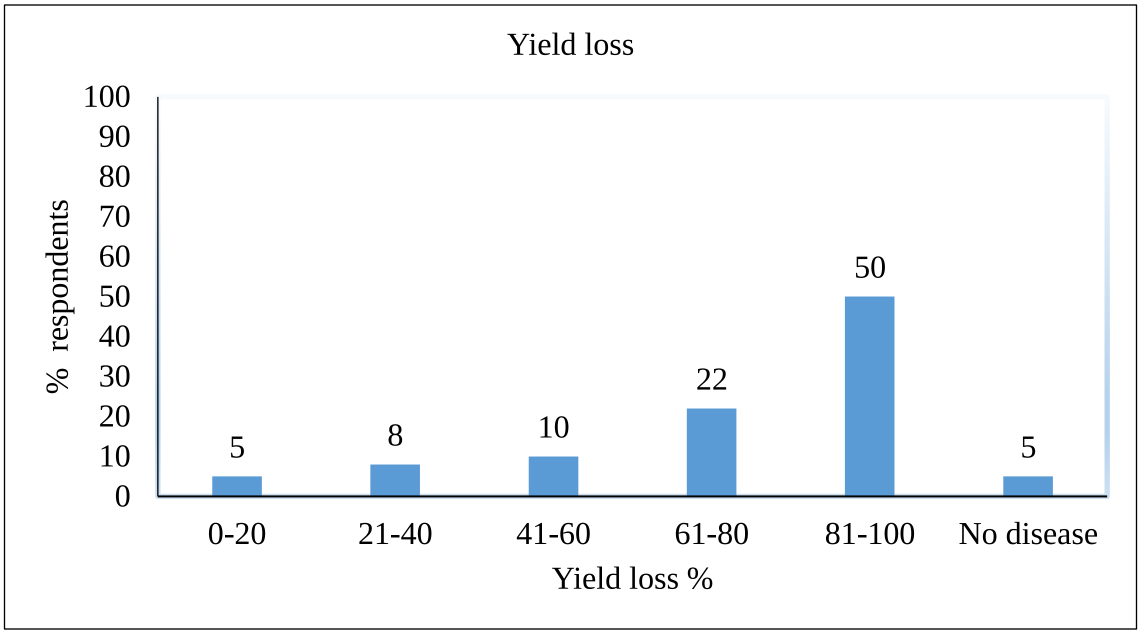

Figure 4.3: Yield loss by angular leaf spot and anthracnose on common bean production

4.2 Perception of bean breeder and key informants on seed availability and disease management practices

4.2.1 Sociodemographic characteristics of bean breeders

Majority of bean breeders interviewed were males from private research institutions (Table 4.3). Most of them have been working as breeders for more than 7 years in different organizations hence they have experience in production and seed availability.

Table 4.3 Sociodemographic characteristics of common bean breeders

Sociodemographic characteristics	Modalities	Percentage
Gender	Male	67
	Female	33
Breeding institution	Government	33
	Private	67
Breeding experience	0-3years	1
	4-6years	32
	7-10years	50
	<10 years	17

4.2.2 Common bean breeding methods and varieties that are commonly bred /sold by breeders

Most breeders prefer to use the conventional breeding method as they are able to select parents with good genetic traits and achieve farmer's desired characteristics (Table 4.4). Molecular method for breeding is important because it can increase the genetic diversity to improve the crop but it is not commonly used by most breeders because it is expensive. The most common bean variety being bred is Rosecoco GLP2 while Nyota and Faida are less popular in the major breeding programs (Table 4.4). Breeders prefer to improve beans characteristics to be tolerant to pests, diseases and early maturity. Ability of seed to be resistant or tolerant to diseases is mostly an important factor to breeders but not farmers.

Table 4.4 Commonly used breeding methods and available bean varieties among breeders

Beans varieties bred	Modalities	Percentage
Breeding methods used	Backcrossing	17
	Conventional	67
	Molecular	16
Beans varieties bred/sold	Rosecoco GLP 2	33
	Katumani B1	17
	GLP 1004	16
	Nyota	17
	Faida	16
Reason for breeding	Pest and disease resistance	33
	Drought tolerance	17
	Early maturity	17
	High yields	25
	Seed size and colour	8

4.2.3 Challenges faced by common bean breeders

There are many challenges that breeders face when they are working on a new variety. When the variety is disease resistant or tolerant the pathogen bred against can change their variability rendering the variety susceptible to the disease. Farmers also have their own desired qualities in seeds for example, early maturity as a trait (Table 4.5). Therefore, the breeder has to work on what the farmers desire to increase the uptake of the seeds from the agro-shops. Constraints on farmers' field for example, presence of plant debris, infertile soils and irregular rainfall are minor problems according to most breeders as they can be managed at farm level.

Table 4.5: Challenges faced by common bean breeders when breeding new varieties

Bean breeding challenges	Modalities	Percentage
Breeding challenges	Pathogen variability	50
	Farmer's Preference	17
	Time constraints	17
	Constraints on farmers' fields	16
Bean production challenges	Pests and Diseases	67
	Unreliable rainfall	16
	High cost of farm inputs	17
Common bean diseases	Angular leaf spot	33
	Anthracnose	30
	Root rot	17
	Rust	16
	Bacterial blight	4
Breeding for resistance to als and anthracnose	Breeding	67
	Not breeding	33
Breeding for tolerance to als and anthracnose	Breeding	67
	Not breeding	33

4.2.4 Availability of certified seeds to farmers

Most agro-shops lack hybrid varieties for beans because of licensing problem by Government Research institution which makes it costly for traders to be authorized to trade on beans. In comparison with locally sold seeds, hybrid varieties are costly therefore reducing their uptake by farmers (Figure 4.4). Certified seeds still get infected when planted despite them being treated. This is because of the environmental conditions which encourage disease development. Pathogens also have the ability to change their variability which makes a once resistant variety to become susceptible to the disease. According to breeders the farm cultural practices have low effect on contamination of certified seeds. Through farm visits, 60% of breeders are able to identify the challenges faced by farmers in order to decide what qualities they should concentrate on during breeding. Most farmers (67%) do not have access to certified seeds because of the high prices agro-shops compared to local markets. Market information is also a factor that affects availability of seeds although it is of minor importance since most farmers are aware of the hybrid varieties. Majority of breeders (50%) suggested that reduction in hybrid seed prices and creating awareness to farmers can increase seed uptake and availability (Figure 4.4). Most breeders source their germplasm from private institutions for example CIAT is the main organization for germplasm.

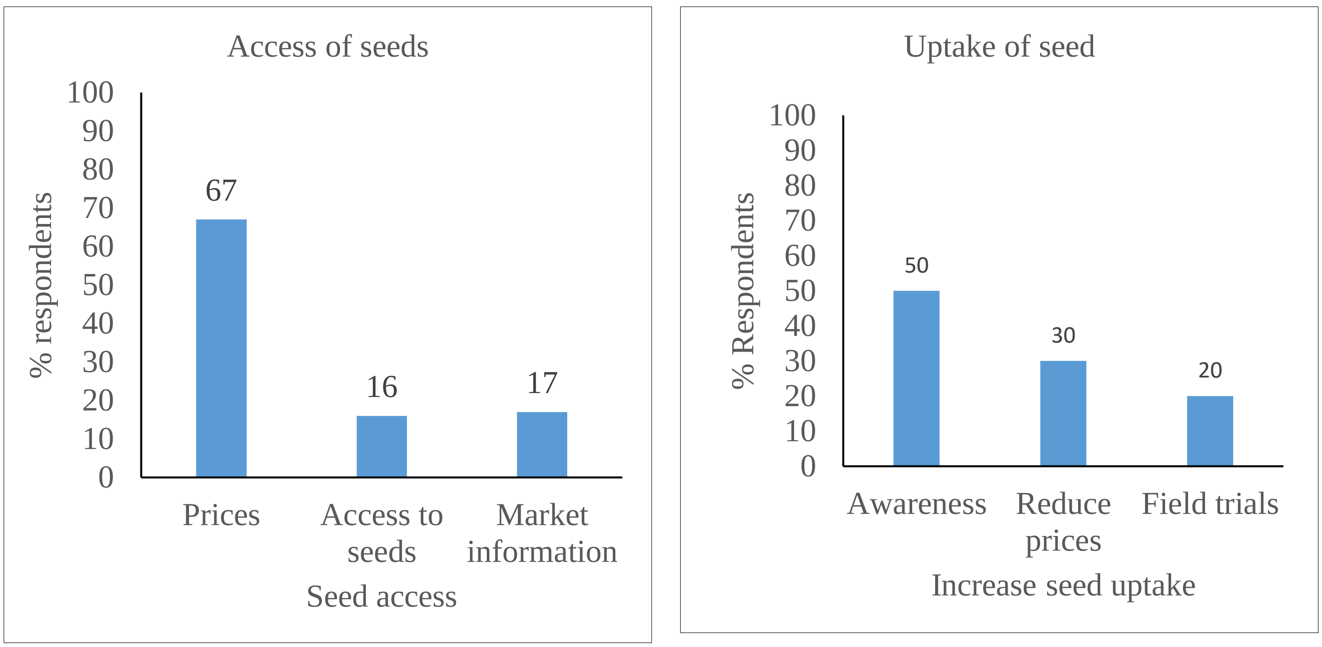

Figure 4.4 Factors affecting availability of certified seeds and approaches to increase seed uptake.

4.3 Effect of temperature and rainfall on the development of angular leaf spot and anthracnose intensity on common beans under field conditions

4.3.1 Pathogenicity of isolated *Pseudocercospora griseola* and *Colletotrichum lindemuthianum* on common beans

Pseudocercospora griseola and *Colletotrichum lindemuthianum* were present on the isolated plant samples (Table 4.6). The culture of *Pseudocercospora griseola* had grey and fluffy mycelium (A). Conidia were dark colored at the base and lighter towards the tip. They were one to three septate, light grey, cylindrical to spindle shaped (B). Synnemata had parallel conidiophores (C) (Figure

4.5). *Colletotrichum lindemuthianum* culture (D) was light pink. The conidia were generally oblong with round end, some were sausage shaped (E and F) (Figure 4.6).

Table 4.6 Incidence and severity of angular leaf spot and anthracnose during the pathogenicity test

Concentration	Angular leaf spot severity (%)	Anthracnose severity(%)	ALS incidence (%)	Anthracnose incidence (%)
0	84.8a	79.1a	83.3a	86.7a
1	73.3b	71.4a	70.0a	70.0a
2	46.8c	47.6b	43.3b	43.3b
3	0.0d	6.7c	0.0c	6.7c
Mean	51.2a	51.2a	49.2a	51.7a
L.s.d	8.8	11.5	8.5	11.6
C.v%	36.5	36.4	35.1	37.8
P-value	<.001	<.001	<.001	<.001

Analysis was carried out using log transformed values log (X+1). Means were separated using Tukey's test at $P \leq 0.05$. Treatment means followed by same letter(s) in each column are not significantly different. Means followed by different letter(s) are significantly different at $P \leq 0.05$. C.v= Coefficient of variation; L.s.d= Least significant difference

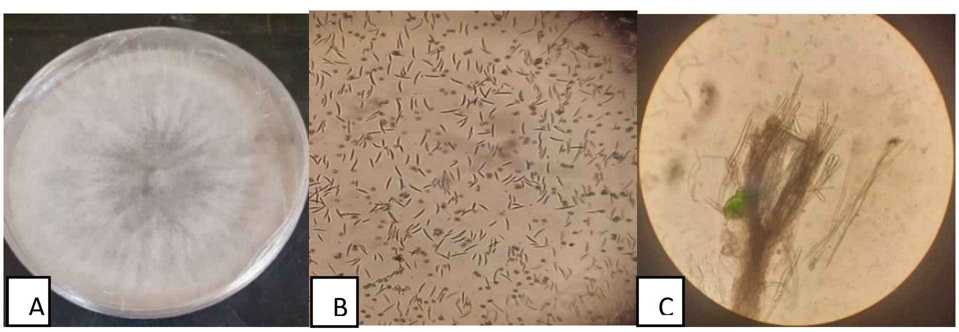

Figure 4.5: Culture and spores of *Pseudocercospora griseola* on modified V8 agar juice.

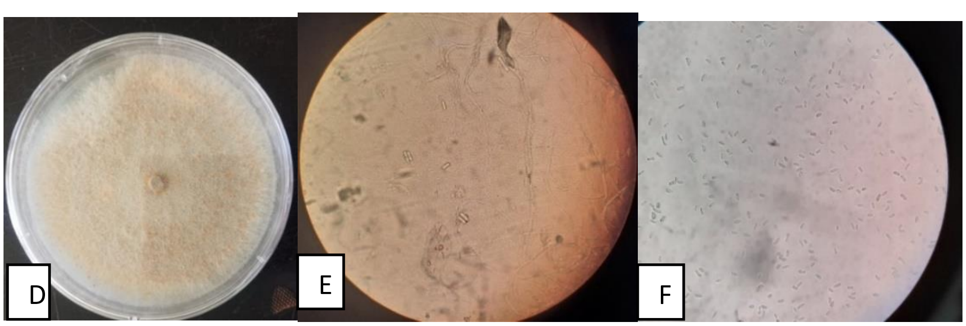

Figure 4.6: Culture and spores of *Colletotrichum lindemuthianum* on PDA

4.3.2 Effect of temperature and rainfall on the development of angular leaf spot

The mean temperature during the short rains and long rains seasons were 18.80℃ and 19.1℃ respectively in UM4 (Table 4.6). There was a significant difference ($P \leq 0.05$) in temperature means in UM4 during the short rains and long rains however there was no significant difference ($P \leq 0.05$) in the amount of rainfall during the two cropping seasons (Table 4.6). During the short rains, the highest temperature was recorded when the crop was at the end of pod filling stage which also coincided with the increased disease severity. Angular leaf spot was present on all the three sites during the two cropping seasons. Disease severity mean was 23.22% and 29.88% during the short rains and long rains respectively. There was a significant difference ($P \leq 0.05$) in disease severity during the short and long rains in UM4. However, disease incidence did not differ significantly across the seasons. Angular leaf spot severity was higher in the long rains which also coincided with increased temperatures and rainfall compared to the short rains (Figure 4.5). While during the long rains, highest disease intensity occurred when the temperature and rainfall were at the lowest although this was after high rainfall was experienced at the beginning of the season (Figure 4.5). There was a great significant difference in disease incidence and severity across the weeks on both seasons. During the short rains increased temperature caused increase in disease severity however it was not affected by the decrease in rainfall which occurred towards the end of the cropping season. Increase in temperature and rainfall during the long rains caused increase in disease severity (Table 4.6).

In UM3 zone, there was no significant difference in means of temperatures and rainfall during the two cropping seasons. The mean of rainfall increased from 3.7mm to 4.5mm in the long rains which also coincided with increased disease severity from 24.6% during the short rains to 29.03% during the long rains. Increased temperatures during the short rains caused increase in disease severity and incidence. The highest disease severity of 79.63% was positively affected by the increase in temperature, however the decreased amount of rainfall did not have an effect on the disease (Table 4.7). The alternating high and low rainfall across the two cropping seasons caused increase in disease development (Figure 4.6). In LH 1 zone, angular leaf spot incidence and severity significantly differed across the week during the short and long rains. There was no significant difference ($p \leq 0.05$) in the disease incidence during the short and long rains. There was a significant difference ($p \leq 0.05$) between temperature and the disease intensity in the short rains. However, rainfall did not significantly affect the development of the disease. (Table 4.8). During the long rains, increase in temperature and rainfall significantly differed (p≤0.05) with disease intensity throughout the cropping season. Increased rainfall at the beginning of the cropping season caused the development of the fungus to increase. There was no rain towards the maturity of the crop in the short rains (Figure 4.7).

Table 4.7: Relationship between temperature, rainfall and angular leaf spot intensity in Upper midland 4 in Trans Nzoia County during the short rains 2020 and long rains 2021

Weeks	Short rains 2020				Long rains 2021			
	Temp	Rainfall	Incidence	Severity	Temp	Rainfall	Incidence	Severity
1	18.4c	9.4ab	0.0g	0.0e	19.6ab	2.3bc	0.0g	0.0g
2	18.1c	7.7abc	0.0g	0.0e	20.1a	3.3bc	0.0g	0.0g
3	18.2c	2.4bcd	0.0g	0.0e	18.6abc	14.5a	0.0g	0.0g
4	18.3c	3.0bcd	0.0g	0.0e	19.2ab	4.7bc	0.0g	0.0g
5	18.3c	4.2bcd	0.0g	0.0e	19.9ab	0.1c	0.0g	0.0g
6	18.2c	4.3bcd	8.0f	3.4e	20.2a	1.0c	13.7g	1.5g
7	18.9b	0.1d	31.0e	18.5d	19.1ab	1.3c	32.7f	8.5f
8	18.9b	12.7a	40.0d	18.2d	19.7ab	0.0c	40.0e	33.3e
9	19.3ab	0.1d	63.0bc	34.9c	20.3a	9.9ab	72.3b	73.5c
10	19.6a	0.0cd	82.0a	48.6a	16.5d	0.4c	83.3a	90.3a
11	19.5a	0.0d	66.0b	52.1a	17.3cd	2.2bc	60.0c	84.6d
12	19.4ab	0.0d	59.0c	39.7b	17.8bcd	6.9abc	51.3d	80.3b
Mean	18.8a	3.7b	29.1a	18.0ab	19.1ab	3.8b	26.4a	28.5a
C.v	0.3	1.7	32.8	122.0	0.1	1.9	37.7	66.6
P-value	<.001	<.001	<.001	<.001	<.001	<.004	<.001	<.001
L.s.d week	0.2	6.5	7.3	4.5	0.4	8.8	7.4	3.9
L.s.d interaction	13.9				19.9			

Analysis was carried out using log transformed values log (X+1). Means were separated using Tukey's test at P≤0.05. Treatment means followed by same letter(s) in each column are not significantly different. Means followed by different letter(s) are significantly different at P≤0.05. C.v= Coefficient of variation; L.s.d= Least significant difference

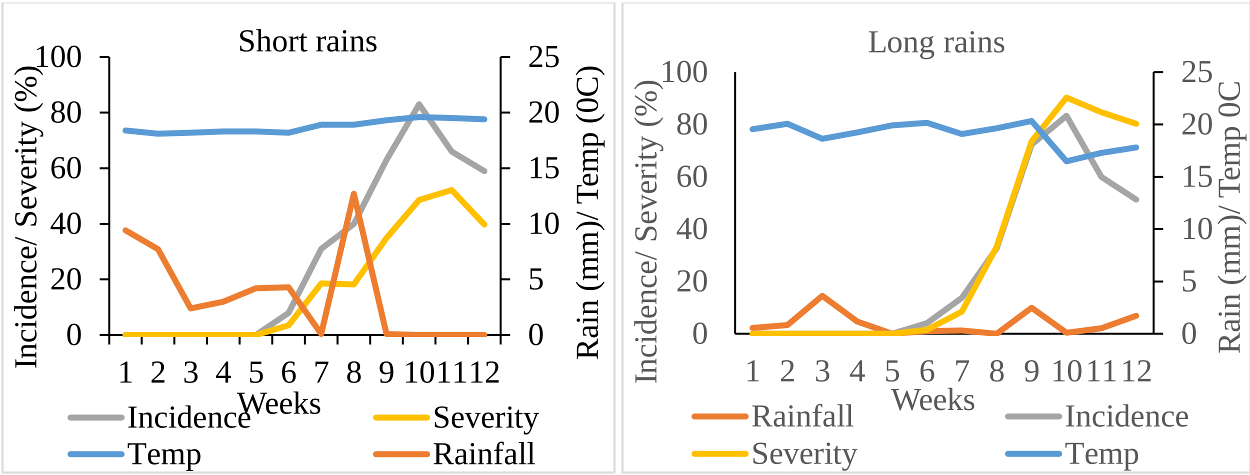

Figure 4.7 Relationship between temperature, rainfall and angular leaf spot intensity in Agroecological zone UM4

Table 4.8: Relationship between temperature, rainfall and angular leaf spot intensity in Upper midland 3 in Trans Nzoia County during the short rains 2020 and long rains 2021

Weeks	Short rains 2020				Long rains 2021			
	Temp	Rainfall	Incidence	Severity	Temp	Rainfall	Incidence	Severity
1	19.0de	5.10bc	0.0g	0.0e	20.14b	2.5b	0.0g	0.0f
2	19.0de	3.20bc	0.0g	0.0e	21.1a	1.9b	0.0g	0.0f
3	18.9e	9.40ab	0.0g	0.0e	18.4cd	17.0a	0.0g	0.0f
4	19.2cd	2.40bc	0.0g	0.0e	18.3d	9.0ab	0.0g	0.0f
5	19.3c	2.80bc	0.0g	0.0e	19.6b	0.0b	0.0g	0.0f
6	19.0de	5.40bc	26.0f	14.5d	19.8b	3.7b	7.0f	3.6f
7	20.1b	0.00bc	52.0e	27.0c	19.3bc	0.7b	17.0e	11.4e
8	20.0b	16.00a	64.0d	28.5c	19.3bc	0.0b	35.0d	31.8d
9	20.0b	0.0bc	82.0b	45.0b	17.9def	8.6ab	78.0b	78.7b
10	20.1b	0.0bc	96.0a	49.5b	18.2de	1.1b	97.0a	96.3a
11	20.2b	0.0bc	93.0a	79.6a	17.3ef	4.0b	56.0c	80.1c
12	20.8a	0.0bc	75.0c	46.8b	16.7f	7.2ab	58.0c	76.5b
Mean	19.6ab	3.7b	41.0b	24.3a	18.9a	4.5b	29.0b	29.0a
C.v	0.2	207.2	21.8	98.4	0.1	2.0	34.5	66.9
P-value	<.001	<.004	<.001	<.001	<.001	<.001	<.001	<.001
L.s.d week	0.3	8.2	8.3	4.9	1.1	11.4	4.0	4.0
Lsd Interaction	16.8				19.8			

Analysis was carried out using log transformed values log (X+1). Means were separated using Tukey's test at P≤0.05. Treatment means followed by same letter(s) in each column are not significantly different. Means followed by different letter(s) are significantly different at P≤0.05. C.v= Coefficient of variation; L.s.d= Least significant difference

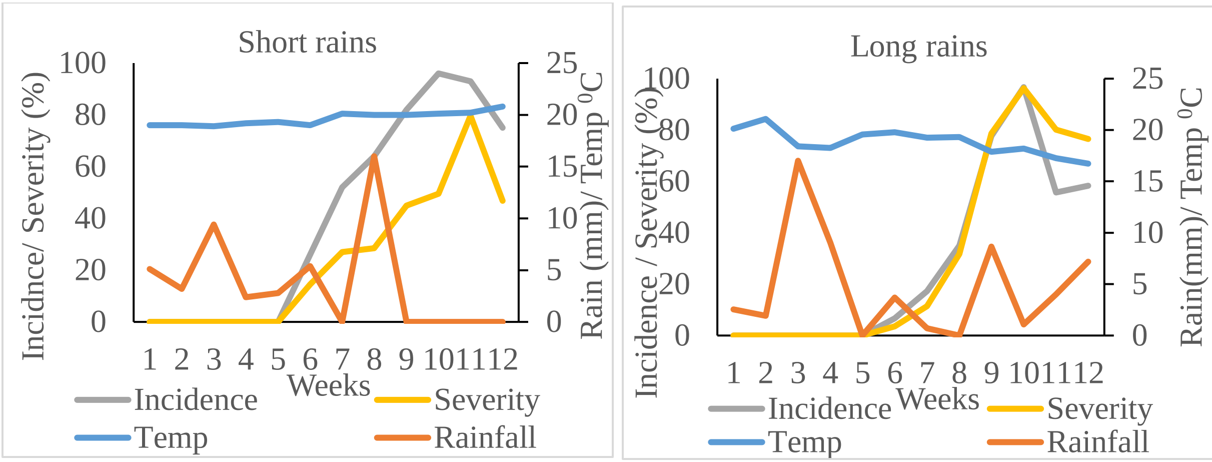

Figure 4.8 Relationship between temperature, rainfall and angular leaf spot intensity in Agroecological UM3

Table 4.9: Relationship between temperature, rainfall and angular leaf spot intensity in Lower highland 1 in Trans Nzoia County during the short rains 2020 and long rains 2021

Weeks	Short rains 2020				Long rains 2021			
	Temp	Rainfall	Incidence	Severity	Temp	Rainfall	Incidence	Severity
1	18.9d	4.4ab	0.0f	0.0g	19.7ab	4.5b	0.0h	0.0g
2	19.2cd	1.8ab	0.0f	0.0g	20.3a	2.4b	0.0h	0.0g
3	18.6d	5.4ab	0.0f	0.0g	18.7abc	14.1a	0.0h	0.0g
4	18.6d	3.6ab	0.0f	0.0g	18.1bc	4.5b	0.0h	0.0g
5	19.0d	1.0b	0.0f	0.0g	17.6bcd	0.5b	0.0h	0.0g
6	18.9d	3.1ab	24.0e	12.5f	19.4ab	4.2b	12.0g	6.3f
7	19.2bcd	0.0b	61.0d	30.7e	19.4ab	1.7b	20.0f	15.4e
8	19.9ab	8.4a	74.0c	31.2e	19.3ab	0.0b	43.0e	39.2d
9	19.1cd	0.0b	90.0b	69.9b	18.3abc	5.9b	83.0b	82.2b
10	19.0d	0.0b	98.0a	54.5c	18.1bc	2.0b	97.0a	97.4a
11	19.8abc	0.0b	95.0a	80.9a	15.9d	4.7b	58.0d	80.9b
12	20.4a	0.0b	77.0c	49.3d	16.5cd	4.3b	67.0c	78.1c
Mean	19.2a	2.3b	43.0b	27.4a	18.5ab	3.8b	32.0b	32.1a
C.v	0.4	2.5	19.5	89.9	0.1	1.7	28.0	59.8
P-value	<.001	<.12	<.001	<.001	<.001	<.04	<.001	<.001
L.s.d week	0.6	6.1	8.0	5.1	2.2	8.4	4.0	4.0
Lsd Interaction	19.2				21.9			

Analysis was carried out using log transformed values log (X+1). Means were separated using Tukey's test at P≤0.05. Treatment means followed by same letter(s) in each column are not significantly different. Means followed by different letter(s) are significantly different at P<0.05. C.v= Coefficient of variation; L.s.d= Least significant difference

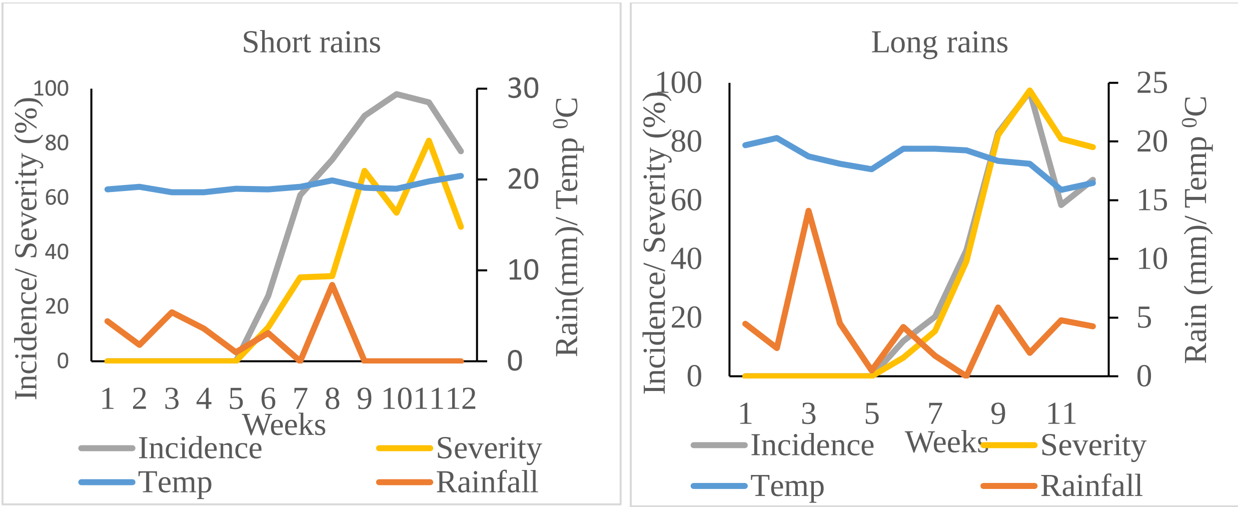

Figure 4.9 Relationship between temperature, rainfall and angular leaf spot intensity in Agroecological zone LH1

4.3.3 Effect of temperature and rainfall on the development of anthracnose

There was a significant difference ($P \leq 0.05$) between temperature, rainfall and disease intensity during the short and long rains. Increase in temperature and rainfall affected the development of anthracnose. The average rainfall measurements did not differ across the two seasons. Temperature and rainfall recorded were higher in long rains than in short rains which also coincided with the increased disease intensity during the long rains (Table 4.9). Anthracnose incidence and severity increased as the temperature and rainfall recorded were at the highest means (Figure 4.8).

There was a significant difference ($P \leq 0.05$) in the means of temperature, rainfall and disease intensity during the two seasons. There was high rainfall at the beginning of the cropping seasons to which favored the development of *Colletotrichum lindemuthianum* (Table 4.10). The symptoms on plants showing anthracnose were small water soaked spots with light pink fungus sporulation, necrotic circular shaped lesions with concentric rings. The increase in temperature significantly affected the increase in disease intensity in the short rains. However, the temperatures in decreased slightly as the disease intensity increased in the long rains (Figure 4.9). In LH1 the disease intensity was higher during the long rains than during the short rains. There was a significant difference between temperature, rainfall and disease intensity during the long rains. However, during the short rains, only temperature differed with anthracnose intensity. There was no rainfall recorded after the peak of disease intensity during the short rains (Table 4.11). In both seasons, the temperature and rainfall were slightly higher at the beginning of the cropping which favored the development of *Colletotrichum lindemuthianum*. The disease intensity gradually increased then it reduced towards crop maturity stage (Figure 4.10).

Table 4.10: Relationship between temperature, rainfall and anthracnose intensity in UM4 in Trans Nzoia County during the short rains 2020 and long rains 2021

	Short rains 2020				Long rains 2021			
Weeks	Temp	Rainfall	Incidence	Severity	Temp	Rainfall	Incidence	Severity
1	18.4c	9.4ab	0.0g	0.0f	19.6ab	2.3bc	0.0h	0.0g
2	18.1c	7.7abc	0.0g	0.0f	20.1a	3.3bc	0.0h	0.0fg
3	18.2c	2.4bcd	0.0g	0.0f	18.6abc	14.5a	0.0h	0.0fg
4	18.3c	3.0bcd	38.0d	12.5c	19.2ab	4.7bc	0.0gh	0.0fg
5	18.3c	4.2bcd	49.0b	19.1ab	19.9ab	0.1c	6.0fg	2.4fg
6	18.2c	4.3bcd	55.0a	22.1a	20.2a	1.0c	9.0ef	4.4f
7	18.9b	0.1d	49.0b	22.6a	19.1ab	1.3c	15.0de	9.0e
8	18.9b	12.7a	42.0bd	20.3ab	19.7ab	0.0c	34.0b	33.2b
9	19.3ab	0.1d	39.0d	17.0b	20.3a	9.9ab	86.0a	84.8a
10	19.6a	0.0cd	23.0e	8.7d	16.5d	0.4c	27.0c	27.3c
11	19.5a	0.0d	15.0f	6.0de	17.3cd	2.2bc	20.0d	17.0d
12	19.4ab	0.0d	10.0f	3.4ef	17.8bcd	6.9abc	20.0d	12.1e
Mean	18.8b	3.7c	27.0a	11.bc	19.1a	3.8b	18.0a	15.9a
C.v	0.3	1.7	15.4	163.5	0.1	1.9	62.7	1.3
P-value	<.001	<.001	<.001	<.001	<.001	<.004	<.001	<.001
L.s.d week	0.2	6.5	0.7	3.7	0.4	8.8	4.8	4.2
L.s.d interaction	11.9				13.7			

Analysis was carried out using log transformed values log (X+1). Means were separated using Tukey's test at P≤0.05. Treatment means followed by same letter(s) in each column are not significantly different. Means followed by different letter(s) are significantly different at P<0.05. C.v= Coefficient of variation; L.s.d= Least significant difference

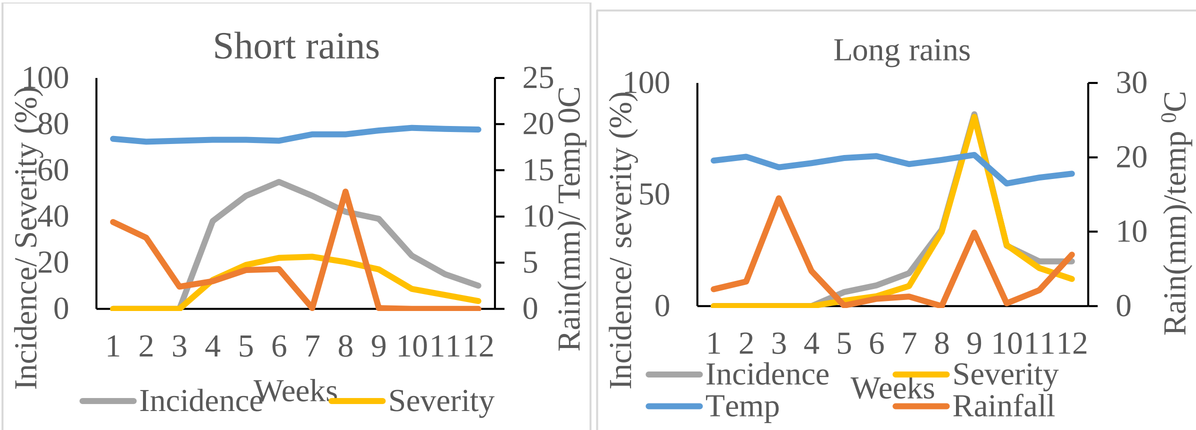

Figure 4.10 Relationship between temperature, rainfall and anthracnose intensity in Agroecologial zone UM4

Table 4.11: Relationship between temperature, rainfall and anthracnose intensity in UM3 in Trans Nzoia County during the short rains 2020 and long rains 2021

	Short rains 2020				Long rains 2021			
Weeks	Temp	Rainfall	Incidence	Severity	Temp	Rainfall	Incidence	Severity
1	19.0de	5.1bc	0.0f	0.0f	20.1b	2.5b	0.0g	0.0f
2	19.0de	3.2bc	0.0f	0.0f	21.1a	1.9b	0.0g	0.0f
3	18.9e	9.4ab	0.0f	0.0f	18.4cd	17.0a	0.0g	0.0f
4	19.2cd	2.4bc	29.0c	7.9d	18.3d	9.0ab	0.0g	0.0f
5	19.3c	2.8bc	55.0a	19.7b	19.6b	0.0b	7.0f	3.3f
6	19.0de	5.4bc	50.0a	25.0a	19.8b	3.7b	14.0e	8.2e
7	20.1b	0.0bc	50.0a	20.6b	19.3bc	0.7b	18.0de	16.9d
8	20.0b	16.0a	48.0a	18.5bc	19.3bc	0.0b	38.0b	46.2b
9	20.0b	0.0bc	36.0b	15.2c	17.9def	8.6ab	91.0a	94.8a
10	20.1b	0.0bc	25.0c	8.5d	18.2de	1.1b	26.0c	22.1c
11	20.2b	0.0bc	18.0d	6.2de	17.3ef	4.0b	24.0cd	19.2cd
12	20.8a	0.0bc	10.0e	3.5ef	16.7f	7.2ab	21.0cd	11.5e
Mean	19.6a	3.7c	27.0a	10.4b	18.9a	4.5b	20.0b	18.5a
C.v	0.2	207.2	12.2	183.2	0.1	2.0	55.6	1.2
P-value	<.001	<.004	<.001	<.001	<.001	<.001	<.001	<.001
L.s.d week	0.3	8.2	0.6	3.9	1.1	11.4	4.6	4.3
L.s.d interaction	12.4				14.3			

Analysis was carried out using log transformed values log (X+1). Means were separated using Tukey's test at P≤0.05. Treatment means followed by same letter(s) in each column are not significantly different. Means followed by different letter(s) are significantly different at P<0.05. C.v= Coefficient of variation; L.s.d= Least significant difference

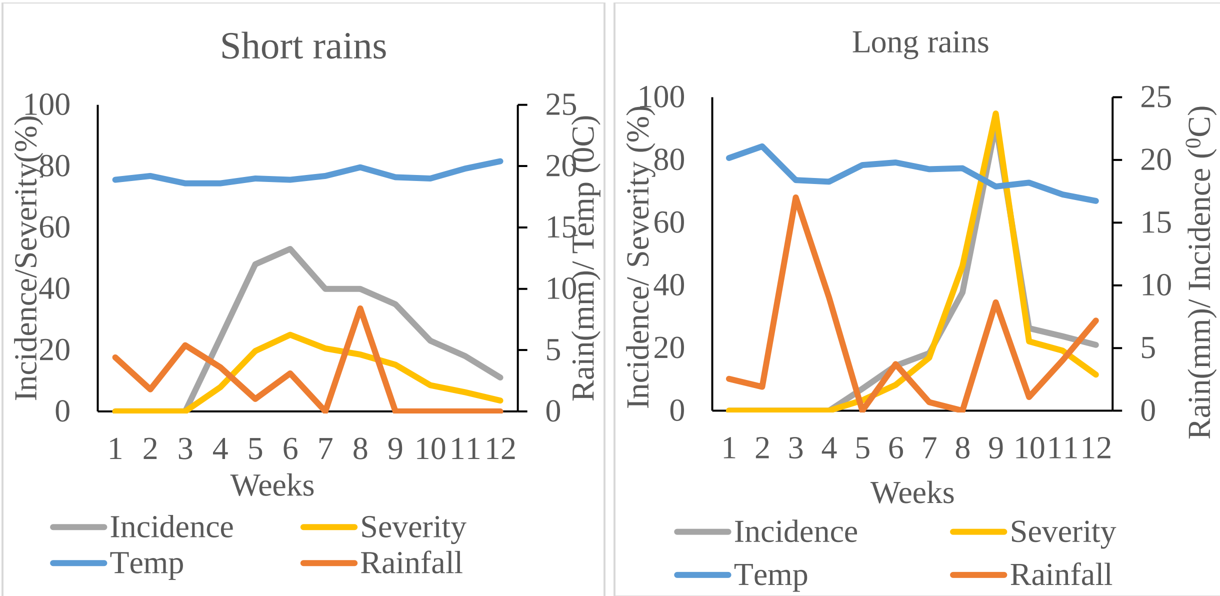

Figure 4.11 Relationship between temperature, rainfall and anthracnose intensity in Agroecological zone UM3.

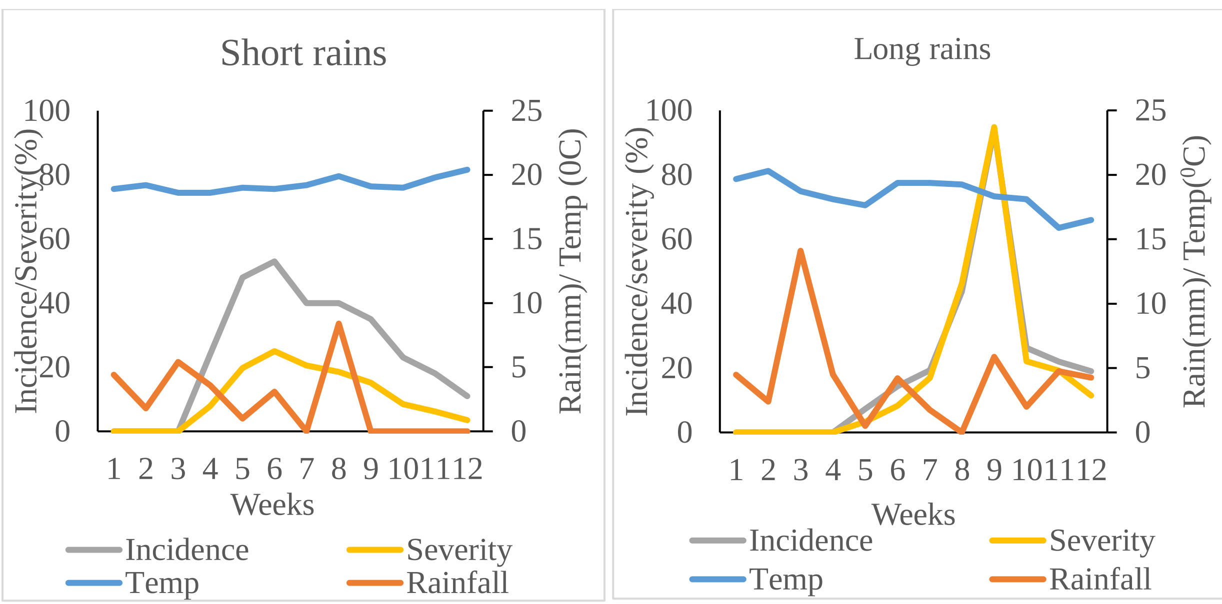

Figure 4.12 Relationship between temperature, rainfall and anthracnose intensity in Agroecological zone LH1

Table 4.12: Relationship between temperature, rainfall and anthracnose intensity in LH1 in Trans Nzoia County during the short rains 2020 and long rains 2021

Weeks	Short rains 2020				Long rains 2021			
	Temp	Rainfall	Incidence	Severity	Temp	Rainfall	Incidence	Severity
1	18.9d	4.4ab	0.0e	0.0f	19.7ab	4.5b	0.0g	0.0f
2	19.2cd	1.8ab	0.0e	0.0f	20.3a	2.4b	0.0g	0.0f
3	18.6d	5.4ab	0.0e	0.0f	18.7abc	14.1a	0.0g	0.0f
4	18.6d	3.6ab	24.0c	7.9d	18.1bc	4.5b	0.0g	0.0f
5	19.0d	1.0b	48.0a	19.7b	17.6bcd	0.5b	7.0f	3.3f
6	18.9d	3.1ab	53.0a	25.0a	19.4ab	4.2b	14.0e	8.2e
7	19.2bcd	0.0b	40.0b	20.6b	19.4ab	1.7b	19.0de	16.9d
8	19.9ab	8.4a	40.0b	18.5bc	19.3ab	0.0b	44.0b	46.2b
9	19.1cd	0.0b	35.0b	15.2c	18.3abc	5.9b	94.0a	94.8a
10	19.0d	0.0b	23.0c	8.5d	18.1bc	2.0b	26.0cd	22.1c
11	19.8abc	0.0b	18.0c	6.2de	15.9d	4.8b	22.0cd	19.2cd
12	20.4a	0.0b	11.0d	3.5ef	16.5cd	4.3b	19.0de	11.5e
Mean	19.2ab	2.3c	24.0a	10.4b	18.5a	3.8b	21.0a	18.5a
C.v	0.4	2.5	15.4	183.2	0.1	1.7	49.1	1.2
P-value	<.001	<.12	<.001	<.001	<.001	<.04	<.001	<.001
L.s.d week	0.6	6.1	3.0	3.9	2.2	8.4	4.9	4.3
L.s.d interaction	12.8				14.4			

Analysis was carried out using log transformed values log (X+1). Means were separated using Tukey's test at $P \leq 0.05$. Treatment means followed by same letter(s) in each column are not significantly different. Means followed by different letter(s) are significantly different at $P \leq 0.05$. C.v= Coefficient of variation; L.s.d= Least significant difference

4.3.4 Effect of temperature and rainfall on bean growth and yield

There was no significant difference in plant emergence in the three sites during the long and short rains. However, the plant stand count was significantly ($P \leq 0.05$) different across the sites during the short rains. In both seasons UM3 had higher emergence and plant stand count. There was a significant increase in plant stand count after emergence until the third week then it decreased across the three sites (Table 4.13). There was a significant ($p \leq 0.05$) difference in the height of the plant from emergence until maturity on all the three sites. Plant height increased independently throughout the cropping season. It was positively correlated to crop growth stage (Table 4.14). In the short rains, rainfall measurement was highest on the eighth week when the crop was at the pod development stage however, it did not rain at this stage during the long rains (Table 4.14). There was high rainfall at the beginning of the season and no rainfall was recorded at the maturity stage of the plants. There was no significant difference ($P \leq 0.05$) in the rainfall means when the crop reached pod filling stage. Anthracnose severity was highest at 25% during the short rains when the crop was at the flowering stage. However, there was a significant increase to 94.8% at pod filling stage during the long rains. Anthracnose disease was first reported when the plant's average height was at 12.6cm when the crop had just produced 3 or more trifoliate leaves at site UM4. Anthracnose incidence was highest at flowering stage then it decreased as the plant matured. Angular leaf spot first symptoms showed when the plant was at popcorn bloom stage and the average height was 29.8cm. There was a significant ($p \leq 0.05$) difference in the height of the plant from emergence until maturity on all the three sites (Table 4.14). There was a significant ($p \leq 0.05$) difference in yields across the three treatments. The number of pods and seeds differed significantly across the three sites. Plot UM 3 had the highest yield during the two cropping seasons. UM4 had the lowest yield during the long rains and short rains despite the land sizes, seed rate and planting dates being the same.

Table 4.13 Average plant stand count during the short rains 2020 and long rains 2021.

	Short rains			Long rains		
Week	UM4	UM3	LH1	UM4	UM3	LH1
1	70.0b	85.0ab	80.0b	72.0bc	88.0bc	82.0bc
2	75.0ab	90.0a	88.0a	78.0b	92.0ab	90.0ab
3	80.0a	92.0a	90.0a	85.0a	95.0a	92.0a
4	75.0ab	90.0a	85.0ab	80.0ab	90.0ab	90.0ab
5	70.0b	85.0ab	80.0b	75.0bc	86.0bc	85.0bc
6	68.0c	80.0c	75.0c	70.0c	82.0c	80.0c
Mean	73.0c	87.0a	83.0b	76.7b	88.8a	86.5a
C.v%	0.1			5.7		
P	<.001			<.001		
L.s.d weeks	6.1			5.5		
L.s.d Aez	3.2			3.2		

Table 4.14 Relationship between temperature, rainfall and plant height in Upper midland 4

	Short rains 2020			Long rains 2021		
Weeks	Temp	Rainfall	Height	Temp	Rainfall	Height
1	18.4c	9.4ab	3.7k	19.6ab	2.3bc	2.8l
2	18.1c	7.7abc	5.7j	20.1a	3.3bc	4.5k
3	18.2c	2.4bcd	8.5i	18.6abc	14.5a	8.7j
4	18.3c	3.0bcd	12.6h	19.2ab	4.7bc	13.3i
5	18.3c	4.2bcd	19.3g	19.9ab	0.1c	18.9h
6	18.2c	4.3bcd	29.8f	20.2a	1.0c	24.9g
7	18.9b	0.1d	38.8e	19.1ab	1.3c	31.0f
8	18.9b	12.7a	43.5d	19.7ab	0.0c	40.2e
9	19.3ab	0.1d	49.7c	20.3a	9.9ab	43.2d
10	19.6a	0.0cd	50.9b	16.5d	0.4c	51.7c
11	19.5a	0.0d	52.5a	17.3cd	2.2bc	56.3a
12	19.4ab	0.0d	52.6a	17.8bcd	6.9abc	55.8b
Mean	18.8a	3.7a	30.6a	19.1a	3.8a	29.3a
C.v	0.3	1.7	0.1	0.1	1.9	3.1
P-value	<.001	<.001	<.001	<.001	<.004	<.001
L.s.d week	0.2	6.5	0.7	0.4	8.8	0.5
L.s.d interaction	33.5			31.9		

Table 4.15 Relationship between temperature, rainfall and plant height in Upper midland 3

	Short rains 2020			Long rains 2021		
Weeks	Temp	Rainfall	Height	Temp	Rainfall	Height
1	19.0de	5.1bc	4.2a	20.1b	2.5b	2.7l
2	19.0de	3.2bc	5.8b	21.1a	1.9b	5.3k
3	18.9e	9.4ab	8.6c	18.4cd	17.0a	8.0j
4	19.2cd	2.4bc	12.5d	18.3d	9.0ab	15.0i
5	19.3c	2.8bc	21.7e	19.6b	0.0b	20.6h
6	19.0de	5.4bc	31.6f	19.8b	3.7b	28.4g
7	20.1b	0.0bc	41.2g	19.3bc	0.7b	36.5f
8	20.0b	16.0a	48.4h	19.3bc	0.0b	43.7e
9	20.0b	0.0bc	52.7i	17.9def	8.6ab	48.8d
10	20.1b	0.0bc	55.7j	18.2de	1.1b	54.2c
11	20.2b	0.0bc	58.6k	17.3ef	4.0b	57.6b
12	20.8a	0.0bc	58.9k	16.7f	7.2ab	58.6a
Mean	19.6a	3.7a	33.3a	18.9a	4.5a	31.6a
C.v	0.2	207.2	0.03	0.1	2.0	2.3
P-value	<.001	<.004	<.001	<.001	<.001	<.001
L.s.d week	0.3	8.2	0.5	1.1	11.4	0.4
Lsd Interaction	36.8			33.7		

Analysis was carried out using log transformed values log (X+1). Means were separated using Tukey's test at P≤0.05. Treatment means followed by same letter(s) in each column are not significantly different. Means followed by different letter(s) are significantly different at P≤0.05. C.v = Coeficient of variation. L.s.d= Least significant difference

Table 4.16 Relationship between temperature, rainfall and plant height in Lower highland 1

	Short rains 2020			Long rains 2021		
Weeks	Temp	Rainfall	Height	Temp	Rainfall	Height
1	18.9d	4.4ab	4.2a	19.7ab	4.5b	2.6k
2	19.2cd	1.8ab	5.2b	20.3a	2.4b	5.3j
3	18.6d	5.4ab	8.4c	18.7abc	14.1a	9.0i
4	18.6d	3.6ab	11.3d	18.1bc	4.5b	16.8h
5	19.0d	1.0b	19.9e	17.6bcd	0.5b	23.2g
6	18.9d	3.1ab	31.2f	19.4ab	4.2b	30.3f
7	19.2bcd	0.0b	41.7g	19.4ab	1.7b	38.2e
8	19.9ab	8.4a	46.4h	19.3ab	0.0b	46.0d
9	19.1cd	0.0b	53.0i	18.3abc	5.9b	50.4c
10	19.0d	0.0b	53.8j	18.1bc	2.0b	57.7b
11	19.8abc	0.0b	57.4k	15.9d	4.8b	61.9a
12	20.4a	0.0b	58.7l	16.5cd	4.3b	61.7a
Mean	19.2a	2.3b	32.6b	18.5a	3.8b	33.6a
C.v	0.4	2.5	0.04	0.1	1.7	1.9
P-value	<.001	<.12	<.001	<.001	<.04	<.001
L.s.d week	0.6	6.1	0.7	2.2	8.4	0.3
Lsd Interaction	37.7			37		

Analysis was carried out using log transformed values log (X+1). Means were separated using Tukey's test at P≤0.05. Treatment means followed by same letter(s) in each column are not significantly different. Means followed by different letter(s) are significantly different at P≤0.05. C.v = Coeficient of variation L.s.d= Least significant difference

Table 4. 17. Yield and yield components of three AEZs in Trans Nzoia county during the short rains 2020 and long rains 2021

Pods	Short rains			Long rains		
Blocks	UM4	UM3	LH1	UM4	UM3	LH1
1	12.5ab	19.3a	18.2a	11.5b	23.7a	21.0b
2	13.0a	21.1a	19.1a	16.0a	23.7a	21.8ab
3	11.7b	20.1a	19a	17.0a	24.8a	22.4a
Mean	12.5c	20.2a	18.8b	14.8c	24.1a	21.7b
C.V(%)	7.4	8.5	6.1	7.5	4.2	3.3
P value	<.001	<.098	<.17	<.001	<.046	<.001
Lsd block	0.8	1.6	1.1	1.0	1.0	0.7
Lsd Aez	0.7			0.5		
Lsd interaction	1.1			0.9		
Seeds	Short rains			Long rains		
Blocks	UM4	UM3	LH1	UM4	UM3	LH1
1	52.5a	130.8a	101.5a	55.3b	176.0a	136.8a
2	56.6a	140.1a	108.4a	82.0a	188.9a	132.5a
3	54.5a	135.3a	107.6a	82.7a	184.7a	142.2a
Mean	54.5c	135.4a	105.8b	73.3c	183.2a	137.2b
C.V(%)	12.3	11.7	9.6	11.6	6.5	7.8
P value	<.4	<.5	<.3	<.001	<.069	<.152
Lsd block	6.3	14.9	9.5	8	11.1	10
Lsd Aez	5.9			5.4		
Lsd interaction	10.2			9.4		
Dry weight(kg/ha)	220.5	862.3	666.3	264.6	960.3	842.7

Analysis was carried out using log transformed values log (X+1). Means were separated using Tukey's test at P≤0.05. Treatment means followed by same letter(s) in each column are not significantly different. Means followed by different letter(s) are significantly different at P≤0.05. C.v= Coefficient of variation; L.s.d= Least significant difference

4.3.5 Relationship among temperature, rainfall, disease intensity and growth parameters

There was a positive correlation between AUDPC and grain yield across the three sites during the two cropping seasons as the sites with higher AUDPC still had the highest yield (Table 4.18). Increase in rainfall during the long rains caused a significant increase in the grain yield. The increase in disease did not cause reduction in yields across the sites (Table 4.19). The correlated parameters were highlighted in yellow. In UM4 during the short rains, there was a high positive correlation among plant height, angular leaf spot incidence and severity with temperature. Increase in temperature caused a high significant increase in angular leaf spot intensity. Rainfall had a negative correlation with disease intensity (Table 4.20). In UM3 and increase in temperature caused a significant increase in angular leaf spot intensity. However, increase in temperature had a weak positive correlation with anthracnose intensity (Table 4.21). In LH1 the correlation among temperature, plant height and angular leaf spot intensity was positive however, rainfall had a negative correlation with the parameters. Plant height had a strong positive correlation with angular leaf spot intensity moreover, the relation was weak on anthracnose intensity (Table 4.22). In UM4 during the long rains, there was a negative correlation between temperature and angular leaf spot severity of – 0.67 and increase in rainfall did not significantly affect the plant height. Increase in angular leaf spot intensity caused a significant increase with anthracnose intensity (Table 4.23). Increase in temperature and rainfall in UM3 did not affect the development of angular leaf spot and anthracnose. The two diseases had positive correlation on each other (Table 4.24). In LH1, there was a positive correlation between temperature and angular leaf spot intensity. However increase in temperature and rainfall did not significantly cause increase in anthracnose intensity (Table 4.25).

Table 4.18 Relationship between temperature, rainfall, angular leaf spot intensity and grain yield for three agroecological zones in Trans Nzoia County

	Temp (°C)	Rain (mm)	Plant height (cm)	Incidence (%)	Severity (%)	AUDPC (m2)	Grain yield (kg/ha)
Short rains							
UM4	18.8a	3.7ab	30.6d	29.0c	18.0d	1369.3c	220.5c
UM3	19.6a	3.7ab	33.3ab	41.0ab	24.3c	1873.7b	862.3a
LH1	19.2a	2.3b	32.6b	43.0a	27.5b	2131.3a	666.3b
Mean	19.2	3.2	32.2	38.0	23.2	1791.4	583.0
Long rains							
UM4	19.1a	3.8ab	29.3e	26.0c	28.5b	2322.7b	264.6c
UM3	18.9a	4.5a	31.6c	29.0c	29.0b	2380.6b	960.3a
LH1	18.5a	3.8ab	33.6a	32.0bc	32.1a	2523.0a	842.7b
Mean	18.8	4.1	31.5	29.0	29.9	2408.8	689.2

Table 4.19 Correlation between temperature, rainfall, anthracnose intensity and grain yield for three agroecological zones in Trans Nzoia County

	Temp (°C)	Rain (mm)	Plant height (cm)	Incidence (%)	Severity (%)	AUDPC (m2)	Grain yield (kg/ha)
Short rains							
UM4	18.8a	3.70ab	30.62d	2.90c	17.96d	910.3b	220.5c
UM3	19.6a	3.70ab	33.31ab	4.1ab	24.26c	1023.1a	862.3a
LH1	19.2a	2.30b	32.58b	4.3a	27.45b	863.4c	666.3b
Mean	19.22	3.23	32.17	3.77	23.22	932.3	583.0
Long rains							
UM4	19.06a	3.76ab	29.28e	26.4c	28.5b	1290.1c	264.6c
UM3	18.90a	4.50a	31.61c	2.89c	29.03b	1417.9b	960.3a
LH1	18.51a	3.76ab	33.59a	3.17bc	32.12a	1515.9a	842.7b
Mean	18.82	4.1	31.5	29.0	29.88	1405	689.2

Table 4.20 Correlation between temperature, rainfall, angular leaf spot and anthracnose intensity in UM4 short rains

UM4		Temp (°C)	Rainfall (mm)	Height (cm)	ALS Incidence (%)	ALS severity (%)	Anthracnose incidence (%)	Anthracnose Severity (%)
Temp	1	-						
Rainfall	2	-0.5076	-					
Height	3	0.9114	-0.4744	-				
ALS_incidence	4	0.9812	-0.4896	0.9292	-			
ALS_severity	5	0.9779	-0.5561	0.9045	0.9784	-		
Anthracnose incidence	6	0.0025	-0.0732	0.3103	0.0349	-0.0478	-	
Anthracnose_severity	7	0.0433	-0.0183	0.3553	0.0773	-0.0174	0.9845	-

Table 4.21 Correlation between temperature, rainfall, angular leaf spot and anthracnose intensity in UM3 short rains

UM3		Temp (°C)	Rainfall (mm)	Height (cm)	ALS Incidence (%)	ALS severity (%)	Anthracnose incidence (%)	Anthracnose Severity (%)
Temp	1	-						
Rainfall	2	-0.3443	-					
Height	3	0.9115	-0.2732	-				
ALS_incidence	4	0.8765	-0.2959	0.9646	-			
ALS_severity	5	0.8295	-0.3814	0.9131	0.9495	-		
Anthracnose_incidence	6	0.1691	0.0991	0.3484	0.1837	0.069	-	
Anthracnose_severity	7	0.1231	0.0906	0.3404	0.1808	0.0676	0.9711	-

Table 4.22 Correlation between temperature, rainfall, angular leaf spot and anthracnose intensity in LH1 short rains

LH1		Temp (°C)	Rainfall (mm)	Height (cm)	ALS Incidence (%)	ALS severity (%)	Anthracnose incidence (%)	Anthracnose Severity (%)
Temp	1	-						
Rainfall	2	-0.1484	-					
Height	3	0.6775	-0.4335	-				
ALS_incidence	4	0.6126	-0.3923	0.9639	-			
ALS_severity	5	0.5689	-0.5097	0.9165	0.9511	-		
Anthra_incidence	6	-0.0076	-0.0688	0.3637	0.2246	0.1326	-	
Anthrac_severity	7	-0.0105	-0.0283	0.3367	0.2076	0.0988	0.9858	-

Table 4.23 Correlation between temperature, rainfall, angular leaf spot and anthracnose intensity in UM4 long rains

UM4		Temp (°C)	Rainfall (mm)	Height (cm)	ALS Incidence (%)	ALS severity (%)	Anthracnose incidence (%)	Anthracnose Severity (%)
Temp	1	-						
Rainfall	2	0.0235	-					
Height	3	-0.5964	-0.1319	-				
ALS_incidence	4	-0.58	0.0411	0.8851	-			
ALS_severity	5	-0.6665	0.037	0.914	0.9707	-		
Anthracnose_incidence	6	0.0745	0.19	0.594	0.7358	0.6308	-	
Anthracnose_severity	7	0.0812	0.2059	0.5427	0.7207	0.6095	0.9937	-

Table 4.24 Correlation between temperature, rainfall, angular leaf spot and anthracnose intensity in UM3 long rains

UM3		Temp (℃)	Rainfall (mm)	Height (cm)	ALS Incidence (%)	ALS severity (%)	Anthracnose incidence (%)	Anthracnose Severity (%)
Temp	1	-						
Rainfall	2	-0.4428	-					
Height	3	-0.7191	-0.1823	-				
ALS_incidence	4	-0.6492	-0.0828	0.869	-			
ALS_severity	5	-0.7324	-0.0382	0.8909	0.977	-		
Anthracnose_incidence	6	-0.3888	0.0103	0.6332	0.7075	0.6424	-	
Anthracnose_severity	7	-0.306	0.0072	0.5503	0.6399	0.5617	0.9871	-

Table 4.25 Correlation between temperature, rainfall, angular leaf spot and anthracnose intensity in LH1 long rains

LH1 S2		Temp (℃)	Rainfall (mm)	Height (cm)	ALS Incidence (%)	ALS severity (%)	Anthracnose Incidence (%)	Anthracnose Severity (%)
Temp	1	-						
Rainfall	2	-0.0748	-					
Height	3	-0.6592	-0.2686	-				
ALS_incidence	4	-0.4883	-0.1501	0.8874	-			
ALS_severity	5	-0.6082	-0.111	0.9031	0.9828	-		
Anthracnose_incidence	6	-0.1304	-0.1056	0.595	0.7063	0.6378	-	
Anthracnose_severity	7	-0.0747	-0.0887	0.5332	0.6609	0.5903	0.9943	-

CHAPTER FIVE: DISCUSSION

5.1. Farmer's perception on production constraints, variety selection and management practices of angular leaf spot and anthracnose on common beans

Majority of farmers practice farming in small scale on their own land which is less than three acres despite the crop being a major legume in the region (Katungi *et al*., 2010). This is because of the high population in the region that leads to land fragmentation thereby reducing the acreage used for farming. Most farmers use their own saved seeds and some buy from local market since it is cost effective and locally available (Mutari *et al*., 2021). The farmers do not want to lose their local variety. They have been growing beans for more than ten years using traditional production methods that is why they get low yields thereby producing for household use only. Most times they do not get the surplus beans to sell due to disease infestation. In addition, Rosecoco GLP2 which was the most preferred variety was also the most susceptible to diseases. Farmers prefer the yield trait and early maturity when selecting a variety other than the ability of a variety to resist or tolerate diseases (Mabeya *et al*., 2020).

The study found that farmers' preferred to use their own saved seeds mainly due to the high cost of certified seeds which could still get infected when the crop was growing which also increased introduction and spread of seedborne diseases (Mutari *et al*., 2021). It also led to increased cost of production incurred by the farmer as the seeds are double the price in the agro-shops compared to local markets. Farmers preferred varieties are not always available in shops when needed. Furthermore, continuous cropping of beans has led to accumulation disease inoculum in crop debris. Crop rotation was not a common cultural practice in most farms (Ojiem *et al*., 2020) due to high land fragmentation which resulted from the increased human populations. Beans were intercropped with cereals such as maize. Muraya *et al*., (2006) reported that beans do not affect the yield of maize, therefore the intercropping was to intensify farming as there was limited land available to rotate crops. It also helps to reduce spread of pests and diseases especially for host specific pests. The extension officers who occasionally visited farmers were able to provide information on good agricultural practices especially on pest and disease control. The use of radio to access information was equally popular on the rural parts of Cherangany and Kiminini constituencies as it was majorly done through the local dialect of the region.

Pest and diseases were the major problem experienced in most parts of the region (Assefa *et al*., 2019) causing high yield losses. Unreliable and irregular rainfall was also of concern since most farmers practice rain fed agriculture. Angular leaf spot and anthracnose diseases were present on most of the farms surveyed since the diseases were seed borne therefore were easily from the farmers own saved and locally sourced seeds. Disease knowledge gap which was evidenced by the farmers' inability to correctly identify the diseases referring to all diseases as blight and the inaccessibility of the extension officers in the remote areas was a challenge to disease management practices. Bean stem fly was present in most of the surveyed fields. It attacked the root stem junction of the plant causing wilting and premature death of plant. Aphids and pod borers were also common pest in the region (Ogecha *et al*., 2019

Angular leaf spot and anthracnose were the major diseases in most of the surveyed farms as the diseases were favored by warm and wet environmental conditions in the region. This agrees with Mwang'ombe *et al*., (2007) working on occurrence and severity of Als in Kenya that the disease was present on 89% of the farms surveyed. The diseases have been a challenge for more than 10 years as most farmers do not know the identity of those diseases and referred all of them as "baridi" to mean blight. However, from the photos shown, they were able to identify the different diseases on their farms where they have been using cultural methods such as early planting and timely weeding to control the spread since it was cheap and safe as compared to use of chemicals. There was a possibility that the variability for resistance once existed between the two genotypes for angular leaf spot and anthracnose on common beans which made them to be disease resistance since even the certified seeds still got infected as reported by Pastor-Corrales *et al.,* (2010). In the last 3 years, there was an outbreak of the disease due to the recent change in climate conditions as the pathogens are favored by high humidity of 90% and temperature range of 19℃. The pathogens also keep changing their variability as reported by Deeksha *et al*., (2009) therefore crops that were once resistant to the diseases can now be infected by the new race of pathogens

Rosecoco was the most susceptible variety even thou most farmers preferred to grow it as they preferred its high yielding and early maturity characteristics. In farms where the two diseases occurred simultaneously there was high yield loss of upto 80% especially when no fungicide was used at crop blooming stage. Since the disease symptoms were present on leaves, stem and pods, the expected harvest as the infected seeds harvested were shrinked and discolored thus reducing their market quality. Most farmers would prefer to listen to radio early in the morning before going to work as the radio had local languages and could be most preferred means to give information to farmers as radio is commonly used in most rural set ups. Since the farmers have different challenges on the farm, it would have been more convenient if they were registered and sent for personalized messages depending on their needs. However, most farmers were not willing to pay any amount so as to be updated on early warning signs for pests and diseases as they felt it was the role of the government to send them direct messages for free to avoid yield losses on the farms. The few who found the idea of sending direct messages useful, were only able to pay upto ten shillings per message in a week so as to be updated on expected pests and management methods depending on the crops planted.

The farmers should be trained on the importance of planting using certified seeds and proper farm management practices to avoid introduction and spread of diseases. Extension officers should visit the farmers frequently to identify their personal challenges to help in profiling their personal needs so that control measures can be implemented in good time. Seed producing companies should do proper marketing at farm level so that they are aware of the farmers preferred varieties to be able to stock them in local agroshops. At the same time certified seeds' prices should be reduced to make them economically accessible to small holder farmers.

5.2 Common bean breeders' perception on bean breeding, availability of certified seeds and disease management practices

Breeders were focused on the farmers preferred variety and characteristics for example, Rosecoco GLP2 instead of disease tolerant characteristics and this reduced the chances of producing disease resistant varieties as the variety to be improved was influenced by farmers' uptake. This was similar with the survey results which showed that majority of farmers in Trans Nzoia county preferred to grow Rosecoco GLP2 because it matures fast and has high nutritional value. This makes this variety on high demand in many breeding facilities. Nyota and Faida varieties are less popular among the breeders since the farmers rarely plant them hence most agroshops prefer not to stock it. Breeders normally look at the ability of a variety to resist or tolerate diseases when they want to produce a new one. However, this is not the case as farmers prefer the physical characters of large seeds, high yields and good cooking quality when selecting seeds to plant, which has constrained the effort of most breeders.

Conventional breeding method is popular among most breeders because it is easy to use as they can select parents with desired characteristics depending on the needs of farmers in different regions. Molecular methods are equally used in private breeding institutions since they have high thorough put capacity. When working on the release of new variety, breeders are faced with several challenges that directly affect the output of their work. Pathogens keep changing their variability. This makes a once resistant or tolerant variety to become susceptible to the diseases. So, the farmer will be hesitant to adopt the use of hybrid variety since it will still get infection when planted. The farmers have their own desired characteristic in a new variety. Early maturity and high yield are traits that the breeder has to consider in order for the new variety to have high market demand. Therefore, the breeder will not independently work on their own objectives but will focus on the farmers' needs so as to increase the variety uptake. There are several constraints on the farmers' fields that will affect the quality of bean production. Common cultural practices and management methods employed by the farmer will determine if the certified seeds will be able to produce the expected yield. According to breeders, when the farmers are well trained, they are able to manage diseases on the farms.

Local agro-shops lack hybrid varieties for beans. The government research institution which is mandated to license and authorize agroshops to sell hybrid seeds gives traders conditions that they are not able to meet before they can stock beans and other hybrid seeds. This makes them not to sell the newly released varieties. Additionally, hybrid seeds are twice the price of local market seeds. This makes the farmers not to access the seeds as most of them produce on small scale. This was also the main concern for farmers during the survey. It was uneconomical for a farmer producing seeds for household use to buy certified seeds. Despite being treated, certified seeds still get infected due to the farmers' field conditions such as plant debris and the atmospheric factors like warm temperatures that affect the development of diseases. So, this also affects the rate at which farmers buy certified seeds. Breeders are also constrained by the ability of pathogens to develop into new races. For instance, Rosecoco GLP 2 which used to be resistant to *Pseudocercospora griseola* and *Colletotrichum lindemuthianum* is now very susceptible to these pathogens. Therefore, the breeder has to keep producing new varieties and improving the available ones. It is time consuming and costly for a breeding institution to produce a new disease tolerant/ resistant variety. When breeding, the breeder has to factor in the challenges that the farmers face and their desired qualities in seeds. Information on farm production challenges were mostly sourced through farm visits by extension officers and also through market profiling.

Most farmers do not have access to certified seeds because of the high prices at the agro-shops compared to local markets. Market information is also a factor that affects availability of seeds although it is of minor importance since most farmers are aware of the hybrid varieties. The breeders suggested that reduction in hybrid seed prices and creating awareness to farmers can increase seed uptake and availability. Most breeding organizations get their germplasms from CIAT and KALRO to use for research. Upon successful breeding, the variety is tried before release. However, the breeders do not share information on their findings with other institutions unless they are working together. Most breeders think the farmers should be actively involved in producing a new variety and also allow them to bring their local varieties to be improved. This will increase seed demand when it is locally produced by the farmers and this result concur with those reported by Morris *et al*., 2004 on participatory plant breeding research on opportunities and challenges for international crop improvement system.

5.3 Effect of temperature and rainfall on phenological development of angular leaf spot and anthracnose on common beans

The current study showed that increase in temperature and rainfall caused an increase in the severity of angular leaf spot and anthracnose since the fungi development was favoured by high humidity. Positive correlation between the weather elements and the diseases demonstrated that rainfall and temperature positively affect development of the pathogens thereby increasing disease intensity. Most parts of Trans Nzoia experience warm and wet weather conditions and it is therefore difficult to control the diseases due to the high humid environment. The temperatures were higher towards the crop maturity stage when the disease severity was high across the different AEZs. The disease severity was highly significantly ($p \leq 0.05$) affected by increase in temperature. The effect of the disease on the three AEZs was attributed to the varying environmental conditions. However, there was no significant difference in the temperature records on UM4, UM4 and LH1 during the long rains as the AEZs bordered each other hence the close climatic condition. Certified seeds were used to plant although the crops were still infected and the results showed that Rosecoco GLP 2 was highly susceptible to angular leaf spot and anthracnose which were seedborne diseases

(Nay *et al*., 2019). This could have also been caused by infected plant debris on the farmers' fields. There was a higher disease recording of angular leaf spot than anthracnose under the same field conditions. At the temperature of 20.83℃ the plants infected had higher severity scale score compared to 18.12℃. Upper midland 4 had the highest number of bean stem fly larvae, pupae and adult which could have attributed to the decrease in yields since the larvae attacked the root stem junction of the plant causing it to rot, wilt and dry.

The positive correlation between temperature, rainfall and disease intensity was an indication that the disease development was dependent on the weather elements. The highest temperature was recorded in week 12 when the crop was at maturity stage in short rains while it was highest in the second week when the crop had just produced the two trifoliate leaves during the long rains. However, at maturity the disease severity reduced. Upper Midland 3 had the highest temperature while UM 4 had the lowest temperature of 19.6 and 19.2 in the short rains which could have caused the low disease intensity. The high temperatures and rainfall across the AEZs at the beginning of the cropping season created a favourable environment for the sporulation of the fungi. The average temperature significantly increased towards the crop maturity stage as the disease severity also increased. There was a high positive correlation between ALS and anthracnose incidence and severity during the long rains across the sites showed that there was synergistic effect by the pathogens. The establishment of anthracnose made the crop susceptible to angular leaf spot

There was a dry period at the onset of planting which alternated with the wet period as there was a delay in the start of the long rains. The increased rains during the podding stage increased disease severity as the pathogen's lifecycle was favored by the high humidity. There was high rainfall at the beginning of the season and no rainfall was recorded at the maturity stage of the plants on all the three sites as the pathogens had established earlier before the symptoms were visible. The plant reached the physiological maturity stage during the dry period which facilitated pod filling and drying. There was no significant difference ($P \leq 0.05$) in the rainfall means when the crop reached pod filling stage until maturity in all the three sites. The unreliable rainfall patterns that are experienced in Trans Nzoia caused no significant differences in the rainfall means.

Angular leaf spot severity increased from the popcorn bloom stage until maturity while the amount of rainfall was highest at the beginning of the season when the crop was at the emergence stage. The correlation between rainfall means and disease severity was negatively weak which showed that the decrease in rainfall did not have an effect on the increase of the disease towards the end of the cropping season. The positive correlations of temperature and rainfall showed that an increase in the weather elements caused increase in disease intensity. An increase or decrease in rainfall was not highly significant to the development of the disease. During the short rains, the amount of rainfall was higher at the beginning of the cropping season which helped in the germination and establishment of the causal agents then it reduced as the plant matured. High humidity of 80% had a significant effect on the two diseases as this helped to increase the pathogens' life cycle. The present study from both seasons confirmed that high humidity experienced as the plant matured coincided with increased disease severity across the three AEZs which showed that when the air was humid there was increased pathogens activities. These results concur with that reported by Delgado *et al*., 2013 on the effectiveness of saccharin as resistance inducers against angular leaf spot on common beans

The delaying of the short rains caused the late development of anthracnose disease as planting was done late at the onset of rains. The disease was favored by high humidity and rainfall. The plant leaves, stem and pods had symptoms of brick red water-soaked spots with raised margins. Light pink fungal sporulation was seen on the leaves early in the morning which confirmed the presence of *Colletotrichum lindemuthianum.* Results showed that angular leaf spot disease infects the plant and symptoms of dark brown angular shaped lesions were recorded when the crop was at the flowering stage and the highest severity was at pod filling stage. This could be attributed to decrease in yield since the malformation of pods affect seed setting in bean crops. The negative binomial model was used because the data was over-dispersed. The disease severity mean is dependent on the mean of temperature, rainfall, agro ecological zones and is also affected by the time. Angular leaf spot and anthracnose affect crop production and the expected yields which then cause decline in farm agricultural production, poverty and poor rural livelihood (Muthomi *et al*.,2007; Giller *et al.,* 2011). Yield losses by ALS can be upto 80% when no control method is used. Fungicides are expensive to use especially in small scale farmers. The result here differ with those reported by Nay *et al*.,2019 on review of ALS who reported that yield losses of upto 80% in susceptible common bean plants. However, in this study the sites (UM4 and LH1) with the highest disease severity had the highest yields. UM4 had the lowest yields of 220.5hac/kgs and 264hac/kgs in the short rains and long rains respectively. This was due to the high infestation of bean stem maggot which was present before the crop germinated until crop maturity stage. The results of low yields in UM4 can also be attributed to low plant emergence across the two seasons. The site also recorded lower plant height compared to UM 3 and LH 1. Therefore, the diseases severity will increase causing qualitative and quantitative losses in bean production.

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The farmers' perception on availability of certified seeds and management practices have an effect on the development of angular leaf spot and anthracnose. The use of own saved seeds by most farmers cause increase in the diseases therefore lowering the expected yields. Farmer's choice of bean varieties and farm cultural activities will either increase or decrease disease incidence on the fields. This later affects the expected yields. Seed producing companies should do proper marketing at farm level so that they are aware of the farmers preferred varieties to be able to stock them in local agro-shops. At the same time certified seeds' prices should be reduced to make them economically accessible to small holder farmers. Breeders' biasness to concentrate more on early maturity characteristics so that their variety can be accepted by farmers will have a negative effect on disease control programs. The most effective strategy to control anthracnose and ALS was to use resistant varieties to reduce yield losses without using fungicides that have a negative effect on the environment (Gonçalves-Vidigal *et al*., 2020). Therefore, management of the disease should start with field sanitation to avoid introduction and spread of pathogen's inoculum to the farms. In addition, knowledge of angular leaf spot and anthracnose by farmers will help to improve disease diagnostics hence proper and timely management measures.

Weather prediction models should be used to warn farmers on the upcoming disease outbreaks to be able to do timely management and upscale common bean production. Temperature and rainfall variations significantly affect development of angular leaf and anthracnose of common beans by causing an increase in the development of the pathogens. Alternating periods of high and low rainfall with long periods of high humidity caused increase in both diseases across the three AEZs. The disease being seedborne still infected the plants despite being treated and certified. This shows that there were pathogens inocula already present in the field before planting from the remaining plant debris on the farm. There was no chemical used and that is why the expected yield was slightly lower than the actual yield. Use of fungicides was recommended in order to reduce yield losses. Highest disease severity was recorded in UM4 and LH 1 respectively. However, the two sites still had the highest yield. Low yields in UM 4 could be attributed to the black cotton soils that was present and had low nutrients since it has been used for farming for more than 50 years in all cropping season. The farm has been used to grow beans and maize in all cropping seasons. There was bean stem fly that were recorded in large numbers at site UM4 which could have attributed to decreased yields. The red volcanic soils in UM3 and LH1 had high nutrient concentration that led to the increased yields. This study showed that disease development is affected by is affected by both abiotic and biotic factors with pests and diseases being the major cause of yield losses. Other cultural control practices for example, field sanitation through eradication of plant debris can be implemented as the debris act as alternative hosts of disease-causing organisms. The distribution and severity of the angular leafspot and anthracnose have not been fully documented since common beans are cultivated in majority of the agro ecological zones in Kenya.

6.2 Recommendation

Based on the results of this study, the following recommendations can be made:

i. Information on correlation of weather elements, disease development and crop growth stages documented during this study should be shared with all the relevant stakeholders in Trans Nzoia to upscale bean production

ii. Disease and pest diagnostic chart to be created and shared with farmers for ease in disease identification hence timely control plan.

iii. Pest warning messages to be sent to farmers monthly at subsidized cost.

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APPENDICES

Appendix 1. Farmers Questionnaire

UNIVERSITY OF NAIROBI/ CAB INTERNATIONAL

STACEY ACHIENG' ODUNGA MSC FIELD RESEARCH

SURVEY QUESTIONNAIRE FOR ANGULAR LEAF SPOT ON COMMON BEANS IN TRANS NZOIA COUNTY

A. Personal details

Name of Farmer/Respondent: ______________________________

Date of interview: ________________ Gender: Male ☐ Female ☐

Relation to farm: owner ☐

Manager ☐

Employee ☐

other ☐

B. Information on area

County ________________ Sub County ________________

Location ________________ Village ________________

Agro ecological zone ____________ Latitude: ________________

Longitude ________________ Elevation ________________

C. General Production information

1. What is the total size of farm (Acre)
2. What size of farm is used for bean production?
3. How long you have been producing beans? (months/years) _______
4. Do you grow beans for household use or for selling?
5. What is your source of seeds?

Own saved seeds ☐ Local Market ☐

Neighbours ☐ Agro-shops ☐

6. Give reasons for your sources of seeds

7. Which bean variety (s) do you grow and reason?

Bean variety	Reasons

D. Production Challenges

8. What are the main challenges of bean cultivation beginning with the most challenging?

Challenges	Importance (Major/ Minor)

9. Which diseases do you know that affect beans and how do you manage them?

Diseases	Rank of importance	Management methods

10. Which diseases do you know that affect beans and how do you manage them?

Pests	Rank of importance	Management methods

E. Angular Leaf spot disease

11. Have you ever seen angular leaf spot (pictogram) on your crop? (Show farmers pictures of diseased leaves, pods and seeds). Yes ☐ No ☐

12. If yes for how long has it been a challenge? Months? Years?

13. Are you able to remember the last worst outbreak of Angular leaf spot?

14. Which bean varieties are more susceptible to the disease?

15. How do you manage Angular leaf spot disease?

Angular leaf spot disease	Management methods	Reasons

16. Which is your most preferred management method and why?

17. Do you practise crop rotation?

18. If yes which crops do you rotate beans with?

19. Are you willing to use certified seeds from the agro-shops if available? Yes ☐ No ☐

20. If YES, Why?

21. What is the impact of the disease on bean production?

22. How do you obtain information good agricultural practices on crop production including beans?

23. Do you interact with agricultural extension officers for advice? If yes, do they come to the farm or go to their offices?

24. Is it easy to access extension services? Yes ☐ No ☐

25. Have you ever visited a plant clinic? If Yes, on what crop were you seeking advice?

26. Have you received agricultural information through:

a) Agricultural extension officers?

b) Radio?

c) Mobile phone as a message?

d) Any other?

27. If you were to receive bean crop production tips, which method do you prefer and why?

28. What time of the day do you like to get the information if via radio?

29. Would you be willing to pay for pest warning messages to be sent to your phone for particular bean pests?

a) Yes, how much? Why?
b) No, why?

Appendix 2: Breeders questionnaire

UNIVERSITY OF NAIROBI/ CAB INTERNATIONAL

STACEY ACHIENG' ODUNGA MSC FIELD RESEARCH

SURVEY QUESTIONNAIRE FOR ANGULAR LEAF SPOT AND ANTHRACNOSE ON COMMON BEANS IN TRANS NZOIA COUNTY

D. <u>Personal details</u>

Name of Breeder/Respondent: ____

Name of Institution/Organization ____

Date of interview: ______________________ Gender: Male ☐ Female ☐

E. <u>General Breeding information</u>

6. How long have you been a bean breeder?

7. Which bean variety (s) have you bred and reason?

Bean variety	Reasons

F. Breeding Challenges

8. What are the main challenges of bean breeding beginning with the most challenging?

Challenges	Importance (Major/ Minor)

9. Which diseases do you know that affect beans and how do you breed for resistance against them?

Diseases	Rank of importance	Breeding methods

G. Angular Leaf spot and anthracnose disease

10. Do you do breeding for resistance against Angular leaf spot and anthracnose disease?
    Yes ☐ No ☐

11. Do you do breeding for tolerance against Angular leaf spot and anthracnose disease? Yes ☐ No ☐

12. If yes for how long have you been breeding for resistance against ALS and anthracnose? Months? Years?

13. How long does it take to produce ALS and anthracnose resistant bean varieties?

14. Why do most agro-shops lack hybrid bean varieties?

15. Why do certified seeds still get infected by angular leaf spot and anthracnose when growing?

16. In your opinion, what are the main challenges of bean cultivation beginning with the most challenging?

Pests	Management
Diseases	
Other challenges	

17. How do get to know the bean diseases farmers are faced with and how do you rate them and include them in your breeding program?

18. What are the factors that influence farmers access to certified bean seeds?

19. How can availability of tolerant/resistance seeds be made more accessible to farmers?

20. Are there any bean varieties you have bred for ALS and/or Anthracnose and farmers do not accept? Why?

21. What are some of the approaches you have adopted to help increase uptake of the new bean varieties you are breeding?

22. What breeding methods do you use and why?
    a. conventional plant breeding methods.

    b. Molecular approaches such as marker-assisted selection

23. What are your main sources of germplasm for breeding?

24. Are you part of any bean research networks to share information? If yes, which one?

25. Do you share your germplasm, or data with other breeding institutions in Kenya, Regionally or globally?

Appendix 3: Media preparation for *Pseudocercospora griseola* and *Colletotrichum lindemuthianum* isolation

Incubation of infected bean tissue and media preparation for isolation of *Pseudocercospora griseola*

The small leaves with the symptoms were washed with distilled water to remove the soil particles. They were then sterilized with 1% Sodium hypochlorite for 60 seconds. The leaves were washed four times in sterile distilled water. Moist chambers were prepared using sterile filter papers where the disinfected symptomatic leaves were incubated to induce sporulation. Bean leaf dextrose agar medium (BLDA) was prepared for isolation of Angular leaf spot (Kamei *et al*., 2020). Fifty gm of fresh bean leaves was weighed and crush in a blender with a small amount of distilled water. The mixture was filtered through a double layer of cheese cloth and sterile distilled water added to make 500mls. The pH of the mixture was adjusted to 6.8 after adding 10g glucose and 10g agar. Sterilization of the mixture was done in the autoclave at 121^0C and 15psi for 15 minutes. The medium was then dispensed at a rate of 20mls per petri dish. V8 juice agar was modified as follows: 200g of fresh carrots, 4g of young bean leaves and 120g of ripened tomatoes were sterilized using 1% NaOCl and the washed in sterile distilled water four times. They were cut into small pieces and blended in one litre of distilled water. A filtrate of 200mls was obtained from sieving the mixture then mixed with 3g of $CaCO_3$ (Unichem calcium carbonate powder), 50mg of b-sitosterol (Sigma) and 15g technical agar (Oxford agar No. LP0013). The mixture was topped to one litre then sterilized using autoclave at 121^OC at 15PSI for 15 minutes. It was then cooled to 40^OC then aseptically dispensed into petri dishes (Ethel *et al*., 2019).

Maintenance of *Pseudocercospora griseola* cultures

Pure cultures of *Pseudocercospora griseola* isolates were sub cultured on modified V8 agar and they were incubated in the dark for 10 days at 25^0C. Agar slants were prepared from the pure cultures and stored in refrigerator at 4 ^{0}C. Nine slide cultures of *Pseudocercospora griseola* (PG K1A, PG K1B, PG K1C, PG K2A, PG K2B, PG K2C, PG K3A, PG K3B and PG K3C) isolates were prepared for further identification. A modification of slide culture techniques was used for further studies of the morphological characteristics of the fungus.

Isolation of Anthracnose

Preparation of Potato Dextrose Agar (PDA)

PDA concentration was in 39g/1000mls of water. There were 5 plates for each of the three farms. A total of 30 plates were used to isolate anthracnose. Each plate had about 20mls of PDA. PDA was sterilized in autoclave at 121^0C for 15 minutes at 15 PSI. Preparation of the plates of potato dextrose agar (PDA) medium was done and media allowed to cool to 45^0C in a water bath. The PDA was dispensed into 9 cm plastic Petri dishes under sterile conditions in the airflow chamber. Infected leaves showing symptoms of anthracnose were selected for the experiment. The leaves were cut into 1cm cubic squares and washed with distilled water to removed soil particles. Sterilization was done with 1% Sodium hypochlorite for 60 seconds. The leaves were washed 4 times with sterile distilled water then blot dried in sterile paper towels. Sterile forceps were used to aseptically place 5 pieces of the leaves on the surface of non solidified PDA. The media was left to cool then it was carefully sealed using cling film. This was done in the laminar flow hood to ensure sterility. The plates were arranged in complete randomized design and incubated for 5 days at room temperature of 25^0 C. Examination of the fungi growing out from the leaves was done visually and under stereomicroscope to observe colony characters and morphology of sporulating structures.