EVALUATION OF TARO LEAF BLIGHT (*Phytophthora colocasiae*) DISEASE INCIDENCE, SEVERITY, ENVIRONMENTAL EFFECTS AND RELATIONSHIP BETWEEN RESISTANCE AND AGRONOMIC TRAITS OF SELECTED TARO (*Colocasiae esculenta*) ACCESSIONS IN WESTERN KENYA.

BY

OTIENO CARREN ADHIAMBO

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DEPARTMENT OF BOTANY

MASENO UNIVERSITY

DECLARATION

DECLARATION BY CANDIDATE

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RECOMMENDATION BY SUPERVISORS

This thesis has been developed under our supervision as University supervisors

Prof. Valerie Palapala
School of Science and Technology
United States International University
P.O Box 14643-00800
Nairobi. **Signature……** **Date……**

Dr. George Opande
Department of Botany
Maseno University
Private bag
Maseno **Signature……** **Date……**

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To God Almighty,

My dear husband Ben and children, Pascaline, Reinhard, Shama and John for understanding why I couldn't be there for them every time they needed me

ABSTRACT

Taro (*Colocasiae esculenta* L. Schott) popularly known as 'nduma' is an aquatic plant grown for its edible leaves and corms. It is mainly cultivated in Western and Central Kenya but its production is constrained majorly by *Phytophthora colocasiae,* a taro leaf blight (TLB) disease. The disease causes destruction of leaf and corm. Knowledge pertaining to taro association with the disease incidence, severity, index, Rainfall, R.H, temperature, interrelationship between agronomic traits and disease resistance of Kenyan and Pacific – Caribbean taro accessions remain unknown in Western Kenya. The study was conducted at MMUST University farm, Maseno university laboratory and greenhouse to determine disease incidence, severity, index, resistance and agronomic traits of Pacific - Caribbean and Kenyan taro both *in-vivo* and *in-vitro*. Field experiments were arranged in a C.R.D and replicated five times while the control experiments in the greenhouse were blocked. Disease incidence was obtained by calculating the percentage number of leaves infected per accession. Severity was derived from a subjective score scale of 1-9 adopted from Simongo *et al.* (2016). Effect of R.H, rainfall and temperature was determined based on disease incidence, severity and index vis a vis the meteorological data obtained from Kakamega weather station. Number of leaves, suckers, plant height and leaf surface area represented the agronomic traits. Relationship between agronomic traits and disease resistance was determined by correlation and dendogram analyses. Analysis of variance was used and significant means separated by the L.S.D at 5% significance level. Disease incidence ranged between 17.71% - 29.86%, severity 33.2% - 53.5% and index 0.71 - 1.54 for Pacific - Caribbean and Kenyan taro respectively. The peak rainfall amounts of 174 and 223.9 mm, maximum temperature of 28.6°C and R.H range of 56 - 66% yielded the highest incidence, severity and index. Disease resistance ranged between 58.27% - 89.73% for Kenyan and Pacific – Caribbean taro respectively with BL/SM/128 portraying the highest resistance of 89.73% while KNY/ELD/75 had the highest resistance (84.34%) among the Kenyan taro accessions. Disease incidence and severity negatively correlated with number of leaves and corm weight. Plant height was not affected by disease infection. BL/SM/120 had the highest mean number of leaves (8.1) and KNY/KSM/20 had the lowest (4.6). The identified tolerant taro accessions could be suggested for future breeding. Further evaluations should be done on the identified taro under diverse environments and screening with more virulent TLB isolates to aid in understanding disease pattern. These would guide in ascertaining the right planting time to prevent disease epidemic and to develop accessions with improved resistance and productivity.

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ACRONYMS/ ABBREVIATIONS

ANOVA	Analysis of Variance
AUDPC	Area under Disease Progression Curve
BL/HW	Improved taro from Hawaii
BL/PNG	Improved taro from Papua New Guinea
BL/SM	Improved taro from Samoa
CA/JP	Improved taro from Japan
CE/IND	Improved taro from Indonesia
CE/THA	Improved taro from Thailand
CRD	Completely Randomized Design
D.I	Disease Index
EHL	Effective healthy leaf
F.S.M	Federated States of Micronesia
FAO	Food and Agriculture Organization
GLA	Green leaf area
INEA	International network for edible aroids
K/CNT	Central Kenya taro accessions
K/KAK	Kakamega - Kenya taro accessions
K/KSM	Kisumu - Kenya taro accessions
K/KTL	Kitale - Kenya taro accessions
K/MU	Mumians - Kenya taro accessions
KEPHIS	Kenya plant health inspectorate service
L.S. D	Least Significant Difference
P.C.A.	Principal component analysis

P.S.B	Philippine seed board
PDA	Potato Dextrose Agar
RNA	Ribonucleic Acid
SAS	Statistical Analysis System Package
SNPs	Single nucleotide polymorphism
SPC	Secretariat of Pacific Community
TLB	Taro Leaf Blight

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CHAPTER ONE

INTRODUCTION

1.1 Background

1.1.1 Taro production

Taro (*Colocasiae esculenta* (L) Schott), a member of the *Araceae* family is a staple food in many developing countries in Africa, Asia and the Pacific Island. It is produced mainly in Africa but is most important per capita in Oceania. It is the fourteenth most consumed vegetable and the fifth most harvested root crop in the world. Taro has a better adaptation to saline and swampy soils than other related crops such as cassava and potatoes. (Singh *et al.,* 2012).

The natural habitat of taro is the edge of water courses and in marshy areas where few crops would succeed (Wanyama and Mardell, 2006). In many countries, taro is being replaced by sweet potatoes and cassava, largely due to disease and pest problems which are becoming a limiting factor for its production (Deo *et al.,* 2009). It is a rich source of carbohydrates, proteins, minerals and vitamins and has medicinal properties to reduce tuberculosis, ulcers, pulmonary congestion and fungal infections (Sharma *et al.,* 2008). The corms are utilized in various industries for the preparation of high fructose syrup and alcohols (Vishnu *et al.,* 2012).

1.1.2 Taro leaf blight disease

Taro leaf blight disease (TLB) poses a serious threat to food security in national economies where it is grown. It has contributed to significant changes in dietary patterns and cropping systems (Trujillo, 1996). Prior to leaf blight outbreak, taro was the major export earner in countries like American Samoa and over 90% of households were

growing the crop, after the outbreak, only 1% of the total supply of *Colocasiae esculenta* were available to the local market (Asraku, 2010). The majority of varieties of taro that existed have been lost primarily through infection by the pathogen. In Hawaii, prior to the arrival of taro leaf blight, there were approximately 350 different varieties in the country which overtime as a result of TLB disease became less than 40 different varieties (Asraku, 2010). The use of planting material from infected corms, increases the disease incidence in subsequent taro crops. Other factors like, density of plants, temperature and humidity are among factors influencing infection and spread of TLB disease warranting research on the same (Whehan, 1992).

The disease (TLB) if not managed early may lead to yield reduction of more than 50%. The survival of the crop and genetic data base is threatened and may lead to extinction. Taro leaf blight pathogen brought about wide spread famine in countries that used it as a staple food. Due to the outbreak of the disease, farmers especially from Cameroon were skeptical of the etiology and health consequences of the disease and they abandoned the crop in the field which led to widespread poverty (Chan *et al*., 1994). As a result of this disease epidemic, huge financial losses have been incurred by many farmers since taro was the main crop grown and also their main source of income both locally and for exportation to nearby countries (Mbong *et al*., 2013).

1.1.3 Taro leaf blight disease management

A lot has been done globally on control measures of taro leaf blight which include: broadcasting on radio, training and seminars on control methods but these efforts have had minimal effects. There is also difficulty in choosing the right parental genotypes as a result of inaccurate assessment of the genetic constitution of different taro cultivars which

help to discriminate between susceptible and resistant taro cultivars (Quero *et al.,* 2004). Other management strategies have also been used to control the disease which include crop rotation and use of fungicides (Asraku, 2010).

Early cultural disease management has been recommended in reducing the inoculum level and relative humidity in the field. Infected leaves should be removed from plantation, burnt and buried. The plants should be widely spaced and be away from older infected ones (Hunter *et al.,* 2002). This has been found to reduce the disease, however negligible (Mandy *et al.,* 2009). Rouging reduces inoculum levels but it is only effective during the early stages of disease development. Taro leaf blight is an explosive disease hence cultural and physical control methods are usually ineffective during an epidemic. As disease severity and intensity increases, physical leaf removal mimics the blight by further reducing total leaf surface area (Hunter *et al*., 2001).

Field sanitation may decrease disease levels early in the season, but sporulating leaf lesions supply enough propagules (sporangia, zoospores) to increase disease (Asraku, 2010). It has also been demonstrated experimentally both in the presence and absence of leaf blight, that planting taro closer together improves yield. It has also been found that close spacing increases the total weight and number of corms, though individual corms become smaller (Brooks, 2005). Close spacing (e.g. 0.5 m) may as well increase leaf blight severity. Other cultural methods recommended include; deep planting, delay of planting on the same land for a minimum of three weeks, avoiding planting close to older infected ones and preventing the carry-over of corms or suckers which can harbour the pathogen from one crop to the other (Jackson, 1999). Adjusting date of planting to escape periods known to be of high disease prevalence have been recommended to reduce initial

inoculum of the pathogen and incidence of early season disease development (Nwanosike *et al.,* 2015). Moreover, lower disease incidence and severity of taro leaf blight was reported in taro, maize intercropping system than those grown in monoculture. The effect of planting time, leaf removal, intercropping and role of fertilizer on incidence and severity of the disease has been unknown (Asraku, 2010).

Successful control of taro leaf blight is also possible with chemicals especially with the use of protective and systemic fungicides (Nelson *et al.,* 2011). Infected plants would be sprayed with fungicides such as Ridomil MZ and Manzate (Hunter *et al.,* 2002). Mancozeb (e.g., Dithane M45), copper (e.g., copper oxychloride), metalaxyl (e.g., Ridomil Gold MZ) and phosphorus acid (e.g., Foschek) have also been recommended. Mancozeb and copper have protective activity only but Metalaxyl and phosphorus acids were generally specific for *Phytophthora* diseases with the former prone to the development of resistance by the organism (Fullerton and Tyson, 2003). Copper fungicides such as copper oxychloride would be applied at the rate of 4.1kg per 100 litres of water per hectare. Protestant chemical sprays containing copper, manganese, or zinc, have been effective against taro leaf blight, but heavy rains make repeated applications necessary. Good results have also been reported with metalaxyl, a systemic agent used against the oomycetes (Vishnu *et al.,* 2012). Despite the effectiveness of fungicides in controlling taro leaf blight, the presence of waxy coating on the leaf lamina makes it ineffective, rendering it uneconomically feasible as large quantities of fungicides and repeated applications are required. The efficacy of fungicides is also strongly governed by the severity of the disease at the time of application, and the prevailing weather conditions (Fullerton and Tyson, 2003).

Generally, fungicides are most effective when disease incidence is low and timely applications reduce inoculum levels. When diseases enter exponential phase, efficacy of disease control is reduced. Method of application also influence efficacy. Motorized knapsack applications are superior to conventional hydraulic machines due to large coverage and speed of application especially in high rainfall situations (Jackson, 1999). Moreover, there are known disadvantages to over reliance on use of fungicides, one being an increased frequency of resistant mutants, especially in pathogen populations with the higher evolutionary potential. Recent years of research have shown an increase in the occurrence and spread of pathogen strains resistant to major types of fungicides and even strains resistant to more than one chemical (Vishnu *et al.,* 2012). Spraying chemicals every two weeks for 3-5 months is neither cost-effective nor compatible with a subsistence agriculture system common in many parts of Western and Central Kenya counties. Under epidemic conditions of taro leaf blight disease, chemical treatments are unable to control the disease (Brooks, 2000). Taro is a subsistence crop and routine chemical use is neither economically practical nor environmentally suitable, sprays are not effective when applied just before or during, the frequent periods of heavy rainfall (Vishnu *et al.,* 2012). Controlling taro leaf blight using chemicals is difficult and cultural methods have generated interest in finding varieties resistant to the disease. Most farmers who traditionally grow taro cannot afford the extra cost required for fungicides and labour involved in leaf removal and spraying (Hunter *et al*, 2001). Host resistance is probably the most valuable control in Agriculture. Resistant varieties are not only environmentally friendly but also require little additional disease control input from

farmers. To select for quantitative resistance, there is need to accumulate the resistant plants.

It has been reported that soil application, seed treatment and foliar spray of rhizobacterial cultures isolated from taro on *Phytophthora* blight reduces disease incidence and severity and increases yield, compared to untreated pathogen inoculated plants (Askaru, 2010). Experiments using saprophytic micro-organisms have shown that *Pseudomonas fluorescence, Bacillus subtilis* and *Gliocladium flimbriatum* can control the fungus *in-vivo* and *in-vitro.* The potential for this biological control however has not been effectively tested at the farmer level (FAO, 1999). The use of resistant varieties offers the most suitable management and long-term strategy against taro leaf blight disease. It is cost effective and environmentally acceptable (Brooks, 2005). The success of breeding for resistance against TLB depends on the availability of genetic resources and the type of resistance they confer (Iramu *et al.,* 2004). The use of polygenic or horizontal resistance (HR) is one of the most effective means to control taro leaf blight (Singh *et al* 2010). Horizontal resistance (HR) is controlled by a number of minor genes and does not involve a gene-for-gene relationship.

1.1.4 Taro leaf blight disease resistance

The resistance mechanism of taro against TLB is considered to fall under the HR category based on several host-pathogen interaction models and genetic studies (Robinson, 1996). Ivancic *et al.* (1994) reported that horizontal resistance was effective against all races of pathogen and has a reputation for durability, therefore referred to as durable resistance. This breeding strategy involves the systematic selection of the resistant individuals from a population followed by recombination of the selected

individuals to form a new population (recurrent selection). With HR breeding strategies, it is normal to generate many progenies of good agronomic quality differing widely in their degree of disease resistance. Such a range of material provides the opportunity to match the degree of resistance to the potential risk of disease (Fullerton and Tyson, 2003). On the other hand, Vertical resistance (VR), also referred to as monogenic resistance is generally controlled by one or few major genes and provides complete control against certain races of a pathogen (Singh *et al*., 2001). It is often characterized by a hypersensitive reaction in the host. Subsequently, new pathogen races evolve that are able to attack previously resistant plants making vertical resistance a non-durable resistance (Singh *et al.*, 2001). According to Atak (2016), hybrid genotypes of *V. vinifera* crossed with *V. labrusca*. varied in resistance to fungal diseases and that the most resistant cultivars could be used as resistant donors. A major challenge however, is the reliable identification of the least susceptible individuals in the population for use in the next cycle of inter-crossing. The breeder selects the plants or lines with the lower levels of disease severity and by doing that continuously over the seasons, the level of quantitative resistance will increase fairly rapidly (Do Vale *et al*., 2001).

Samoa implemented a programme to screen and evaluate the exotic varieties of taro which included; 'Toantal", "Pwetepwet", "Pastora" and "PSB-G2". The first three varieties originated from the Federated States of Micronesia (FSM) whereas "PSB-G2" was obtained from the Philippine Seed Board (Fonoti, 2005). Genetic resistance of cultivars offers the best long-term control of taro leaf blight. However, desirable cultural characteristics and eating qualities are often lost during breeding. Current breeding efforts therefore are focused on improving yield, suckering desirable for vegetative propagation,

time to maturity, taste, and texture (Hunter *et al*, 2001). Trip report at National root crops research institute, Nigeria by Graham (2012) revealed that out of 343 abstracts presented to the symposium on International network for edible aroids (INEA) in 2012, only three were on *Colocasiae esculenta*. Out of the three, the aspects of its agronomy were very minimal.

Controlling taro leaf blight by use of host resistance and tolerance can make a major contribution towards world food production. (Wanyama and Mardell, 2006). The phenomenon of incidence, severity, resistance and susceptibility in regard to taro leaf blight disease of taro are incompletely understood particularly in Kenya. The epidemiological parameters such as rainfall, temperature and relative humidity and their contribution to taro leaf blight disease incidence and severity on Pacific - Caribbean and Kenyan taro has rarely been ascertained. The taro leaf blight pathogen is capable of releasing their spores in water and this usually increases during rainy season and high humidity reducing corm yields as a result of reduced leaf area for photosynthesis (Miyasaka *et al.,* 2007). This leads to low productivity, low quality planting materials, low level value addition and processing (Wanyama and Mardell, 2006).

1.1.5 Production of taro in Kenya

Taro production has reduced drastically in the local market with a subsequent increase in its retail price especially due to the epidemic outbreak of taro leaf blight (Jugurnauth *et al*., 2001). The growth of taro in Kenya is on a subsistence basis with very limited record of production status. It is poorly researched and its production is negatively affected by at least 10 major diseases and pests in different parts of the world (Benjaw, 2017). The impact of the blight in Kenya has led to continued loss of taro and its genetic resources.

However, the interaction effect of environment and taro leaf blight disease epidemic has hardly been investigated in different counties of Kenya (Lebot *et al.,* 2003). The study of relationship between disease progression with weather parameters would be paramount for effective disease management (Lebot *et al.,* 2008). Taro agronomy and quality are among the aspects that have pausley been studied in Kenya (Akwee *et al.*, 2015). The effect of the disease on leaf and corm production in taro needed to be investigated to establish the extent of damage caused by the disease in different counties of Kenya. More in-depth studies are required to find out the best way for breeding for taro leaf blight disease resistance.

Taro (*Colocasiae esculenta*) is one of the principal root crops that have shown great promise in generating income among rural communities in Kakamega and Nairobi counties of Kenya. Its production in Kenya has however been low as compared to the Pacific - Caribbean countries. Kenya has experienced decreasing food security as a result of smallholder farmers and improper disease control and prevention (Akwee *et al.,* 2015). The agricultural diversification by growing a variety of crops including underutilized crops is the alternative way to address food security and alleviating poverty amongst rural communities. In Kenya, the disease has been managed to some extent with a combination of chemicals. However due to leaf texture, angle of leaf, wax coating on leaf surface and coincidence of the disease incidence with high rainfall amounts in the tropics, the disease management has become a major challenge to farmers. Apart from developing resistance to fungicides, depending on chemicals alone for disease control would cause environmental pollution. The most sustainable option for managing taro leaf blight

disease is proficient use of both biocontrol and disease resistant accessions (Wanyama and Mardell, 2006).

Pathogenicity of taro leaf blight isolates from western Kenya on taro accessions from different counties of Kenya (Kakamega, Kisumu, Siaya, Mumias, Busia, Trans-Nzoia, Uasin Gishu and Nairobi) together with those from Pacific - Caribbean has pausley been established. Screening on Kenyan taro accessions to determine their level of tolerance to TLB is very crucial in improving taro production in Kenya. (Fullerton and Tyson, 2004). This study aimed to determine disease incidence, severity and index of taro leaf blight and effect of rainfall, temperature and relative humidity on the same in Kakamega county of Kenya. The need for designing solutions in combating the devastating effects of taro leaf blight disease cannot be overemphasized. This research work has sought to determine the incidence and severity of *Phytophthora colocasiae* in Pacific - Caribbean and Kenya taro accessions through conducting field trials and greenhouse pathogenicity test. The baseline information on the incidence and severity of the disease in Kenya would foster a strategic planning towards its management (Omege *et al.,* 2016).

1.2 Statement of the Problem

Production of taro in Kenya has faced many challenges, one of which is leaf blight disease caused by *Phytophthora colocasiae*. Taro leaf blight incidence, severity and disease index on Kenyan and Pacific - Caribbean taro accessions has been unknown. The incidence and severity of the pathogen has never been compared between the Kenyan and the Pacific - Caribbean taro. Pacific - Caribbean communities have had intensive and promising research towards development of taro leaf blight resistant taro accessions.

Taro leaf blight disease has been a serious problem of taro in the humid tropics where rainfall is greater than 2500 mm per annum. The effect of Rainfall, relative humidity and temperature on TLB disease of Kenyan and Pacific - Caribbean taro accessions has hardly been done in Kenya and particularly Kakamega county. Taro leaf blight spores, rainfall, temperature and humidity are the factors that closely correlate with the occurrence of this disease (Terefe *et al*., 2015).

The relationship between agronomic traits and TLB disease resistance of Kenyan and Pacific - Caribbean taro accessions as been unknown and Kenyan taro accessions have rarely been compared with the accessions from Pacific - Caribbean countries so as to determine their level of resistance to taro leaf blight. Results from such study will enable use of plants with reasonable resistance.

The problem associated with low taro production and low level of TLB resistant accessions in Kenya has not been established. Moreover, the agronomic traits of Kenyan taro have hardly been compared with the accessions from Pacific – Caribbean to enable determination of the highest yielding and TLB disease tolerant taro accessions. Although vast genetic diversity exists in well adapted taro accessions, so far not much systematic study on resistance or susceptibility level of existing taro genetic resources has been conducted in Kenya and the empirical information on resistance to TLB is not available.

1.3 Objectives

1.3.1 General Objective

Evaluation of taro leaf blight (*Phytophthora colocasiae*) disease incidence, severity, environmental effects and relationship between resistance and agronomic traits of selected taro (*Colocasiae esculenta*) accessions in Western Kenya.

1.3.2 Specific Objectives

1. To determine the incidence, severity and disease index of TLB disease on Kenyan and Pacific - Caribbean taro accessions
2. To determine the effect of Rainfall, relative humidity and temperature on TLB disease of Kenyan and Pacific - Caribbean taro accessions.
3. To establish the relationship between agronomic traits and TLB disease resistance of Kenyan and Pacific - Caribbean taro accessions.

1.3.3. Hypotheses

1. Pacific - Caribbean taro accessions record higher taro leaf blight disease incidence, severity and index than the Kenyan taro
2. Taro leaf blight disease on Pacific - Caribbean is more highly affected by rainfall, temperature and relative humidity than Kenyan taro
3. There is no relationship between agronomic traits and taro leaf blight disease resistance of Kenyan and Pacific - Caribbean taro accessions.

1.4 Justification

Resistant taro accessions had been developed in most Pacific - Caribbean countries. This was why it was important in this present study to compare the Kenyan taro accessions with those screened from Pacific - Caribbean to determine the level of TLB incidence and severity of Kenyan accessions in an effort to breed for resistance to taro leaf blight.

Weather factors such as rainfall, relative humidity and temperature play a crucial role in taro leaf blight epidemic development. For that reason, Kakamega where field experiments were conducted was well suited for the study due to its high annual rainfall and environmental condition that were conducive to epidemic of taro leaf blight. A comprehensive knowledge and understanding of epidemiological triggers of taro leaf blight in Kenya was needed for better management of the disease. The correlation between weather and disease incidence together with severity has been recognized in the effort to manage taro leaf blight disease (Ekta.*et al.,* 2017). Based on understanding the disease epidemiology, effective control and management measures of the blight could be developed and implemented.

Use of fungicides has proved expensive and non-environmentally friendly thus there was need to develop integrated management strategies such as use of resistant varieties which are natural and non-hazardous (Vishnu *et al.,* 2012). The impact of taro leaf blight on Kenyan taro, the continued loss of taro genetic resources is a driving force towards the development of sustainable strategies for the management of the disease. Research on taro leaf blight disease incidence done by Chiejina and Ugwuja (2013), showed that most parts of East Africa produced TLB susceptible taro accessions hence development of

genetically resistant accessions alongside other management measures were paramount in solving this present problem.

Host plant resistance is considered the most practical, feasible and economical method of plant disease management. It is necessary to develop an integrated disease management strategy by combining host plant resistance and fungicides as efficient components. The use of resistant taro accessions reduces proliferation of plant pathogens and for this approach to be successful it is essential to analyze the plant pathogen populations for the understanding of the epidemiology, host–pathogen co-evolution, and resistance management (Vishnu *et al.*, 2012). This will help in initiating suitable breeding programmes for the development of resistant cultivars of taro.

CHAPTER TWO

LITERATURE REVIEW

2.1 Taro Plant Biology

Taro, an herbaceous plant also known as elephant ear grows to a height of 1-2 m but survives from year to year by means of corms and cormels. It consists of a central corm lying just below the soil surface. Roots grow downwards while cormels, daughter corms and runners (stolon) grow laterally. The root system is fibrous and lies mainly in the top one metre of soil (FAO, 1999). Root formation takes place immediately after planting followed by rapid growth of the shoot. Shoot growth shows rapid decline at about six months after planting, this is followed by a reduction in active leaves, decrease in mean petiole length and decrease in total leaf area (FAO, 1999). Each leaf is made up of an erect petiole and a large lamina. The petiole is 0.5-2 m long and is flared out at its base where it attaches to the corm. The petiole is thickest at the base and thinner towards its attachment. The lamina is 20-50 cm long, oblong–ovate, with the basal lobes rounded. It is entire, glabrous and thick (Vivasane *et al.,* 2011). Taro is due for harvesting 5-12 months after planting (Benjaw, 2017).

2.2 Taro Classification

Taro belongs to the family *Araceae* within the sub-family *Colocasioideae* and the genus Colocasiae. There are several taro species, some of which are wild such as *Colocasiae affinins* (wild), *C. falax* (wild), *C. gagantea* (wild and cultivated), *C. oresbia* (wild), *C. virosa* (wild) and *colocasiae esculenta* (wild and cultivated). The wild types are more acidic, have smaller corms, long thin stolons and entirely green leaves (Jugurnauth *et al*., 2001). The cultivated species of taro are classified as *Colocasiae esculenta*, but the

species is considered to be polymorphic. They were distinguished into two botanical varieties; *Colocasiae esculenta var. esculenta* (Dasheen) and *Colocasiae esculenta var. antiquorum* (eddoes) (FAO, 2012). *Colocasiae esculenta* var. *esculenta* is characterized by the possession of a large cylindrical central corm, and very few cormels. It is agronomically referred to as the dasheen type of taro (FAO, 2012). *Colocasiae esculent* var. *antiquorum*, on the other hand, has a small globular central corm, with several relatively large cormels arising from the corm. This variety is agronomically referred to as the eddoes type of taro. Other taro species include; *Xanthosoma sagittifolium, Cyrtosperma mercusii* and *Alocasia macrorrhizos* (Brooks, 2000).

2.3 World distribution and production trends of taro

Taro world production is estimated at 11.8 million tonnes per annum (Vishnu *et al.*, 2012). It is produced globally from about 2 million hectares with average yield of 6t/ha (Singh *et al.*, 2012). Most of the global production comes from developing countries characterized by small holder production systems and relying on minimum external resource input (Singh *et al*., 2012). Taro plays a role in food security, nutrition, culture and income generation to resource-poor farmers and consumers even though it is under-studied (Sharma *et al.*, 2008).

Table 2.1: Estimated production of taro in 2009 from the 20 highest producers worldwide (FAO, 2011)

Country	Production (tonnes)	Country	Production (tonnes)
Nigeria	4 459 650	Central African Republic	113 667
China	1 692 551	Thailand	104 472
Cameroon	1 668 130	Côte d'Ivoire	90 000
Ghana	1 504 000	Gabon	70 131
Papua New Guinea	313 814	Fiji	69 863
Madagascar	239 901	Democratic Republic of Congo	65 000
Japan	182 000	Solomon Islands	48 449
Egypt	160 000	Burundi	44 502
Rwanda	136 849	Sao Tome and Principe	35 066
Philippines	120 000	Chad	32 732

According to Ayogu *et al.* (2015) and FAO (2009), Nigeria was the world's largest producer of taro, accounting for up to 4.5 million tonnes out of 9.2 million tonnes produced annually throughout the world.

Table 2.2: Taro Production in Africa in (2005-2006)

Rank (USD 1000)	Country	Production (Tones)	Production Value
1	Nigeria	554, 968	5,387000
2	Ghana	173,931	1,688,000
3	Cameroon	98,899	1,200,000
4	Madagascar	17,307	240,000
5	Egypt	13,698	151,971
6	Rwanda	11,394	110,607
7	Central Africa Republic	10,302	100,000
8	Cote d'Ivoire	7,717	93,639
9	D. R.C Congo	6,825	66,250
10	Burundi	5,988	58,125
11	Gabon	5,279	56,000
12	Liberia	3,090	30,000

Source: Http://Faostat.Fao.Org

It is cultivated extensively but at a subsistence level for local consumption in the South-East Nigeria. In the past few years, taro production drastically declined, by about 50% (Ayogu *et al.*, 2015). Japanese are the major world importer of the small-corm taro, with annual quantities averaging 20,000 tons fresh and 55,000 tons frozen. China supplies most of the imports to Japan. A part from China, the Philippines has the largest area devoted to taro in Asia proper. About 34,000 hectares of land was devoted to taro in 1996 producing about 117,000 tones (Simongo *et al* 2016). Most Pacific Islands produce large corm taro for house and domestic consumption and for export to New Zealand, Australia and the USA. In Africa, high production of taro of about seventy-four per cent (74%) comes from the west and central African countries (FAO, 2012).

Taro production system is dominated by the West Africa compared to East Africa. The FAO database (2012) indicated that West Africa is by far the largest taro producing region. From 2008 – 2012, Africa accounted for 86% of global area harvested and 74% of total taro production. The West African sub-region alone accounted for 61% of global area harvested and 50% of global production. These figures indicated a decline in the contribution of the region to global taro production in the preceding 5 years (2003 – 2007). Akwee *et al*. (2015) reported that the events of production and consumption of taro in East Africa is neither known nor the variety of taro being grown. This is partly because even in research and development, their production system is regarded as informal being managed outside convectional market. Yet, in the region, taro could contribute substantially to food and income security of many households. Onyeka (2014) reported that taro production system is regarded as an informal activity by both researchers and policy makers. This has contributed to its under-exploitation despite the

nutritional value and its potential as food and cash crop. Although the crop is contributing substantially to the food and income security of many households in East, West and Central Africa, there is inadequate if any well documented and consolidated information on its cultivation, consumption and importance to livelihoods in those regions. This necessitates research-based knowledge information to the rural farmers on efficient and proper utilization of taro crop like any other dominated cash crops in the mainstream farming.

2.4 Production trends of taro in Kenya

Taro production is decreasing in many countries due to several diseases and pests. This has made it to be replaced by sweet potatoes and cassava. There are competing demands on labour to produce crops both for food and cash. This has seen a trend towards the replacement of traditional cultivars by a smaller number bred for high yield in monoculture (Akwee *et al*., 2015). The loss of this traditional diversity may have serious repercussions. It may mean that in the face of serious pest and disease outbreaks, or a need for other traits, such as nutritional quality, ecological adaptation including climatic changes, food processing potential, pharmaceutical products, cultivars will not be available to evaluate (Tyagi *et al.*, 2003). In Kenya, the production of taro is extremely low compared to the neighboring countries like Uganda, Rwanda and Burundi which are exporters of the same.

Taro production system is lower in comparison to other root and tuber crops like cassava, sweet potato and yams. The low productivity is probably due to low quality planting materials and low level of value-addition and processing (Wanyama and Mardell, 2006). In some counties in Central Kenyan, Western and Rift valley and Nyanza regions, taro is

grown by small scale farmers near the streams or river banks since most rural population lack modern irrigation facilities for an upland taro cultivation. The agricultural diversification by growing variety of crops including underutilized crops is the alternative way to address food security and alleviating poverty amongst rural communities in Kenya (Akwee *et al*., 2015).

Some of the challenges that Kenyan farmers face include difficulty in selecting the right germplasm in the absence of an accurate assessment of their genetic constitution (Quero *et al.*, 2004). There is genetic erosion of resources of indigenous African crops including taro. Moreover, Kenyan farmers reluctantly adopt taro accessions that can withstand the ever-changing climate and the increasing biotic and abiotic plant stresses that limit maximum crop production. There is an urgent need to preserve the remaining indigenous germplasm of native food crops for future crop development and posterity. In Kenya, taro crop is perceived to be a traditional food by many communities (Onwueme, 1998).

Taro contains carbohydrates, proteins, very good essential mineral elements like potassium, calcium, phosphorous, vitamins and dietary fibres (Opara, 2001). There is need for more research on local taro production, their diseases and pests. Although taro crop is more expensive than other root crops in Kenya, its agronomical potential is low (Lee, 1999). There is limited research work and information on it in Kenya and as such minimal modern varieties have been developed. Furthermore, there is limited information concerning the diversity of species or varieties, agronomy, production and contribution to food sustainability and security (Singh *et al.*, 2012).

Taro is affected by at least 10 major diseases and pests in different parts of the world. Taro leaf blight disease is one of the major diseases of taro. It was first recorded in Guam in 1918 and later in Hawaii in 1920 (Singh *et al.,* 2012). The disease can reduce corm yield by up to 50% and leaf yield by 95% in susceptible varieties. It also deteriorates corm quality causing heavy losses during storage. If uncontrolled it causes great loss of crop genetic diversity as well as impact on personal incomes and national economies (Singh *et al.,* 2012).

2.5 Cultivation

Taro can be planted from three kinds of planting material; Tops which are the leaf stalks with little of the top of the taro root. It is the most common planting material and usually has flat base, second is the suckers which grow from sides of the taro roots or corm and usually has pointed base, third type is the runners which grow out from corms and run over the surface of the ground, they make shoots that can be used to plant taro (FAO, 1999). Taro can be grown where water is abundant or in upland situations where watering is supplied by rainfall or by supplemental irrigation. It can be grown under flooded conditions due to air spaces in its petiole which permit gaseous exchange with the atmosphere under water (Mare, 2009). For maximum yields, the water level should be controlled; so that the base of the plant is always under water. Flooded cultivation has some advantages over the dry-land cultivation in that they have higher yields and it controls weeds (FAO, 1999). On the other hand, in flooded production system taro needs a longer maturation period, investment in infrastructure and operational costs are higher, and monoculture is likely.

Like most root crops, taro does well on deep, moist or even swampy soils where the annual rainfall exceeds 250 mm per annum. Eddoes are more resistant to drought and cold than dasheen type. The crop attains maturity within six to twelve months after planting in dry-land cultivation and after twelve to fifteen months for wetland cultivation (Tumuhimbise, 2009). The crop is harvested after a decline in the height and when the leaves turn yellow. The signals are usually less distinct in flooded taro cultivation. Harvesting is usually done by hand tools, even in mechanized production systems. First the soil around the corm is loosened and then the corm is pulled up by grabbing the base of the petioles (FAO, 1999).

2.6 Significance of Taro

Taro is an important staple crop throughout the tropics and part of the traditional culture in places like Hawaii and the Samoan Archipelago. Simongo *et al* (2016) stated that taro is a very significant crop in the life and culture of the highlanders not only as one of their staple food but also indispensable part in the performance of sacred activities and rituals. In Cameroon and other west African countries, taro is a cultural food. It is sacred and honoured (Carnot *et al*., 2016).

Taro is nutritionally superior to both cassava and yam in the possession of higher protein, mineral and vitamin contents as well as easily digestible starch. The leaves are eaten cooked, and the corm is baked, boiled, fried, pounded into a paste (poi), or made into flour (Brooks, 2005). The young leaves are a nutritious spinach-like vegetable, which provides a lot of minerals, vitamins and thiamine (Onyeka, 2014). The taro leaf contains about 23% protein on a dry weight basis. It is also a rich source of calcium, phosphorus, iron, Vitamin C, thiamine, riboflavin and niacin, which are important constituents of

human diet. The fresh taro lamina has about 20% dry matter, while the fresh petiole has about 6% dry matter (Doe *et al.,* 2009). The food value of taro is as shown in Table 2.3.

Table 2.3: Proximate Composition of the Taro Corm on a Fresh Weight Basis

Component	Content
Moisture	63-85%
Carbohydrate (Mostly starch)	13-29%
Protein	1.4-3.0%
Fat	0.16-0.36%
Crude fibre	0.60-1.18%
Ash	0.60-1.3%
Vitamin C	7-9 mg/100 g
Thiamine	0.18 mg/100 g
Riboflavin	0.04mg/100g
Niacin	0.9 mg/100 g

Source*:* Onwueme, 1994

2.7 Taro leaf blight disease

Taro leaf blight disease is caused by *Phytophthora colocasiae* (Raciborski) and is one of the most important economic disease of taro because it reduces corm yield by up to 50% (Singh *et al*., 2006) and leaf yield by up to 95% in susceptible genotypes (Nelson *et al*., 2011). The blight disease affects the leaves and petioles of taro plants, resulting in extensive damage of the foliage. It belongs to the genus *Phytophthora* (Jugurnauth *et al.,* 2001). Among the pathogenic oomycetes, members of the genus *Phytophthora* are among the most devastating and attack a range of economic crop species such as pepper, tomato and soybeans (Brooks, 2005).

Taro leaf blight disease was first recorded in Samoa in 1993 but first described in Java (Mathews, 1999). Its outbreak caused farmers to diversify into other subsistence food crops (Fonoti, 2005). The *Phytophthora colocasiae* is an oomycete fungus, generally

prevalent under cloudy weather conditions with intermittent rains and temperature around 28^0C. It has limited host range. It is known to infect primarily *Colocasiae spp.* (*C. esculent, C. esculent var. globulifer, C. antiquorum*) and *Alocasia mycorrhiza* (giant taro) (Singh *et al.*, 2012). Although taro can be infected by the pathogen, the ability of the disease to become epidemic on this host is restricted by very low inoculum production. *Xanthosoma spp* and *Xanthosoma saggittifolia* are immune. Other reported hosts include *Amorphophallus campanulatus* (elephant-foot yam), *Bougainvillea spectab* (periwinkle), *Draconian polyphyllum* (guava), *Hevea brasiliensis* (rubber), *Panaxilis* (bougainvillea), *Cantharanthus roseus quinquefolius* (American ginseng), *Piper beetle* (betel), *Piper nigrum* (black pepper), *Ricinis communis* (castor bean) and *Vincarosea* (periwinkle) (Singh *et al.*, 2012).

Taro leaf blight symptoms begin with small patches on leaves, they appear as small, water-soaked spots, which increase in size and number. The presence of the fungus is also characterized by white mycelium around the wound. With the advancement of the disease, lesions enlarge and become irregular in shape (Dipa, 2017). The leaves become dark brown in colour with yellow margins (Vishnu *et al.*, 2012). A small circular speck, brown on the upper surface and water soaked below which begins on lobes and sides of the leaf where water collects. Initial spots give rise to secondary infections (Jackson, 1999). According to Bandyopadhyay *et al.* (2011), *Phytophthora colocasiae* appeared as small brown coalescing lesions with orange exudation. White sporulation was observed on the lesion surface under wet condition followed by massive leaf defoliation and death of plant. Clear yellow to red droplets ooze from the spots and develops into dark brown hard pellets as they dry. Spores may be trapped inside the pellets. Petioles are not

attacked but later collapse as the leaf blade is destroyed, collapses and dies (Vishnu *et al.*, 2012).

The fungus also causes post-harvest corm rot only discovered when cut open (Jackson, 1999). *Phytophthora colocasiae* is characterized by the production of chlamydospores in the isolates, ovoid, ellipsoid, semi-papillate sporangia that are caduceus and with medium pedicel (Brooks, 2005). Brooks (2005) further reported that circular and regular spots occur on the margins of the leaf which regularly increased in diameter. Further investigation by Brooks (2005) revealed yellow and red liquid drops in the middle of the spot in the morning but when dry, the liquid became solid and brown in colour. White ring of sporangia around the edge of lesions also depicted taro leaf blight symptoms. Later the center of the lesion become papery and fall out producing 'shot hole' appearance. In Irian, Jaya and Indonesia, Paiki (1996) reported taro leaf blight disease symptoms as purple brown spots on the upper part of the leaf which appeared wet on the lower side.

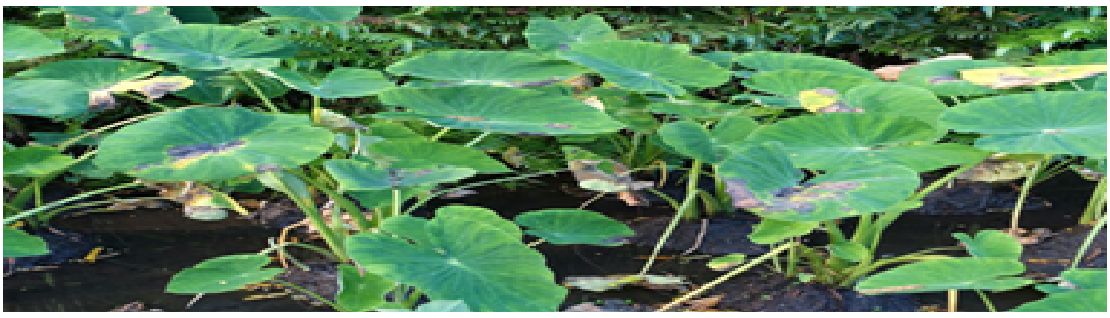


Plate 2.1: *Colocasiae esculenta* showing TLB disease infestation**.**

The progress of taro leaf blight disease is measured in terms of the number of lesions, the amount of diseased tissue, or number of diseased plants. Plants can individually be evaluated for disease scoring by observing and recording the percentage leaf infection .

According to Chothani *et al*. (2017), development of late blight disease of tomato was initially slow but, later increased with time. Table 2.4 below shows disease progression in plants.

Table 2.4: Stages of lesion development

Stage	**Observation time**	**Symptoms**
1(early stage of infection)	2 days after inoculation	Appearance of water-soaked lesions on leaves
2 (intermediate stage of infection)	7-8 days after inoculation	Yellowing of leaves
3 (late stage of infection)	7-10 days after inoculation	Increase in intensity of blackening and decay of leaves
4 (very late stage of infection)	10-20 days after inoculation	Destruction of entire leaf, total yellowing of all leaves, wilting and death of plant.

Misra *et al*., 2008

The mechanism of taro leaf blight disease infection is not yet fully understood (Hiraida, 2016). The pathogen can cause biochemical changes in taro. Misra (2008) noted that taro has mechanisms to eliminate pathogens by increasing phenolic levels which accelerates recovery during inflammation. Several methods to test the pathogenicity of taro leaf blight on taro have been used. Bandyopadhyay *et al*. (2011) used detached leaves of taro of one-month old plants. These were inoculated with two isolates of zoospore suspension after which they were incubated in moist chambers at 22^0C. Twenty-four hours after inoculation, water – soaked lesions, showing typical leaf blight symptoms appeared on the leaves and the detached leaves completely got rotten within 48 hours. Uninoculated detached leaves were not affected.

Padmaja (2013), reported a pathogenicity test with 30 leaf discs removed from three-month-old plants and inoculated with 10 µl of a suspension of $3x10^5$zoospore per ml. The discs were later incubated in the dark at 27^0C for five days. The inoculated discs developed taro leaf blight disease symptoms while the control produced no symptom. Nelson *et al.* (2011) further reported pathogenicity test done on selected young taro plants of approximately 30 cm height grown in green house. The plants were inoculated with zoospore suspension of *Phytophthora colocasiae.* They were covered with plastic bag and incubated at room temperature for 2-3 days. Water soaked lesions were formed on all inoculated sites just after three days.

2.7. Fungal disease incidence and severity

Taro leaf blight disease causes corms to rot both in the field and in storage leading to heavy storage losses (Mbong *et al*., 2015). Worse still, taro crop has very narrow genetic diversity suggesting that with the severity of the blight incidence if positive steps are not taken, the crop might face extinction with the rural-poor's situation worsening (Bassey *et al*, 2016). The phenomenon of incidence and severity, in regard to taro leaf blight disease of taro are not completely understood in Kenya. According to Miyasaka *et al*. (2012) taro cultivars differed significantly in severity of TLB and in severity of corm rots. George (2016) in his ICAR (Indian Council of Agricultural Research)-CTCRI (Central Tuber Crops Research Institute) Annual Report 2015-16 revealed that, out of the 1271 accessions screened, 288 showed high incidence of cassava mosaic disease, while 513 accessions were found to be free of any symptoms in the early stages of plant growth. Within an infected area, the first lesions were due to infection from adjacent plants (Ayogu *et al*., 2015). It has been revealed that while some plants become severely

diseased with continuous night time sporulation, others immediately adjacent may have little or no disease (Fullerton and Tyson, 2003). According to Tarla *et al*. (2014) taro blight severity increased rapidly immediately after the appearance of the first symptoms and then decreased eventually.

Generally, older leaves or younger leaves lower in the canopy were most severely affected because of a number of factors which included: a constant supply of inoculum deposited by runoff water or dew from above; a more conducive microclimate for the oomycete lower in the canopy; and also, because the less waxy cuticles of older leaves tolerate better adhesion of spore-carrying water drops (Fullerton and Tyson, 2003). Tyson and Fullerton (2015) further indicated in their research outcome that taro leaf discs taken from the youngest fully expanded leaves produced best results for discriminating between TLB disease incidence and severity among different accessions of taro. Furthermore, lesion development was generally greater on leaf discs taken from second or third leaves.
The importance of soil borne chlamydospores in the epidemiology of the disease has not been established but they could allow survival of the pathogen between crops (Fullerton and Tyson, 2003). In situations where, vegetative material dies off because of drought or cold conditions, the pathogen most likely survives between seasons as vegetative mycelium in the infected corms. While most of these die within the first few days, a small proportion develops thick walls, forming chlamydospores that are able to survive in soil for up to three months (Ayogu *et al*., 2015). In wetland taro production, the movement of paddy water carries these sporangia and zoospores among plants and between fields. Because growers propagate taro vegetatively, they often unknowingly transport taro leaf blight pathogen between fields and over long distances by the movement of infected

planting material (Nelson *et al*., 2011). Adinde *et al*. (2016) reported a significant difference in taro leaf blight disease incidence among six villages in Nigeria. The variation was attributed to varied agronomic practices such as plant spacing, farm sanitation and use of fungicide across the villages. Close spacing is thought to contribute to increased chances of disease dissemination. Source of planting material and handling could also be responsible for the significant differences in TLB infestation (Brooks, 2005).

Onyeka (2014) evaluated 70 farmer's field across eight state representatives of taro growing agro-ecologies of Nigeria and reported TLB incidence range of 65% to 90% and a generally high disease severity within fields. Chiejina and Ugwuja (2013) similarly attributed significant difference in incidence of taro leaf blight disease in some sites within a location in Nsukka area in Nigeria to differences in agronomic practices observed by each individual farmer before, during and after planting. Further investigation by Chiejina and Ugwuja (2013) revealed that wide spacing of plants and avoiding to plant near an infected plot reduced disease incidence and severity (Tyson and Fullerton, 2015). Time of planting also affected incidence and severity of taro leaf blight. It was revealed that farmers who planted their crops long before the disease incidence period had less disease infection on their crops than those who planted at the peak of the disease (Chiejina and Ugwuja, 2013). Asraku (2010) reported that transportation and the use of diseased planting materials represent a major means of transmitting TLB disease. Previous research showed that the rate of disease development observed on taro in the field differed with leaf age (Tyson and Fullerton, 2015). Brooks (2008) found out that older leaves were more susceptible to TLB than young leaves and suggested the need to

standardize the age of the leaves selected for leaf disc assays. Adinde *et al*. (2016) reported that disease severity appeared to increase with increase in disease incidence across different locations.

2.8. Environmental influence on fungal disease incidence and severity

Environment is one of the major factors that influence the process of an epidemic, having the capacity to induce or retard it (Chiejina and Ugwuja, 2013). The epidemiological parameters such as rainfall, temperature and relative humidity and their contribution to taro leaf blight disease incidence and severity has been unknown in Kenya. Rainfall, humidity and temperature are the key factors controlling the taro leaf blight disease cycle and epidemiology. Favorable temperatures and regular periods of leaf wetness, particularly in the humid tropics promote TLB epidemics by favouring pathogen dispersal, infection, and disease development (Ayogu *et al.,* 2015). Outbreaks of the disease in new areas distant from known centers of infection probably result from the introduction of infected planting material.

The study of relationship between disease progressions with weather parameters is of paramount importance for effective disease management (Shakywar *et al*., 2013). Disease development under natural conditions was found to be influenced by environmental factors (Chothani *et al*., 2017). Climate influences the pathogen and the host environment separately and in interaction throughout the period of crop growth from infection to host death (Benzohra *et al.,* 2018). Brooke (2005) revealed that apart from other environmental factors, moisture, sunshine and wind also influence fungal disease incidence and severity and that epidemics generally flourish when night temperatures are

in the range of 17–20 °C. The cool temperatures stimulate the release of infective zoospores, promoting multiple infections (Fullerton and Tyson, 2003).

Taro leaves have waxy hydrophobic leaf cuticles, which assist the wash-off of sporangia and zoospores from the leaves into the soil, or their splash onto other leaves and petioles, particularly the lower older ones. However, in the absence of regular rainfall, conditions favourable to re-infection occur on most nights ensuring regular cycling and survival on infected plants thus making it endemic (Ayogu *et al*., 2015).

According to Cabi (2016), TLB pathogen grows rapidly in areas with high humidity and heavy rainfall. Rai *et al*. (2002) reported that moisture levels were positively correlated with the development of number and size of leaf blight of maize lesions in both susceptible and resistant varieties of maize. Similarly, Adipala *et a1*. (1993) and Ramathani *et al.* (2009) noted a prevalence of Northern leaf blight in highlands and wetter areas of Kenya and Uganda. Temperature govern the rate of reproduction of fungi and the physiological conditions of the host. Temperature highly affects the growth and aggressiveness of pathogens and expression of disease symptoms in the plants (Benzohra *et al*., 2018).

The warm, humid days and cool, wet nights of the tropics are ideal for reproduction and spread of *P. colocasiae*. During rainy weather, leaves of taro that normally live for 30-40 days may be destroyed in less than 20 days. Therefore, a healthy plant that carries 5-7 functional leaves may have only 2-3 leaves when infected. This reduces net photosynthesis, resulting in a reduced corm yield. Plants growing in extremely hot and humid environments show high susceptibility to blight diseases than those growing under

normal conditions (Campbell and Benson, 1994). These important aspects have received scanty investigation about taro leaf blight disease in western Kenya. Benzohra *et al*. (2018) in his study, indicated differences in effect of temperature levels on mycelial growth and sporulation of *Ascochyta fabae.* It was revealed that most mycelial growth, sporulation and pycnidial formation were first observed at 22°C, but progressively the good morphological and cultural characters declined below and above 22°C, with absence of sporulation at 26 and 30°C. According to Chothani *et al*. (2017) increase in early blight disease severity index in tomato was comparatively higher in the temperature range of 35.2 – 38.3^{0}C (maximum), 17.1–24.4^{0}C (minimum) and 26.80–31.35 ^{0}C average temperature. The disease severity index was also high at 30-58% evening relative humidity and 1.2–2.2 wind speed. The above conditions were most congenial for disease development. Sahu *et al*. (2014) reported that minimum temperature had a negative highly significant correlation with early blight disease of tomato. Pefoura *et al*. (2007) showed that radial growth of *Trachysphaera fructigena* decreased to minimum at higher temperatures, which could be considered as lethal for radial growth of the pathogen. Sehajpal and Singh (2014) noted that temperature of 20±1°C was the best for mycelial growth of *Botrytis gladiolorum* and the least was observed at 30±1°C. No conidial and sclerotial production was recorded at lower and extreme temperatures. The rate of mycelial growth of *Sphaeropsis pyriputrescens* increased as temperature increased up to 20°C and then decreased rapidly as temperature increased. Sehajpal and Singh (2014) also reported that temperatures ranging from 25-28ºC and 65% humidity during the day and 20-22 ºC and 100% humidity during the night favoured the fungus. TLB spores were

produced mainly during rainy nights with heavy dew in the morning facilitating the scattering of the spores allowing germination and infection. (Matthews, 1999).

Spores of the fungus are also moved in wind driven rain and dew to new areas of same leaf, nearby plants or new plantings. Spores are delicate and on sunny day shrivel and die within 2-3 hours as humidity falls (Jackson, 1999). Free water collecting on older leaves, as well as high temperature and high humidity are conducive to onset, spread of the disease and germination of the spores. The disease can spread from plant to plant by wind and splashing rain. Spores survive in planting material for three or more weeks (Matthews, 1999). Infected planting materials is a means of dispersal of the disease over long distances and from season to another. Correlation coefficient study by Chothani *et al*. (2017) on early blight disease of tomato revealed that, maximum temperature was significant, whereas morning relative humidity and evening relative humidity were highly significant with negative effect on development of early blight. Increase in temperature by 1^0C increased the development of early blight by 3.61% (Chothani *et al*., 2017).

Asexual reproduction by taro leaf blight, occurred mainly during wet weather. Sporangia were formed at the end of short, un-branched or sparingly branched sporangiophores at the edge of lesions. They were ovoid to ellipsoid with a distinct narrow apical plug, average 40-50 x 23 µm. Sporangia were separated from sporangiophores by rain, leaving a stalk 3-10 µm in length attached to their base. During wet weather, sporangia germinate on the upper surface of leaves (Brooks, 2005).

It is well known that temperature influences pathogen development as well as expression of host resistance. The effect of temperature on aggressiveness component had been

established for many pathogen species and presents an optimum for spore germination, lesion development and sporulation. However, the response to temperature differed among individuals. Spore production rate of two leaf rust isolates (*P. triticina*) were found to be identical at 2-18 °C but different at 10- 30 °C (Tsopmbeng *et al.*, 2014). Growth was found to be faster between 27-30 °C (Scot *et al*., 2011).

Minimum and maximum temperatures for growth were reported to be 10 and 35 °C respectively (Brooks, 2005; Scot *et al.,* 2011). *In-vitro*, the optimum temperature for growth of taro leaf blight pathogen was approximately 25°C (Brooks, 2005, Fullerton and Tyson, 2004). According to Tsopmbeng *et al.* (2014) the growth of taro leaf blight disease increased with temperature and the maximum growth was obtained at 27 and 30 °C independently of the pH value. Taro leaf blight pathogen was found to be strongly influenced by temperature both in laboratory and field observations (Tyson and Fullerton, 2015).

When temperatures were near 20°C and humidity was high (90-100%), most germination was indirect, producing zoospores that swim for a few minutes, encyst and form germ tube. This process could occur in two hours or less. Sporangia germinated directly between 20-28°C. The incubation period of taro leaf blight pathogen was reported to be 2-4 days at optimal temperatures of 24-27°C (Brooks, 2005). Tsopmbeng *et al.*, (2014) on effect of different pH and temperature levels on *in-vitro* growth and sporulation of taro leaf blight, revealed that a pH of 7 and a temperature of 27 °C were the optimum conditions for the pathogen growth while those of sporulation were 6 and 18 °C respectively. In the leaf disc assays performed by Tyson and Fullerton (2015), temperature had a statistically significant effect on lesion size and percent successful

infections. At 15°C the rate of infection of leaf discs was very low. The rate of development of lesions on leaf discs was however greatest at 25 and 30°C, but suppressed at 35°C. Colony growth of the pathogen was also completely inhibited at 35°C (Tyson and Fullerton, 2015). Taro leaf blight disease spread faster among leaves of the same plant and between plant by rain splash and wind-blown rain. It is highly adapted to wet humid environment and favoured by flooding conditions in the field (Shakywar *et al*., 2013). Data obtained by Shakywar *et al*. (2013) indicated that weather parameters viz., average relative humidity, cumulative rainfall and sunshine hours were positive but significantly correlated with taro leaf blight disease incidence and severity.

Other factors involved in plant disease spread include; susceptible host, virulent pathogen, frequency of each element over time and duration and frequency of favourable environment. The host factors that affect epidemic development include; levels of genetic resistance or susceptibility of the host. The pathogen factor that affect epidemic include; levels of virulence, quantity of inoculum near host, type of reproduction of the pathogen, ecology of the pathogen and mode of spread of the pathogen. According to Agrios (2005) the process of epidemic is influenced by environment (Whehan, 1992). Research has shown that absence of certain important nutrients such as calcium and phosphorus increase taro leaf blight disease infection. This needs to be investigated further (Askaru, 2010). Human activity also plays a role in TLB disease epidemics and they include; site selection and preparation, selection of propagative materials, cultural practices, disease control measures and introduction of new pathogens.

2.9. Resistance of plants to fungal diseases

Limited published research has been done on pathogenicity of TLB pathogen isolates of Western Kenya and Kenya as a whole. There is a major constraint for existing breeding programs, particularly with reference to resistance to TLB caused by *Phytophthora colocasiae* (Lebot *et al.,* 2008). Long term breeding strategy for taro, based on recurrent selection of wide genetic base composed of carefully selected parental genotypes from diverse geographical origin could be used to maximize mutagenic resistance in progenies (Lebot *et al.,* 2008).

Controlling plant diseases by use of host resistance and tolerance can make a major contribution towards world food production. It has proven to be an extremely cost-effective and environmentally acceptable approach (Iosefa *et al.,* 2010). This breeding strategy involves the systematic selection of the resistant individuals from a population followed by recombination of the selected individuals to form a new population (recurrent selection). The main advantage of this strategy is its ability to accumulate minor resistance genes, which individually would confer minimal resistance (Singh *et al.,* 2010). But together they are likely to be additive and provide durable disease resistance. Several studies have been carried out to determine the resistance level of taro to various diseases and to identify resistant accessions for use in breeding studies. However, there has been difficulty in choosing the right parental genotypes. This has made it difficult to discriminate between susceptible and resistant taro cultivars (Quero *et al.,* 2004). More research is required in order to breed for resistance to taro leaf blight disease. Characteristic defense response in taro like many other host species likely includes systemic events through signaling and possibly constitutive and hydrolytic enzymes,

enzyme inhibitors and phytoalexins (Ayogu *et al*., 2015). However, the phenomenon of resistance, tolerance and susceptibility using epidemiological parameters are incompletely understood.

Atak (2016) investigated the resistance level of some grape species to different strains of *Uncinula necator*, the causal agent of powdery mildew and realized differences in resistance among different grapes (*Vitis vinifera*) cultivars. Miyasaka *et al*. (2012) in a study found out that mechanism of resistance found in cultivars resistant to taro leaf blight was effective against other fungal pathogens. Gaforio *et al.* (2015) realized generally lower resistance of *Vitis vinifera* cultivars from humid regions of Spain to downy mildew than those from other regions. Results of field evaluations by Tyson and Fullerton, (2015) revealed that, individual taro accessions responded quite differently in successive tests in terms of resistance to taro leaf blight. It was suggested that in some plant-pathogen interactions such as Pythium damping off, downy mildews, *Phytophthora* diseases and viral infections, the hosts which had attained reasonable maturity and vigour before the outbreak of an infection, would show more resistance to the infection than those in their juvenile stages (Chiejina and Ugwuja, 2013).

Prajongja *et al.* (2014) reported that climate of Thailand being very favourable for fungal diseases, even in hybrid grape cultivars some susceptible individuals were discovered. However, during hot, dry conditions, lesions developed slowly and in some, the pathogen died out and the lesions failed to expand further. This suggested a great influence of environmental factors on fungal diseases. The extreme effect of environmental conditions on symptom development makes field assessments of resistance unreliable (Tyson and Fullerton, 2015). In a study by Atak (2016), the resistance levels of some cultivars

belonging to different species were determined against two fungal diseases, namely downy and powdery mildew, under climatic conditions in Yalova, South Africa and were found to vary indicating that different cultivars responded differently to taro leaf blight infection. Miyasaka *et al*. (2012) in his study revealed that most traditional Hawaian taro cultivars did not have high natural resistance to taro leaf blight. Planting heavily susceptible taro could also multiply the number of spores in the field increasing taro leaf blight severity and decreasing the yield of the resistant cultivars (Yalu *et al.,* 2009).

The cultivars with higher disease resistance are intended for use as parents in future breeding programmes because in recent years, the protection of human health and safer food production have emerged as very important issues. Using intensive spray applications to control fungal diseases in grape production is not recommended, especially for fresh consumptions. Singh *et al*. (2012) reported ineffective management of TLB in the Pacific through chemical and cultural measures and suggested the use of disease resistance cultivars for sustainable management of the disease. Recent breeding programmes in Hawaii have crossed TLB resistant cultivars from other areas of the world with commercial cultivars in Hawaii. According to the 2015-2016 ICAR-CTCRI Annual Report by George, (2016), of the nineteen taro accessions screened artificially, six (IC087153, IC012601, IC012294, IC310104, TCR-267 and TCR-326) showed moderate resistance to taro leaf blight. The knowledge about taro leaf blight resistance is still limited on Kenyan taro accessions. Repeated comparisons with the best cultivar are a useful statistical procedure to identify promising accessions among others for conventional breeding with commercial parents to improve disease resistance and yields.

2.10. Yield and Quality of taro

Taro agronomy and quality are important aspects that have pausly been studied in Kenya. The study on its agronomic requirements are needed to improve its productivity and storage. The crop is underutilized, with very limited information on its production status, protection, agronomy, social-economic values and post-harvest management (Benjaw, 2017). Of all the different kinds of cocoyam, taro (*Colocasia esculenta*) stands out among others due to high corm and cormel yields, early maturity, high palatability and ease of cooking (Bassey *et al*., 2016). In composition, the main economic parts of the taro plant are the corms and cormels, as well as the leaves (Ayogu, 2015). The fresh corm has about two-thirds water and 13-29% carbohydrate, which is predominantly starch. Mukherjee *et al*. (2016) reported relationships among the yield attributing characters of taro and observed mean weight of corme1s, number of cormels per plant and leaf area index (LAI) to be positively and significantly correlated with yield. Taro blight is a yield-limiting constraint in taro production (Tarla, *et al*., 2014). In addition, the use of poor yielding cultivars and decreased cropping areas (Udoh *et al*., 2010), as well as cocoyam leaf and root rot blight complex (Mbanaso *et al*., 2008) have affected both growth and yield of the crop in the humid topics (Udoh *et al*., 2010). Highly susceptible cultivars appeared to produce smaller leaves on shorter petioles. The impact of taro leaf blight on production of taro in Kenya need to be ascertained in order to check on to the continued loss of taro and its genetic resources (Brooks, 2005).

Taro crop has been ignored as a legitimate crop for research which is managed outside conventional agricultural production, marketing and economic channels (Mare, 2009). Such knowledge gaps limit the understanding of accession's sensitivity to pathogen

infection in terms of agronomic performance warranting further investigation (Whehan, 1992). Inadequate literature has been generated from Kakamega county of Kenya to describe the yield and quality of taro they produce particularly in relation to weather and taro leaf blight infection. In recent years, several farmlands have been devastated by leaf blight resulting in the disappearance of the crop from most world markets. It has also become inaccessible to rural poor in particular. Besides, the livelihood of many rural farmers particularly in Kenya who depend on it for income either as occupation or for commerce purpose has been greatly affected. The disease can cause yield losses of 30-50%, and results in lowering of the quality of harvest (Tadele, 2009). In many Pacific countries, Guarino (2012) reported taro yield losses of up to 90 % in Cameroon. In some parts of the North West and South West Regions of Cameroon, the disease damaged the farms completely leading to a stop of the cultivation since then. Tarla *et al.* (2014) reported yield losses of 100 % of tomato fruits due to late blight caused by *P. infestans*. Fontem and Schippers (2004) reported a total damage of huckleberry nurseries due to late blight caused by *P. infestans.* Plants with the disease have fewer leaves than normal, healthy leaves last up to 40 days and those infected have 3-4 leaves instead of 6-7. The yield may be 30-50% lower. It also reduces the size of planting material (Jackson, 1999).

Miyasaka *et al*. (2012) in his study revealed that mean dry weight of cultivars were correlated negatively with severity of corm rot and that greater TLB resistance for taro accessions was associated positively with greater dry weight of corm. This meant that taro leaf blight causes corm rot in addition to leaf blight. It was also reported that increasing levels of apparent resistance to TLB and to corm rots in cultivars were associated with increased dry weight corm yields. George (2016) in his ICAR-CTCRI

Annual Report 2015-16 revealed that the corm weight of elephant foot taro ranged from 0.2 to 100 g. Preliminary evaluation trial in tannia taro with seven accessions showed that the average cormel yield/plant ranged from 14.40 g to 85.80 g. Further study by Miyasaka *et al*. (2012), revealed that low-rainfall periods resulted in poor survival of vegetative propagules and poor corm quality due to loss of starch. Mukherjee *et al*. (2016) reported that leaf number was highly influenced by environment and dry matter percentage of taro corms were least affected by the environment. The future is uncertain, as it is not clear if alternative food crops can fill the gap left by insufficient production of taro. Maize production has never met the demand and plantains are usually very expensive. Taro leaf blight disease has a potential to create a devastating effect such as reduction in food and household incomes, increased poverty and even starvation (Singh *et al.*, 2012).

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Area

Experiments were established at two locations: Masinde Muliro University of Science and Technology in Kakamega county and Maseno University in Kisumu county. Kakamega town is located within the upper highland agro-ecological zone. Its climate is classified as tropical with a great deal of rainfall even in the driest month. It belongs to group Af (Tropical rainforest) by Koppen- Geiger system of climatic classification (Wambua, 2004). The average temperature is 20.4^0C. The variation in temperature throughout the year is 2.0^0 C. The lowest average temperature usually occurs in July when it is approximately 19.3^0C. The annual rainfall is approximately 1971 mm. Between the driest and the wettest months, the difference in precipitation is 212 mm (Kakamega –data.org). Kakamega county of Kenya is known to receive high amounts of rainfall throughout the year which is favorable for the fungal pathogen.

MMUST University lies between longitudes of $34^032'0''$E - $34^057'0''$W and latitudes of $0^007'30''$N - $0^010'15''$S of the equator at an altitude of about 2000 m above sea level (Wambua, 2004). The trials were conducted from January 2013 to November 2013, and September 2013 to April 2014 at MMUST university garden and Kakamega Mlimani estate garden, respectively in the two respective cropping seasons. Maseno University lies within Latitude: 0° 00' 60.00" N and Longitude: 34° 35' 59.99" E and 1503 metres above sea level. Rainfall provided all the water for plant growth except for the first one month that water was provided approximately 2 litres per plant in the morning and

evening. Weeding was done twice a month by uprooting and use of a hoe. The soils of Kakamega and Maseno farms showed some similarities being generally loamy sandy, slightly acidic with relatively deep top soil. No chemical was used throughout the study. Harvesting occurred ten months after planting for the first experiment, and for the second and third it was after seven months. A completely randomized design was used in the two fields to avoid biasness because there was no control experiment. This ensured that the extraneous factors affected the treatment conditions equally.

The laboratory and greenhouse experiments were conducted at Maseno University due to the availability of materials and equipments. *Phytophthora colocasiae* isolates were obtained from University of Eldoret laboratory.

3.2. Determination of taro leaf blight disease incidence, severity and disease index on Pacific - Caribbean and Kenyan taro accessions

A series of studies were done on taro leaf blight disease incidence, severity and disease index on Kenya and Pacific - Caribbean taro which included two field studies and one greenhouse study. The first field study was from January - November 2013, second field study from December 2013 - April 2014 and finally the greenhouse experiment was conducted from September 2015 – January 2016.

3.2.1 Determination of taro leaf blight disease incidence on Pacific-Caribbean and Kenyan taro accessions under MMUST garden, Milimani estate garden and greenhouse

3.2.1.1 MMUST Field study

The Field study – 1 was conducted on Pacific - Caribbean taro accessions from January - November 2013. Three hundred Pacific - Caribbean taro tubers imported from the Pacific

community (Hawaii, Papua New Guinea, Samoa, Japan, Indonesia, Malaysia and Thailand) through the Secretariat of the Pacific Community (SPC) based in Suva, Fiji Islands in conformity to KEPHIS requirements were used. All the quarantine measures were undertaken to ensure safety of all crops before they were airlifted and imported to Kenya. The Pacific - Caribbean taro was preferred since they had already been improved for resistance to TLB.

3.2.1.1.1 Preparation of imported taro accessions for planting

Three hundred plants obtained from 25 different accessions used in MMUST field study included the following; (BL/HW/08, BL/HW/26, BL/HW/37, BL/PNG/10, BL/SM/111, BL/SM/116, BL/SM/120, BL/SM/128, BL/SM/132, BL/SM/143, BL/SM/149, BL/SM/151, BL/SM/152, BL/SM/158, BL/SM/43, BL/SM/80, BL/SM/92, CA/JP/03, CE/IND/01, CE/IND/06, CE/MAL/12, CE/MAL/14, CE/THA/07, CE/THA/09, CE/THA/24). The coding was used to represent the different regions from which they were obtained i.e. BL/HW was from Hawaii, BL/SM from Samoa, BL/PNG from Papua New Guinea, CA/JP from Japan, CE/IND from Indonesia, CE/MAL from Malacia and CE/THA from Thailand. Each of the accessions were twelve in number. The plants were placed in a greenhouse at MMUST University for two weeks to stabilize before planting. In the greenhouse they were watered every day with approximately 1 liter of water per plant.

Experimental area measuring 3500 m^2 (70 m by 50 m) not previously cultivated was cleared using a machete, hand ploughed and harrowed twice using jembes and hoes before planting. Soil was made into raised beds in preparation for planting. Three hundred taro suckers were planted in 60 cm deep holes and each sucker firmly placed

using hands according to the methods of Brooks (2011).The spacing was 0.5 m between plants and 1.0 m between rows. Watering was done in the morning and evening for one month approximately one liter per plant using a sprinkler. The plants were arranged in a completely randomized design (CRD) since there were no control experiment in the field The design also ensured that each individual plant had the same chance of becoming a participant in the study.

3.2.1.1.2 Determination of TLB disease incidence for the Pacific - Caribbean taro accessions under MMUST garden.

Total number of suckers infected, total number of leaves infected and the disease incidence were recorded at monthly intervals from the appearance of the first symptom (mainly at 3 months) till the crop was harvested. New partially furled leaves and old leaves touching the ground were not evaluated. Incidence of taro leaf blight was recorded monthly. Taro leaf blight disease symptoms which include; yellow and red liquid drops in the middle of the lesion with dry solid, brown particles on leaf lamina often with white ring of sporangia around the edge of lesions, which later become papery and may fall out producing 'shot hole' appearance were carefully observed to confirm the disease. Computation of disease incidence was determined according to the formula of Opara *et al*. (2012) as

$$\text{Percentage (\%) disease incidence} = \frac{\text{Number of leaves affected per accession}}{\text{Total number of leaves sampled per accession}} \times 100$$

The accessions were evaluated on a 0 - 100% incidence of taro leaf blight.

3.2.1.2 Determination of TLB disease incidence for the Kenyan and sampled Pacific – Caribbean taro accessions under Milimani estate garden

The Pacific - Caribbean and Kenyan taro accessions were used from October 2013 - April 2014, Kenyan taro accessions (whole plant) were collected from farmer's plots in seven regions in Kenya where taro was frequently grown; Central Kenya in Karole, Kisumu Dungan beach along Lake Victoria, Siaya along Dominion farm, Kakamega-Milimani, Mumias near sugar company, Kitale- Malbasa, Busia, Bundala area, Eldoret, Lange's area. Some Pacific-Caribbean taro accessions from the first experiment were also sampled, considering the least and the most susceptible accessions. At least 3 samples were collected per region. A total of twenty six taro accessions were obtained. They included; KNY/KIS/81, KNY/BSA/41, KNY/ELD/75, BL/HW/8 CE/JP/3, BL/SM/120, KMM/MM1/75, KNY/KIS/20, KNY/CTR/33, BL/HW/26, BL/HW/80, KMM/MM2/76, KNY/KIS/21, KNY/KTL/61, CE/IND/1, BL/SM/28, KNY/SYA/50, KNY/KIS/22, KNY/SYA/51, CE/THA/7, CE/IND/6, BL/SM/48, KNY/KAK/16, CE/THA/24, CE/MAL/14, BL/SM/111. All the accessions were labelled according to region of origin, tied together with a rope and transported by road to the experimental site which was established within Mlimani estate garden. The area not previously cultivated with taro measured 2,240 m^2(70m by 50m), cleared, hand ploughed and harrowed twice and soil made into raised beds was used in a completely randomized design. Similar procedure as described in 3.2.1.1.2 was used.

3.2.1.3 Determination of disease incidence for the Kenyan and sampled Pacific-Caribbean accessions under greenhouse study

The experiment comprising laboratory and greenhouse was conducted from September 2015 - January 2016.

3.2.1.3.1 Laboratory media preparation

Preparation of media, sterilization, isolation and maintenance of fungal cultures were done according to the methods of Nath *et al.* (2014). Petri dishes were placed in sterilization tins and sterilized in hot air oven at 160^0C for 90 minutes. Potato Dextrose Agar (PDA) media and water used in the study were sterilized at a temperature of 121.6 ^{0}C for 20 minutes in an autoclave as described by Nath *et al*. (2014). The isolates were then sub-cultured to enhance multiplication. The conditions within the greenhouse were controlled majorly in terms of water availability as two litres of water was provided to each plant every two days. Temperature ranged from 22-27^{0}C. The greenhouse activities were as outlined in section 3.2.1.3.5 to 3.2.1.3.7 below.

3.2.1.3.1.1 Sterilization and plating of medium

Work surfaces were sterilized by ethyl alcohol and sodium hypochlorite. Scalpel blades and inoculation loops were sterilized over flame. Plating of medium was done by melting the sterilized medium and distributing in 9 cm diameter petri plates. This was done aseptically at the rate of 20 ml per plate in the laminar flow-hood chamber and allowed to solidify. Taro leaf blight pathogen isolates previously obtained from University of Eldoret and sub-cultured within Maseno University laboratory onto water agar till pure cultures were obtained were aseptically placed in the middle of each Petri dish using inoculation loops. They were then covered with cover slips. The cultures were incubated

for 4 days maintaining them at room temperature in a drawer within the laboratory according to the methods of Shrestha *et al*. (2012). The remaining isolates were then stored at room temperature in 2ml tubes containing 3-4 plugs of mycelium, 3- and 1-ml water for future use.

3.2.1.3.1.2 Pathogenic nature of isolates

The pathogenic nature of the isolates was determined by proving Koch's postulates through pathogenicity test according to the methods of Adomako *et al*. (2016), where disease free taro leaves were placed on sterilized filter paper soaked with distilled water and placed in petri dishes. The plates were inoculated with 2 ml of sporangial suspension containing *Phytophthora colocasiae* which had earlier been sub-cultured in Maseno laboratory. The leaves were then covered with plastic bags and left for two days at room temperature. After two days, the inoculated sites showed water soaking lesions at the beginning but later turned brown according to the observations of Lin and Ko (2008).

3.2.1.3.2 Soil sterilization for greenhouse use

Black sandy loamy soil from Maseno Botanical garden was sifted to remove stones, plastic materials and plant debris. The soil was steam sterilized in a barrel at 100^0C for two hours. The sterilized soil was left in the barrel overnight to cool before use according to the methods of Askaru (2010). The taro plants from the previous experiment two of Pacific - Caribbean and Kenyan taro were sampled considering the least and the most susceptible accessions as obtained from the previous result. They included; KNY/SYA/51, KNY/KAK/16, CA/JP/O3, CE/IND/01 CE/THA/07, KNY/BSA/41, BL/HW/26, BL/SM/80, KNY/SYA/50, KNY/KTL/61, BL/SM/92, KNY/MU/75, KNY/CNT/33, BL/HW/08, CE/THA/24, KNY/KSM/81. KNY/SYA/50.

Ten-liter plastic buckets filled with the sterilized top soil and the samples placed at 1m x 1m using a complete randomized design for the treatments, however, the control experiment was blocked to prevent contamination. The experiment had three replications. The crops were watered with 2 litres per plant in the morning, every two days using clean water and administered at the base of the crop. The tubers were covered with the soil and firmed down according to the methods of Manza *et al*. (2008).

3.2.1.3.2.1 Inoculum preparation

Two *Phytophthora colocasiae* pathogen treatments coded 21R1 and 3R1 isolates were selected for greenhouse inoculation as they had distinctively pure cultures of the pathogen. Distilled water was used on the leaves as control. The inoculation was done by using two most virulent isolates of *Phytophthora colocasiae* (showing very fast growth) in the culture medium. Mycelia mat from the culture were harvested using sterile scalpel into an electric blender. After blending for five minutes, 200 ml of sterile distilled water was added into 500 ml conical flask and filtered using double layer muslin cloth according to the methods of Manza *et al*. (2008).

3.2.1.3.2.2 Plant inoculation

Soil inoculation was done by pouring 20 ml of inoculums suspension at the base of the stem of each plant according to the methods of Manza *et al*. (2008). This was done three months after planting. Control seedlings were treated with the same quantity of sterile distilled water. Both the inoculated and the control seedlings were covered with polythene bags to increase humidity around the plants according to the methods of Manza *et al*. (2008). After 24 hours, polythene bags were removed for 20 minutes and the plants watered. Four days after inoculation, the polythene bags were finally removed. There

were 16 accession with 3 plants per accession per treatment. There were two pathogen inoculation treatments and one control. The greenhouse experiment data was collected for 5 months. Similar procedure as described in the previous experiment for obtaining disease incidence was used.

3.2.2 Determination of taro leaf blight disease severity on Pacific - Caribbean and Kenyan taro accessions under MMUST garden, Milimani garden and greenhouse study

Taro leaf blight disease symptoms which begin with small patches on leaves and water-soaked spots, white mycelium irregular in shape around the lesion (Dipa, 2017) with dark brown color and yellow margins (Vishnu *et al.*, 2012) were carefully observed to confirm the disease. Total area of leaves, total area of leaves infected and the disease severity were recorded at monthly intervals from the appearance of the first symptom (at 3 months) till the crop was harvested.

3.2.2.1 Determination of Leaf area

Areas of leaves were measured by using non-destructive methods of Chan *et al*. (1993) and Lu *et al*. (2002) using the formula W_P x L_{PA} where

W_P=Leaf width passing the petiole attaching point

L_{PA}=Length of the petiole attaching point to the apex of leaf

Area of leaves infected by the disease were assessed using the maximum length and breadth of the affected leaf area. The measurements were obtained by use of a transparent ruler.

3.2.2.2 Determination of disease severity

Disease severity ratings per accession per experiment were undertaken using a subjective score scale of 1-9 adopted from Simongo *et al*. (2016) (Table 3.1). However, records were made as the percentage leaf area infected.

Table 3.1: Severity computation

Scale	% leaf area infected	Description
0 - 1	0	no infection
1 - 2	3	>1% but <10%
2 - 3	10	11-20 small lesions
3 - 4	25	10 % leaf area infected
4 - 5	50	25 % leaf area infected
5 - 6	75	50% leaf area infected
6 - 7	90	75% leaf area infected
7 - 8	97	Only few green areas left (much less than 10%)
8 - 9	100	foliage completely destroyed/dead

The score was repeated monthly for eight months in the first experiment, five months for the second experiment and five months for the greenhouse experiment. The start of scoring took into consideration the beginning of disease development i.e. first appearance of TLB symptoms on taro leaves.

3.2.3 Determination of TLB disease index on Pacific - Caribbean and Kenyan taro accessions under MMUST garden, Milimani garden and greenhouse study

Disease index is a function of disease incidence and severity and it was calculated according to the method of Pandey *et al*. (2003) by transforming percentage severity into scale (Table 3.1 above). The product of the percentage incidence and the corresponding severity scale was obtained as;

Disease index = % incidence x the corresponding severity scale.

This was performed for the three sets of experiments.

3.3 Determination of the effect of rainfall, temperature and relative humidity on disease incidence and severity on Pacific - Caribbean and Kenyan and taro accessions

3.3.1 Collection of meteorological data from Kakamega weather station

Relative humidity recorded in the morning (RH600) and afternoon (RH 1200), minimum, average and maximum mean monthly temperature, and average rainfall prevailing at the observation sites were collected from Kakamega meteorological station as secondary data for the interpretation of results. The weather changes were scored against the different accessions of taro used. Similar procedure was repeated for minimum temperature, maximum temperature, relative humidity in the morning and relative humidity in the afternoon.

3.3.2. Determination of effect of rainfall, temperature and relative humidity on taro leaf blight disease incidence of Pacific - Caribbean and Kenyan taro accessions under MMUST garden and Milimani estate garden

Average monthly rainfall in mm, prevailing at the observation sites were collected as secondary data from Kakamega meteorological station for the interpretation of results. The rainfall changes were scored against each month of taro growth. Incidence of taro leaf blight pathogen was obtained as;

$$\text{Percentage (\%) disease incidence} = \frac{\text{Number of leaves affected per accession}}{\text{Total number of leaves sampled per accession}} \times 100$$

This was done monthly for 8 months in the first field study and 5 months for the second study.

3.3.3. Determination of effect of rainfall, temperature, and relative humidity on taro leaf blight disease severity on Pacific - Caribbean and Kenyan taro accessions under MMUST and Milimani gardens

Average monthly rainfall in mm, minimum temperature, maximum temperature, relative humidity in the morning and relative humidity in the afternoon prevailing at the observation sites were collected as secondary data from Kakamega meteorological station for the interpretation of results. The weather changes were scored against each month of taro growth for 8 months. Level of severity of taro leaf blight pathogen as obtained using a subjective score scale of 1-9 adopted from Simongo *et al*. (2016) (Table 3.1).

recorded against every accession monthly. This was done for 8 months and 5 months respectively when the accessions showed signs of maturity.

3.4 Determination of the relationship between TLB disease resistance and agronomic traits of Pacific - Caribbean and Kenyan taro accessions

Determination of resistance to taro leaf blight disease was performed on Pacific-Caribbean and Kenyan taro accessions on field and greenhouse experiments. Healthy leaf area was calculated by subtracting the already obtained percent disease severity from 100 as; Percent healthy leaf area = 100% - % disease severity.

Where disease severity percentage was calculated per accession per experiment using a subjective score scale of 1-9 adopted from Simongo *et al*. (2016) to arrive at the disease severity percentages.

Resistance was then calculated using the formula of Fonoti *et al*. (2008) with slight modification as;

Resistance = Percentage healthy leaf area (100% - % disease severity)
This was done for each accession and for each replicate.

3.4.1. Determination of the severity categories and disease reaction of MMUST, Milimani estate garden and greenhouse Pacific - Caribbean and Kenyan taro

The percent disease severity determined in 3.4. above was used to categorize the disease severity index according to Rana (2006). The severity percentage categories were as indicated in Table 3.2. below.

Table 3.2. Resistance and susceptibility scale, Rana, (2006)

Severity percentage range	Disease reaction
0.0 - 10%	Resistant (R)
10.1 - 25.0%	Moderately resistant (MR)
25.1 - 50%	Moderately susceptible (MS)
50% and above	Susceptible (S)

3.4.2. Determination of Agronomic traits of MMUST, Milimani estate garden and greenhouse Pacific - Caribbean and Kenyan taro

The agronomic traits of Kenyan and Pacific - Caribbean taro accessions were determined to identify the most productive taro accession. Morphological and yield trait parameters of the taro accessions were evaluated 3-10 months after planting. This was achieved by counting the total number of suckers (corm plants) i.e. the number produced from each plant per month.

Total number of leaves in each plant were counted every month only for fully unfolded leaf according to the methods of Mabhaudhi (2012). No fertilizer or agrochemical against pests was administered. The totals from each taro accession were summed up and average determined. Cluster analysis on the basis of accessions' disease incidence, severity and agronomic performances was also performed. Plant height in centimetres was measured using a tape measure at one-month interval across 5 months from the base of the plant immediately above the soil surface up to the base of the second youngest fully unfolded leaf according to the methods of Mabhaudhi, (2012). Corm length was measured in centimeters by use of tape measure from the part attached to the stem to root tip. Corm diameter was also measured in centimetre at the middle and the largest part of the corm by use of Vernier calipers. Corms were cleaned and placed on an electronic weighing scale. They were then measured in grams once at harvesting. The totals from each taro accession were summed up and average determined.

3.5 Data Analysis

The data collected were pooled and subjected to analysis to obtain descriptive statistics (Percentages, S.D and Means) using the Statistical Package for Social Scientists (SPSS 20). Analysis system (SAS), statistical package 9.1(5), was used to determine the analysis of variance (ANOVA). Correlation analysis was done to establish the relationship between taro leaf blight disease resistance and taro agronomic traits. Whenever there was a significant difference between the means, the least significant difference (LSD) method was used to separate them at 5% to compare mean differences as described by Obi (2002). Linear model was used to compare variability between regions in terms of disease resistance and agronomic traits. The incidence and severity data were also analyzed statistically with weather parameters using correlation and regression techniques.

Furthermore, data was subjected to cluster analysis on the basis of accession disease incidence, severity and agronomic performances. The relationship between taro leaf blight disease resistance and agronomic traits of taro was determined by generating the correlation coefficients and coefficient of determination between disease resistance and agronomic performance according to the methods of Nwanosike *et al*. (2005).

CHAPTER FOUR

RESULTS

4.1 Taro leaf blight disease incidence on Pacific - Caribbean taro accessions of MMUST garden

Results on TLB disease incidence of Pacific - Caribbean taro accessions under MMUST garden conditions were as shown on Table 4.1. Percentage TLB disease incidence had very high ($p<0.001$) significant effect on accessions. The mean disease incidence for the taro accessions was 21.88%. The accessions portrayed similarity in that all of them had their least disease incidence in their 10^{th} month (Table 4.1). Unique qualities of disease tolerance were observed in accession BL/SM/128 which increased in disease incidence between age 3 and 4 from 30.56 to 38.8% and then decreased between age 4 to 10 months from 38.8 to 18.6%. Similar superior quality was observed in accession BL/HW/26 which also increased in incidence between age 3 and 4 months from 18.05-20.3%, decreased between 4-6 months from 20.3 to 11.6%, increased between age 6-7 from 11.6-15.5% and eventually decreased between age 7 to 10 from 15.5 to 9.6% incidence. CE/THA/07 increased in incidence between age 3 to 8 months from 15.39 to 32.3% then finally decreased from 32.3 to 22.8% between age 8 and 10 months. The longest continuous increase in disease incidence from month 3-8 was observed in accession CE/THA/07 from 15.39-32.3% incidence respectively.

Table 4.1: Percentage of TLB disease incidence on Pacific - Caribbean taro under MMUST garden

	Age of plant in months								
	3mth	**4 mths**	**5mths**	**6mths**	**7mths**	**8mths**	**9mths**	**10 mth**	**Pld M**
Pacific taro accessions	**Mean Percentage TLB disease incidence**								
BL/HW/08	18.05	20.3	15.5	12.3	14.3	19.3	13.8	10.2	15.47
BL/HW/26	22.03	23.9	17	11.6	15.5	14.6	12.3	9.6	15.82
BL/HW/37	22.86	25.8	24.4	17.9	22.6	18	16.8	12.8	20.15
BL/SM/152	27.01	25.1	29.9	18.3	23.2	15.9	16.7	17.4	21.69
BL/SM/132	34.15	29.8	23.8	17.9	20	19.5	21.1	17.2	22.93
BL/SM/120	18.83	11.4	19.2	18.6	24.4	26.1	22.8	18.6	19.99
BL/SM/128	30.56	38.8	24.7	22	20.2	16.6	15	13.6	23.98
BL/SM/92	13.68	24.7	24.6	24.3	20.9	23.9	17.2	13.7	20.37
BL/SM/143	17.11	45.2	28.7	24.6	25	27.7	22.6	18.1	26.13
BL/SM/149	24.36	22.6	19.6	14.7	20.9	23	25.2	18	21.48
BL/SM/151	11.59	23.1	18.4	18.3	21.7	28.4	26.1	18.8	20.79
BL/SM/116	10.58	11.5	10.8	12.2	20.7	19.7	21.4	18.9	15.72
BL/SM/111	16.51	40.4	26.3	38.7	25.6	28.7	32.9	20.3	28.68
BL/SM/158	21.52	18	19.8	21.7	23.5	29.3	27	25.8	23.33
BL/SM/153	16.35	30.4	26.5	25.4	34.1	36.9	29.2	24.9	27.97
BL/SM/80	21.69	12.9	11.8	8.9	11.9	14.7	13.2	9.5	13.07
CE/MAL/12	20.17	12.2	16	13.6	27.2	29.7	23.6	20.2	20.33
CE/MAL/14	13.69	37.2	36.9	23.2	27.8	24.3	20.8	19.7	25.45
CA/JP/03	10.00	39.9	41.2	29	38.7	41.6	35.9	31.2	33.09
CE/IND/01	28.87	27.9	27.1	24.4	26.3	26.8	25.1	21.5	25.99
CE/IND/06	32.23	12	15.1	15.7	39	42.5	37	32.6	28.27
CE/THA/07	15.39	20.3	21	25.8	32.2	32.3	27.7	22.8	24.69
CE/THA/09	23.93	32.7	32.2	21.8	19.5	30.2	28.8	27.2	27.04
CE/THA/24	21.02	29	30.9	29.2	35.1	30.1	23.3	17.5	27.02
BL/PNG/10	10.47	25.5	23.2	20.2	24.4	25.7	23.2	19.1	21.47
Mean	20.11	25.24	22.73	18.87	23.47	24.50	21.88	18.26	21.88
S. D	6.73	9.49	7.42	5.95	6.99	7.41	6.17	5.64	5.51
L.S.D $p<0.05$	0.64	0.9	0.7	0.56	0.66	0.7	0.58	0.53	
C.V	33.47	37.6	32.63	31.53	29.78	30.25	28.18	30.91	24.7

The result revealed that most taro accessions differed ($p<0.05$) significantly in incidence of TLB caused by *Phytophthora colocasiae*. The accession with the highest mean disease incidence of 33.09% was CA/JP/03 and the lowest incidence of 13.07% was from BL/SM/80 as shown in figure 4.1. Most of the accessions ranged between 15 - 25% disease incidence (fig 4.1).

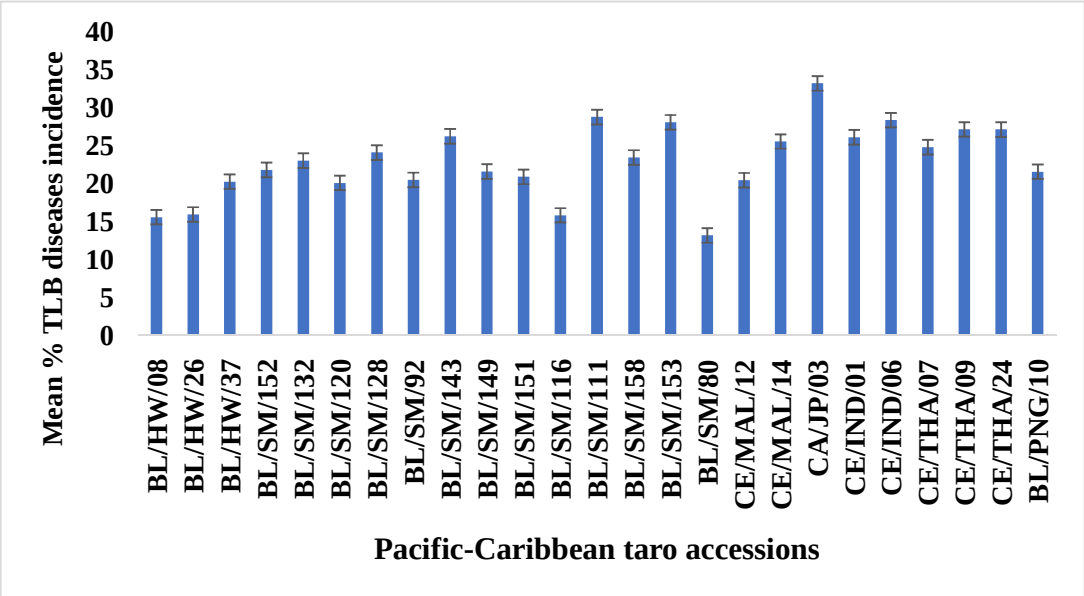


Figure 4.1: Mean TLB disease incidence of Pacific - Caribbean taro accessions under MMUST garden.

No accesson showed regular increase in TLB disease with age**.** At four months of age, TLB disease incidence obtained the highest mean of 25.24%. The second highest mean incidence of 24.5% was at eight months old. The tenth month which was also the last month had the lowest mean incidence of 18.26% (Fig 4.2).

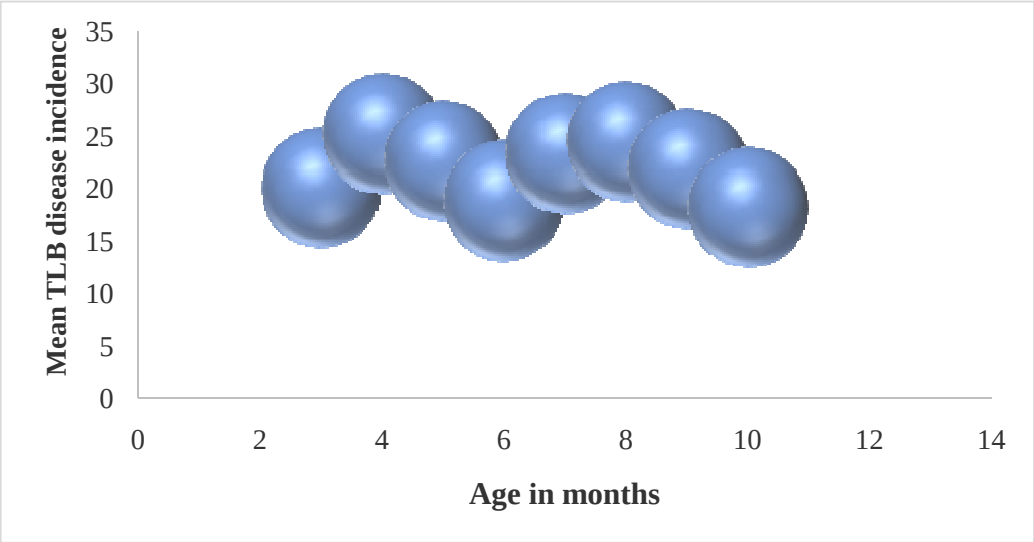


Figure 4.2: Mean TLB disease incidence vis age of Pacific - Caribbean taro under MMUST garden.

4.1.1 Taro leaf blight disease incidence of Pacific - Caribbean and Kenyan taro under Milimani garden

The result on table 4.2 revealed that region, accession and age independently showed highly ($p<0.001$) significant effect on TLB disease incidence. The interactions of the three however were statistically ($p>0.05$) insignificant. The mean TLB disease incidence for the Pacific - Caribbean accession was 7.14% and that of Kenya was 13.19%. The accessions that reduced in incidence in their last month of growth, between age 6-7months were the Kenyan Mumias KMM/MM1/75, Busia KNY/BSA/41, Kisumu KNY/KIS/22 and the Pacific - Caribbean accessions, Samoa BL/SM/48, Hawaii BL/HW/80 and Malacia CE/MAL/14. Pacific - Caribbean accessions BL/SM/111 and CE/JP/03 however maintained same level of disease incidence between age 6 - 7 and 5 - 6 respectively as shown on table 4.2. Zero (0%) incidence was obtained only in Pacific - Caribbean accessions, CE/THA/07, BL/HW/08, BL/HW/80 and CE/IND/06 and only at age 5 months. It was important to note that the high standard deviation and coefficient of

variation computed in the earlier months of study was as a result of the widely distributed data about the mean. This was more common whenever there was zero incidence, when plants did not show any symptom of TLB disease.

Table 4.2: Percentage of TLB disease incidence of Pacific - Caribbean and Kenyan taro accessions under Milimani garden.

		Age in months			
Region	**Accession**	**05**	**06**	**07**	**Pooled m**
Kenyan	KNY/KIS/81	18.18	16.67	21.28	15.23
Kenyan	KMM/MM1/75	47.06	25	17.65	22.84
Kenyan	KMM/MM2/76	13.64	15.15	35.56	18.20
Kenyan	KNY/SYA/50	13.64	14.71	40.54	18.22
Kenyan	KNY/SYA/51	27.27	23.53	42.11	23.73
Kenyan	KNY/BSA/41	38.89	33.33	29.63	27.04
Kenyan	KNY/KIS/20	9.52	33.33	45.16	22.05
Kenyan	KNY/KIS/21	11.54	19.23	32.35	15.12
Kenyan	KNY/KIS/22	16.67	23.33	21.95	22.39
Kenyan	KNY/KAK/16	3.23	16.13	21.28	8.13
Kenyan	KNY/ELD/75	5.71	11.43	25.58	8.54
Kenyan	KNY/CTR/33	14.71	21.95	28.30	12.99
Kenyan	KNY/KTL/61	3.92	7.84	26.79	7.71
Pacific	CE/THA/7	0	4	21.95	5.19
Pacific	CE/THA/24	14.29	9.09	15.79	7.83
Pacific	BL/HW/8	0	4.35	20.51	4.97
Pacific	BL/HW/26	2.78	12.19	23.69	7.73
Pacific	CE/IND/1	4	16	21.57	8.31
Pacific	CE/IND/6	0	4.76	8.62	3.73
Pacific	CE/MAL/14	5.26	15.79	14.29	7.07
Pacific	CE/JP/3	11.11	11.11	20.51	11.62
Pacific	BL/HW/80	0	20	16.13	7.23
Pacific	BL/SM/28	8.33	4.54	13.64	5.30
Pacific	BL/SM/48	6.67	10	20	7.33
Pacific	BL/SM/111	21.43	10.26	10.26	8.39
Pacific	BL/SM/120	10.71	7.14	23.21	8.21
Mean		14.03	15.03	23.78	12.12
SD		11.06	8.06	9.15	5.72
CV		78.83	53.63	38.48	47.19
LSD		1.462	1.066	1.21	

All the accessions recorded incidences of below 50%. Kenyan taro recorded higher percentage disease incidence than the Pacific - Caribbean throughout the growing period. The highest significant ($p<0.05$) disease incidence of 27.04% was obtained from Kenyan accession KNY/BSA/41 and the lowest incidence of 3.73% from Pacific - Caribbean taro accession CE/IND/06. The lowest percentage TLB disease incidence among the Kenyan accessions of 7.71% was from Kitale accession KNY/KTL/61. The highest TLB disease incidence among the Pacific – Caribbean taro accessions was obtained from Japan CE/JP/03 with 11.62% (Figure 4.3). Among the Kenyan taro accessions, Busia had the highest mean TLB disease incidence of 27.04% while Kitale had the least mean incidence of 7.71% (Figure 4.3).

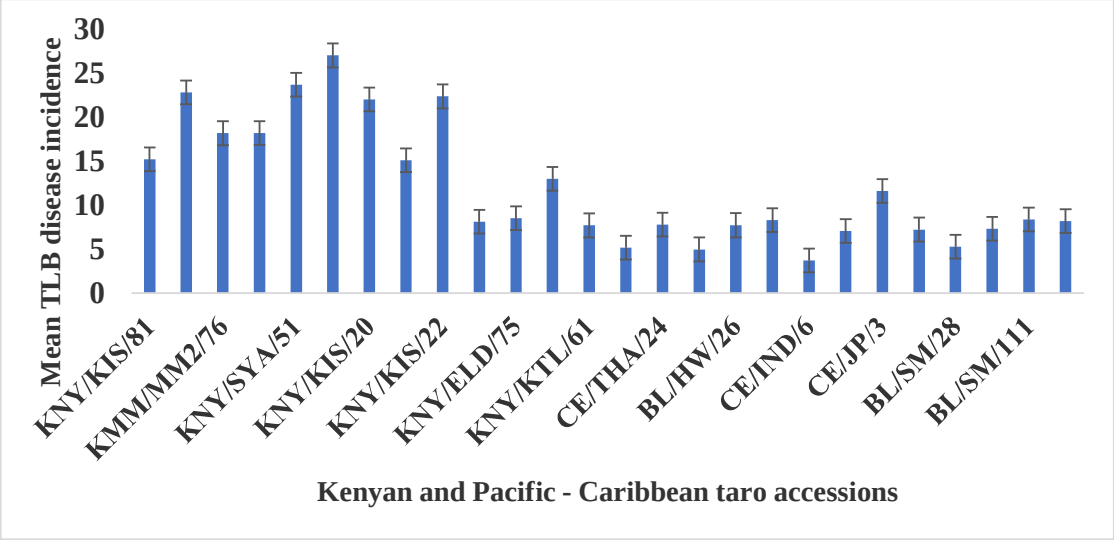


Figure 4.3: Mean TLB disease incidence of Kenyan and Pacific - Caribbean taro under Milimani garden

The highest mean incidence of 23.78% was obtained at plant age of seven months and the least TLB incidence of 14.03% at the age of five months. Age five and six months had significantly ($p>0.05$) the same TLB disease incidence as shown by the error bars (Figure 4.4)

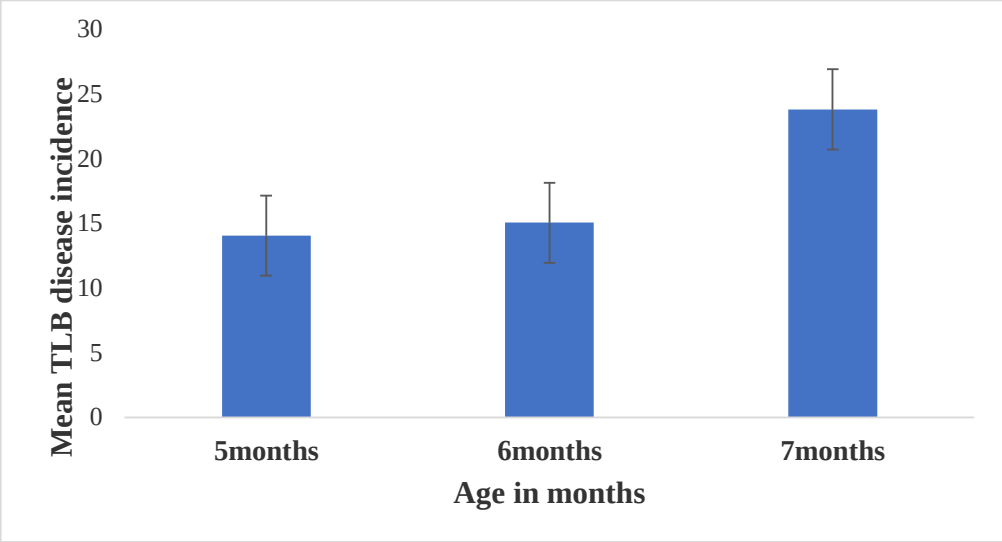


Figure 4.4: Mean TLB disease incidence vis age of Pacific - Caribbean and Kenyan taro under Milimani garden

4.1.1.1 Taro leaf blight disease incidence of Pacific - Caribbean and Kenyan taro under greenhouse study

The result of Pacific - Caribbean and Kenyan taro disease incidence was as shown in Table 4.3. Region of taro origin, the accessions and age portrayed statistically significant ($p<0.001$) effect on TLB disease incidence. Interactions between age and region also significantly ($p<0.001$) influenced TLB disease incidence. All the Pacific - Caribbean taro accessions recorded a decrease in TLB disease incidence between 6-7 months. All the Kenyan taro accessions showed regular increase in TLB disease incidence except KNY/KTL/61 from Kitale that decreased, increased and eventually decreased. The mean

disease incidence for the Pacific - Caribbean accession was 20.08% and that of Kenya was 59.04%.

Table 4.3: Percentage of TLB disease incidence of Pacific - Caribbean and Kenyan taro accessions under greenhouse study

		Age in months					
Region	**Accession**	**3months**	**4months**	**5months**	**6months**	**7months**	**Pooled**
KENYAN	KNY/SYA/51	55.93	59.72	67.53	64.44	69.69	63.47
KENYAN	KNY/SYA/50	54.69	59.74	65	62.22	71.57	62.64
KENYAN	KNY/KSM/81	55.56	63.51	64.97	67.25	65.74	63.41
KENYAN	KNY/MU/75	49.6	56.96	63.92	67.05	70.41	61.59
KENYAN	KNY/KAK/16	18.26	24.65	42	43.29	43.82	34.40
KENYAN	KNY/BSA/41	53.39	61.54	63.58	66.26	66.32	62.22
KENYAN	KNY/KTL/61	63.33	55.26	67.5	64.29	62.75	62.63
KENYAN	KNY/CNT/33	56.29	56.71	61.93	66.29	68.43	61.93
PACIFIC	CA/JP/O3	26.67	20.51	28.21	28.21	21.57	25.03
PACIFIC	BL/HW/26	21.88	19.05	23.81	20.45	17.31	20.49
PACIFIC	BL/SM/92	29.032	28.57	28.95	26.83	22	27.08
PACIFIC	BL/HW/08	20	27.78	30.77	30.95	25.49	26.99
PACIFIC	CE/THA/07	26.67	22.22	38.46	35.71	30	30.61
PACIFIC	BL/SM/80	26.47	30	35	32.56	29.78	30.76
PACIFIC	CE/IND/1	29.03	31.58	37.5	34.88	29.41	32.48
PACIFIC	CE/THA/24	27.27	28.57	35.71	37.21	27.08	31.17
Mean		**38.38**	**40.4**	**47.18**	**46.74**	**45.09**	**43.56**
SD		**15.6**	**16.85**	**16.23**	**17.15**	**20.85**	**17.03**
CV		**40.65**	**41.71**	**34.4**	**36.69**	**46.24**	**39.1**
LSD=(p<0.05)		**2.63**	**2.84**	**2.74**	**2.89**	**3.51**	
Max		**63.33**	**63.51**	**67.53**	**67.25**	**71.57**	**63.47**
Min		**18.26**	**19.05**	**23.81**	**20.45**	**17.31**	**20.49**

The highest disease incidence of 63.47% was recorded from Kenyan accession KNY/SYA/51 and the lowest of 20.49% from Pacific - Caribbean accession BL/HW/26. The highest incidence among the Pacific - Caribbean of 32.48% was obtained from CE/IND/01 of Indonesia. The lowest TLB disease incidence among the Kenyan taro of 34.4% was recorded from KNY/KAK/16 of Kakamega. This indicated that the lowest incidence among the Kenyan accessions was significantly ($p<0.05$) higher than the

highest TLB disease incidence among the Pacific - Caribbean accessions (Figure 4.5). No Pacific - Caribbean taro accession recorded above 30% disease incidence.

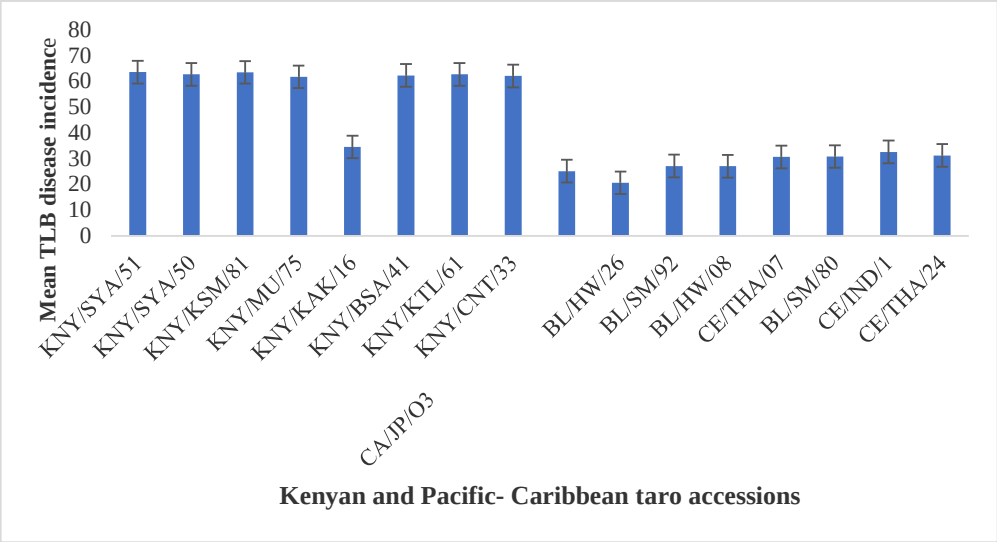


Figure 4.5: Mean TLB disease incidence of Kenyan and Pacific - Caribbean taro under greenhouse study

All the accessions showed incidence right from three months of age. The highest mean incidence of 47.18% was obtained at age 5 months and the least of 38.38% at age three the incidence rate appeared almost constant between age five and seven (Fig 4.6).

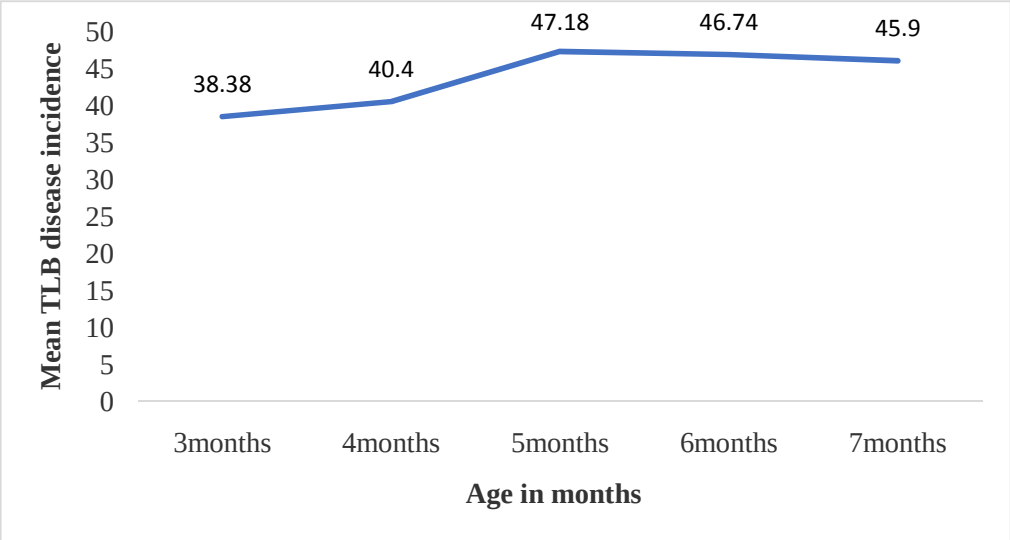


Figure 4.6: Mean TLB disease incidence of Pacific - Caribbean and Kenyan taro vis age under greenhouse study

4.1.2 Taro leaf blight disease severity of Pacific - Caribbean taro under MMUST Garden

The result of disease severity of Pacific - Caribbean taro accessions was as shown on table 4.4. Accession, age and their interactions showed statistically ($p<0.001$) significant effects on TLB disease severity. No accession consistently increased from month 3-8 however most of the accessions increased in disease severity with age as shown on table 4.4. Accessions BL/HW/08, BL/HW/26 and BL/HW/37 had similar reaction to TLB disease incidence in that their percentage severity were higher at the beginning of the study, decreased and finally increased.

Table 4.4 Percentage of TLB disease severity on Pacific - Caribbean taro under **MMUST garden.**

	Age in months								PD M
	3mths	**4mths**	**5mth**	**6mths**	**7mths**	**8mths**	**9mth**	**10mt**	
Pacific taro	**Mean TLB disease severity**								
BL/HW/08	6.4	5.2	3.7	5.5	6.8	17.8	12.0	14.9	9.0
BL/HW/26	5.8	3.4	7.3	6.8	13.7	14.6	12.5	10.0	9.3
BL/HW/37	6.6	3.2	11.7	8.2	34.2	30.3	26.7	12.4	16.6
BL/PNG/10	7.0	14.1	9.8	6.8	14.9	14.9	17.6	15.5	12.6
BL/SM/111	3.8	9.0	10.4	8.9	16.1	13.4	13.1	6.7	10.2
BL/SM/116	20.9	5.8	7.5	5.8	22.4	26.9	17.0	15.8	15.3
BL/SM/120	8.8	6.2	13.3	11.8	17.5	10.7	14.6	11.3	11.8
BL/SM/128	15.3	8.5	7.3	10.7	14.6	24.2	20.0	13.7	14.3
BL/SM/132	9.2	3.2	16.0	14.6	29.0	29.0	27.2	10.8	17.4
BL/SM/143	4.1	4.7	6.4	4.5	14.5	14.7	15.7	12.0	9.6
BL/SM/149	11.8	7.9	5.4	5.8	19.1	17.4	16.8	14.5	12.4
BL/SM/151	1.8	1.8	3.8	3.8	27.8	23.9	19.5	15.8	12.3
BL/SM/152	6.8	3.3	12.9	14.7	26.9	32.3	30.3	10.2	17.2
BL/SM/158	3.1	4.0	8.9	8.5	20.2	25.1	25.7	18.4	14.2
BL/SM/80	7.3	9.1	23.3	20.1	40.9	36.2	40.3	28.3	25.7
BL/SM/92	10.3	4.1	10.4	3.5	13.8	15.9	15.9	5.0	9.9
CA/JP/03	3.1	7.3	8.8	9.6	26.0	32.3	25.6	14.5	15.9
CE/IND/01	22.3	30.3	31.1	12.1	22.8	16.3	21.7	15.8	21.5
CE/IND/06	35.8	42.5	48.2	34.0	45.8	50.0	56.3	39.2	44.0
CE/MAL/12	8.8	11.3	23.7	19.5	33.8	35.9	33.8	23.7	23.8
CE/MAL/14	5.0	3.8	6.0	5.2	26.5	35.3	38.6	24.7	18.1
CE/THA/07	26.1	22.2	21.9	22.8	29.5	29.5	29.5	29.5	26.4
CE/THA/09	11.4	11.4	26.3	24.5	26.0	29.9	27.8	22.4	22.5
CE/THA/24	8.8	14.8	27.3	27.8	33.4	35.5	33.7	18.3	25.0
Mean	**10.2**	**9.7**	**14.3**	**12.0**	**23.6**	**25.1**	**24.3**	**16.6**	**17.0**
CV	**89.7**	**87.4**	**74.4**	**94.9**	**68.2**	**66**	**69.3**	**66.9**	**78.6**
LSD (p<0.05)	**2.54**	**2.69**	**3.40**	**2.95**	**4.27**	**4.27**	**4.19**	**3.28**	

The highest disease severity of 44% was recorded with Indonesia accession CE/IND/06 and the least ($p<0.05$) disease severity of 9% from Hawaiian taro accession BL/HW/08. Accession CE/THA/24 (25% severity) and CE/THA/07 (26.4% severity) had almost

equal TLB disease severity. This similarity in behavior could have been due to their genetic relatedness.

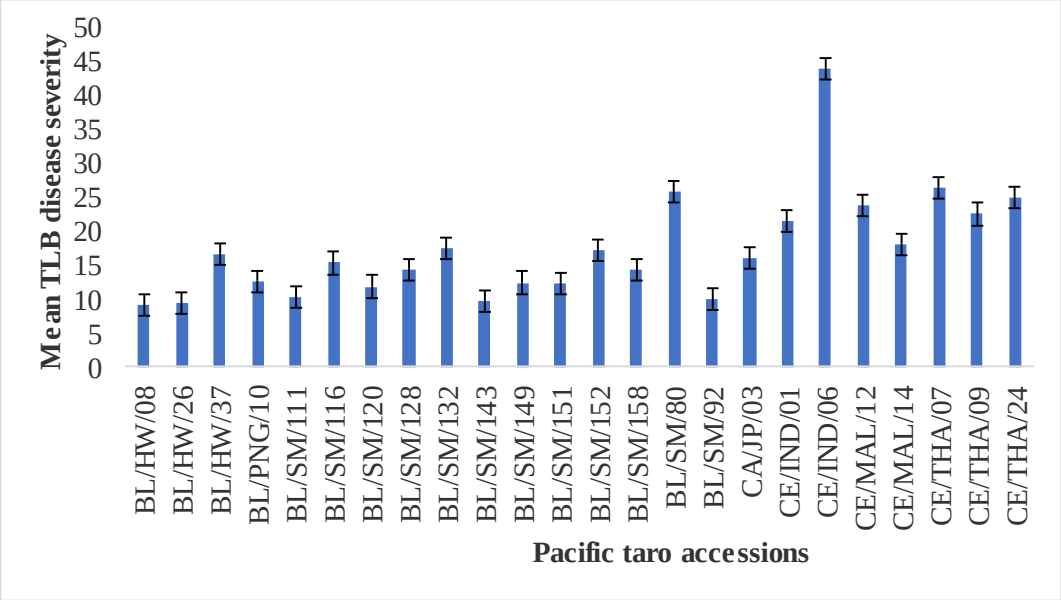


Figure 4.7: Mean TLB disease severity of Pacific - Caribbean taro under MMUST garden

A non-uniform trend of percentage disease severity with age was experienced. The highest TLB disease severity was at age 8 months with 25.1% and the lowest at age 4 with 9.7% disease severity (Fig 4.8).

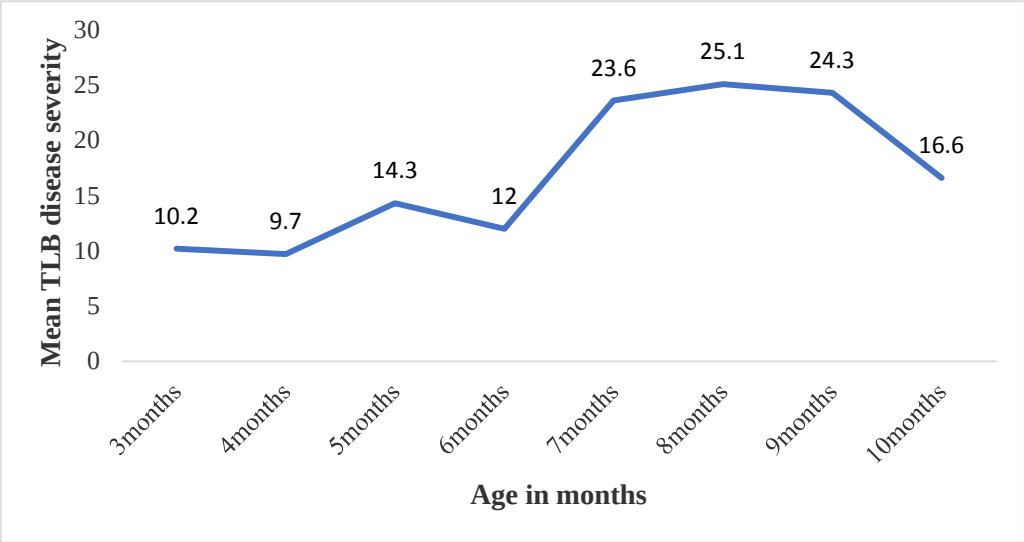


Figure 4.8: Mean TLB disease severity of Pacific - Caribbean vis age under MMUST garden

4.1.2.1. Taro leaf blight disease severity of Pacific - Caribbean and Kenyan taro under Milimani Garden

The results on TLB disease severity on Pacific - Caribbean and Kenyan taro under Milimani garden were as shown on table 4.5. Region, age and their interactions had significant ($p<0.001$) effect on disease severity. The accessions had insignificant ($p>0.05$) effect on TLB disease severity as shown on table 4.5. Unique trend in TLB disease severity was observed in Pacific - Caribbean taro where BL/SM/48 increased in severity between age 5-6 then decreased between sixth (23.3%) and seventh month (17.7%) (Table 4.5). Pacific - Caribbean accessions CE/JP/03 and CE/THA/24 increased initially then finally decreased. All the Kenyan taro accessions increased in disease severity from five months to seven months except Busia accession KNY/BSA/41 and Central Kenya accession KNY/CTR/33 which reduced between six months and seven months as 58.3-

46.7% and 49-47% respectively (Table 4.5). Mean TLB disease severity for the Pacific – Caribbean taro was 10.28% and the Kenyan was 18.75%.

Table 4.5: Percentage of TLB disease severity on Pacific - Caribbean taro and Kenyan under Milimani garden

		Age in months			
Region	**Accession**	**5 months**	**6 months**	**7 months**	**Pooled Mean**
Pacific	BL/HW/26	1.4±3.8	13.6±18.4	44.3±20.9	11.9±20.9
Pacific	BL/HW/08	0±0	2.5±5	31.3±31.5	6.8±17.9
Pacific	BL/HW/80	0±0	23.3±23.1	41.7±38.2	13±24.2
Pacific	BL/SM/111	10±0	31.7±37.5	17.7±28	11.9±21.6
Pacific	BL/SM/120	18.8±23.9	21.3±36.1	33.8±19.7	14.8±23.2
Pacific	BL/SM/28	1±1.7	6.7±5.8	25±43.3	6.5±19.3
Pacific	BL/SM/48	3.3±5.8	23.3±23.1	17.7±28	8.9±17.2
Pacific	CE/IND/01	2.5±5	21.3±21.7	43.8±23.9	13.5±21.8
Pacific	CE/IND/06	0±0	2.5±5	21.3±21.7	4.9±12.3
Pacific	CE/JP/03	12.5±25	8.8±11.8	26.3±32.5	9.8±19.5
Pacific	CE/MAL/14	2.5±5	15±12.2	30±30.8	9.5±17.9
Pacific	CE/THA/24	5±5.8	3.8±4.3	30±23.1	7.8±15,1
Pacific	CE/THA/07	0±0	2.5±5	38.8±12.5	14.3±28.5
Kenya	KMM/MM1/75	8.8±9.5	24±24.1	52±26.6	17.3±24.9
Kenya	KMM/MM2/76	1.8±1.6	16±19.5	66±28.2	17.1±29.2
Kenya	KNY/BSA/41	33.3±14.4	58.3±14.4	46.7±37.5	28.3±29
Kenya	KNY/CTR/33	10.6±13.2	49±35.6	47±23.3	21.3±29
Kenya	KNY/ELD/75	1.5±1.7	10±0	37.514.4	9.8±15.8
Kenya	KNY/KAK/16	0.6±1.3	20.6±26.9	35±22.4	11.2±20.4
Kenya	KNY/KIS/20	5±5.8	46.3±26.9	50±20.4	20.6±26.9
Kenya	KNY/KIS/21	13.3±24.5	31.3±23.9	56.3±12.5	20.3±26.2
Kenya	KNY/KIS/22	17.5±8.7	30±23.1	56.3±12.5	21.4±23.7
Kenya	KNY/KIS/81	1.5±1.7	7.5±5	75±0	17.1±29.9
Kenya	KNY/KTL/61	2.6±4.3	8±4.5	55±20.9	13.1±23.3
Kenya	KNY/SYA/50	3.3±4.7	27.5±26.3	56.3±23.9	17.7±26.5
Kenya	KNY/SYA/51	25±20.4	52.5±30.7	62.5±14.4	28.5±30.5
	Mean	**15.06**	**28.73**	**47.94**	**31.09**
	CV	**96.02**	**82.77**	**49.4**	**84.01**
	LSD (p<0.05)	**3.03**	**5.98**	**6.5**	

The highest disease severity of 28.5% was observed on Kenyan accession KNY/SYA/51 whereas the lowest severity of 6.5% was realized on Pacific - Caribbean accession

BL/SM/28. Among the Pacific - Caribbean accessions, BL/SM/120 had the highest disease severity of 14.8%. The lowest in severity among the Kenyan accessions was KNY/ELD/75 with 9.8%.

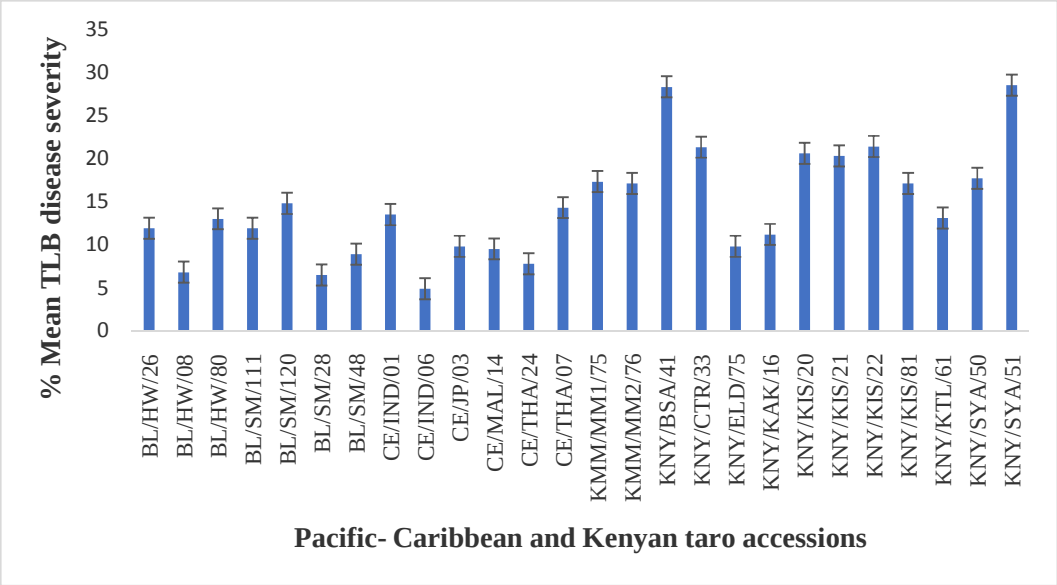


Figure 4.9: Mean TLB disease severity of Pacific- Caribbean and Kenyan taro under Milimani garden

Disease severity advanced with the age of taro plant. Age seven months recorded the highest severity of 47.94% while the lowest disease severity of 15.06% was recorded in the fifth month. (Fig 4.10).

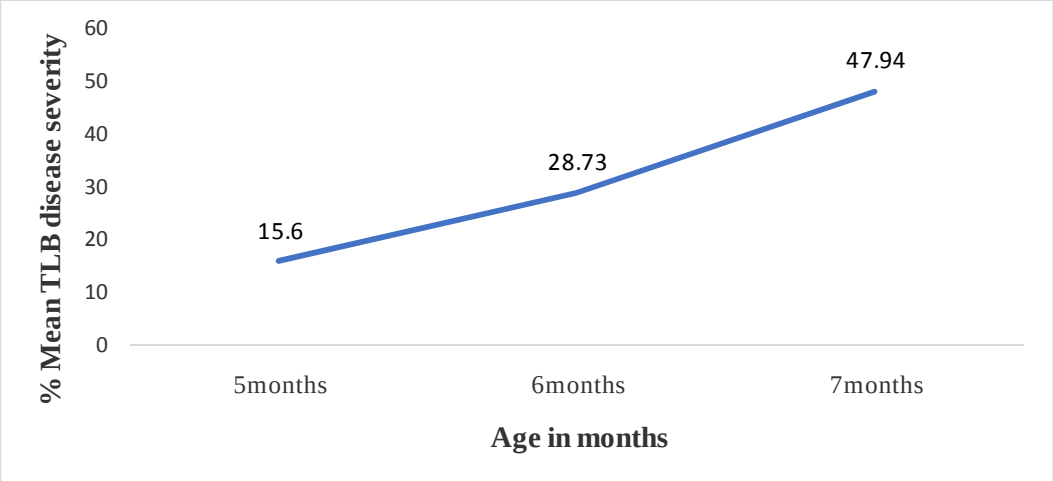


Figure 4.10: Mean TLB disease severity of Pacific – Caribbean and Kenyan taro vis age under Milimani garden

4.1.2.2 Taro leaf blight disease severity of Pacific - Caribbean and Kenyan taro under greenhouse study

The result on taro leaf blight disease severity on Pacific - Caribbean greenhouse taro was as indicated on table 4.6 below. Independently, region, accession and age significantly ($p<0.05$) influenced TLB disease severity. Similarly, the interaction between region of origin and age showed significant ($p<0.001$) effects on disease severity. Further, interactions between accessions and age significantly ($p<0.001$) affected disease severity which steadily increased from third month to seventh month in both Pacific - Caribbean and Kenyan taro (Table 4.6). Pacific - Caribbean accession BL/SM/80 maintained a severity of 30.56% between age five and six months, an indication of tolerance to TLB disease. The mean TLB disease severity for the Pacific – Caribbean taro was 20.47% and that of Kenya was 29.64%.

Table 4.6 Percentage TLB disease severity on Pacific-Caribbean and Kenyan accessions of taro under greenhouse study.

		Age in months					
Region	**Accession**	**3months**	**4moths**	**5months**	**6months**	**7months**	**Pooled mean**
Pacific	BL/HW/08	11.78±21.71	14±20.78	20.56±19.91	26.11±27.02	27.78±26.35	20.04±23.16
Pacific	BL/HW/26	3.22±4.09	3.56±3.91	6.67±5	11.67±10.9	21.67±22.64	9.36±13.16
Pacific	BL/SM/80	12.56±12.2	17.78±16.79	30.56±24.3	30.56±24.3	36.11±28.26	25.51±22.79
Pacific	BL/SM/92	5.11±4.78	10±9.68	21.67±22.64	23.33±22.22	11.67±10.9	14.36±16.61
Pacific	CA/JP/O3	2.44±3.21	5.89±4.96	11.67±10.9	22.22±19.54	33.33±25	15.11±18.49
Pacific	CE/IND/1	9.33±11.82	20.89±23.2	25±21.65	30.56±24.3	33.33±25	23.82±22.41
Pacific	CE/THA/07	16±20.76	14.78±20.44	25.56±31.96	27.78±26.35	41.67±33.07	25.16±27.6
Pacific	CE/THA/24	12±16.35	20.56±19.91	36.11±28.26	41.67±33.07	41.67±33.07	30.4±28.48
Kenya	KNY/BSA/41	34.03±26.83	40.28±30.63	45.28±34.29	48.06±35.58	50.14±36.38	43.56±33.08
Kenya	KNY/CNT/33	17.6±17.16	27.5±23.99	36.32±28.46	41.39±31.76	45.56±33.94	33.67±29.34
Kenya	KNY/KAK/16	4.36±9.21	11.19±13.91	21.78±23.35	30.69±27.78	33.89±28.71	20.38±24.5
Kenya	KNY/KSM/81	7.97±10.55	19.03±18.47	31.33±	42.78±32.61	48.78±35.83	29.98±30.01
Kenya	KNY/KTL/61	18.33±26.22	23.33±25.5	25±25	36.11±28.26	44.44±34.86	29.44±28.55
Kenya	KNY/MU/75	9.28±13.96	13.28±13.67	24.33±21.65	35.42±30.1	41.39±33.65	24.74±26.8
Kenya	KNY/SYA/50	8.44±9.86	12.56±11.83	21.94±20.52	33.89±30.37	45.83±34.57	24.53±26.88
Kenya	KNY/SYA/51	9.56±12.7	21.11±23.98	36.28±28.51	41.67±32.08	45.28±34.79	30.78±30.11
	Mean	**13.25**	**20.36**	**29.75**	**36.76**	**41.49**	**28.32**
	CV	**135.3**	**109.2**	**90.7**	**83.2**	**79.3**	**101**
	LSD	**2.96**	**3.67**	**4.45**	**5.05**	**5.44**	

Most Kenyan taro accessions recorded higher TLB disease severity than the Pacific-Caribbean taro. Kenyan accession KNY/BSA/41 scored significantly ($p<0.05$) the highest blight disease severity of 43.56% and the lowest severity of 9.36% was recorded with Pacific - Caribbean accession BL/HW/26

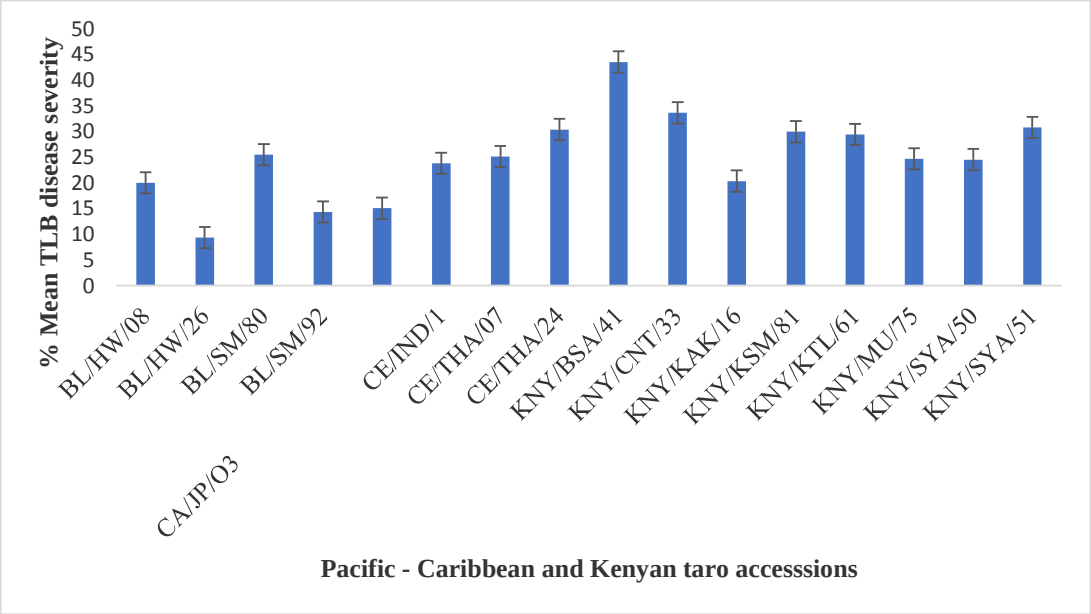


Figure 4.11: Mean TLB disease severity of Pacific- Caribbean and Kenyan taro under greenhouse study

There was gradual increase in disease severity with age of taro plant. The highest severity was recorded at age seven months with 41.49% and the lowest at age two months with 13.25%.

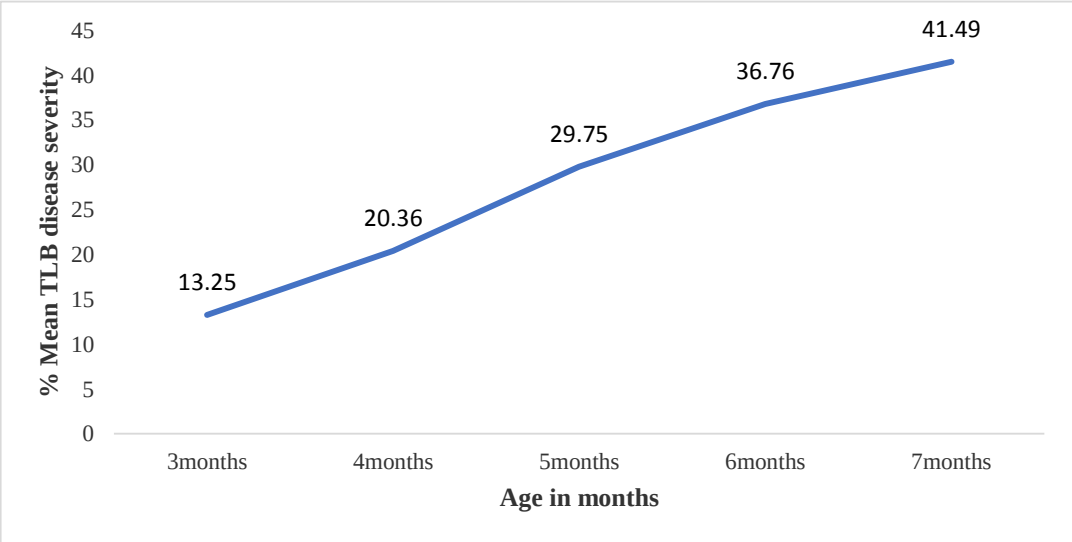


Figure 4.12: Mean TLB disease severity of Pacific – Caribbean and Kenyan taro vis age under greenhouse study.

4.1.3 Taro leaf blight disease index of Pacific- Caribbean taro under MMUST field

The result on monthly taro leaf blight disease index on various accessions of Pacific-Caribbean taro was as shown on table 4.7 below. Age and accessions had independent significant ($p<0.001$) effects on disease index. Moreover, the interactions between accessions and age were statistically ($p<0.001$) significant. In all the accessions, there was no consistent increase in disease index with age (Table 4.7).

Table 4.7: Mean monthly TLB disease index of Pacific - Caribbean taro under MMUST Garden

	Age in months								
	3mth	**4mth**	**5mth**	**6mth**	**7mth**	**8mth**	**9mth**	**10 mnth**	
Pacific taro									**Pld M**
BL/HW/08	0.41	0.41	0.29	0.22	0.28	0.48	0.42	0.28	0.35
BL/HW/26	0.5	0.42	0.38	0.24	0.41	0.43	0.35	0.25	0.37
BL/HW/37	0.48	0.45	0.66	0.41	0.87	0.7	0.62	0.37	0.57
BL/SM/152	0.61	0.8	0.72	0.79	1.01	1.11	1.02	0.55	0.83
BL/SM/132	0.8	0.85	0.84	0.63	1	1.03	0.78	0.43	0.8
BL/SM/120	0.47	0.77	0.63	0.54	0.53	0.33	0.36	0.3	0.49
BL/SM/128	0.94	0.58	0.54	0.62	0.59	0.82	0.53	0.36	0.62
BL/SM/92	0.39	0.26	0.3	0.18	0.31	0.39	0.33	0.18	0.29
BL/SM/143	0.36	0.38	0.34	0.24	0.31	0.39	0.48	0.36	0.36
BL/SM/149	0.61	0.54	0.41	0.34	0.62	0.73	0.63	0.49	0.55
BL/SM/151	0.18	0.2	0.23	0.25	0.72	0.59	0.62	0.48	0.41
BL/SM/116	0.34	0.23	0.4	0.35	0.63	0.82	0.59	0.44	0.48
BL/SM/111	0.32	0.76	0.48	0.31	0.48	0.45	0.52	0.36	0.46
BL/SM/158	0.41	0.39	0.46	0.55	0.74	1	0.92	0.76	0.65
BL/SM/153	0.33	0.57	0.53	0.34	0.84	0.9	0.94	0.61	0.63
BL/SM/80	0.52	0.84	1.01	0.9	1.49	1.4	1.2	0.86	1.03
CE/MAL/12	0.47	0.79	0.93	0.82	1.05	1.07	0.97	0.69	0.85
CE/MAL/14	0.27	0.28	0.43	0.33	1.35	1.77	1.62	1.17	0.9
CA/JP/03	0.16	0.22	0.26	0.23	0.81	1.07	0.78	0.55	0.51
CE/IND/01	1.06	1.43	1.42	0.61	0.92	0.75	0.68	0.57	0.93
CE/IND/06	1.4	1.81	1.96	1.22	1.83	2	1.83	1.35	1.68
CE/THA/07	0.47	0.64	0.68	0.8	1.14	1.14	0.98	0.81	0.83
CE/THA/09	0.66	0.95	1.24	0.78	0.71	1.12	1.03	0.89	0.92
CE/THA/24	0.53	0.75	0.99	0.84	1.24	1.21	0.88	0.54	0.87
BL/PNG/10	0.19	0.52	0.63	0.37	0.7	0.48	0.53	0.54	0.5
Mean	**0.52**	**0.63**	**0.67**	**0.52**	**0.82**	**0.89**	**0.78**	**0.57**	**0.68**
SD	**0.28**	**0.367**	**0.401**	**0.27**	**0.38**	**0.42**	**0.37**	**0.28**	**0.29**
CV	**54.37**	**57.89**	**59.85**	**52.1**	**45.6**	**47.13**	**46.6**	**48.6**	**43.7**
LSD (p<0.05)	**0.03**	**0.03**	**0.04**	**0.03**	**0.04**	**0.04**	**0.03**	**0.03**	
Max	**1.4**	**1.81**	**1.96**	**1.22**	**1.83**	**2**	**1.83**	**1.35**	**1.68**
Min	**0.16**	**0.2**	**0.23**	**0.18**	**0.28**	**0.33**	**0.33**	**0.18**	**0.29**

Most Pacific - Caribbean taro accessions recorded disease index below 1.0. The accession with the highest significant ($p<0.05$) disease index of 1.68 was CE/IND/06 from Indonesia and the one with the lowest significant ($p<0.05$) disease index of 0.29 was BL/SM/92 from Samoa.

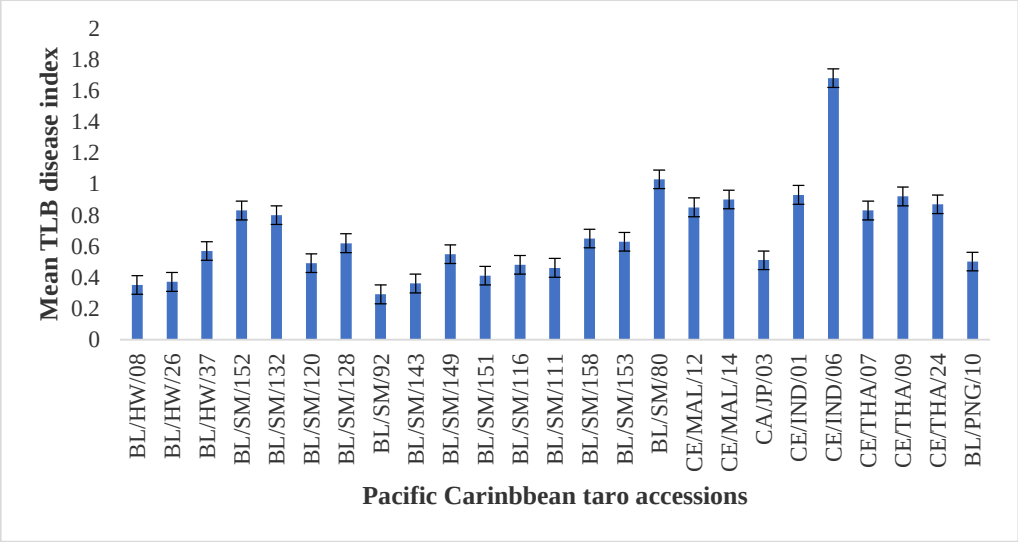


Figure 4.13: Mean TLB disease index of Pacific - Caribbean taro under MMUST garden

There was irregular increase in TLB disease index with age of plant. The highest significant ($p<0.05$) disease index of 0.89 was obtained in month eight and the lowest significant ($p<0.05$) index of 0.52 was recorded in the month three and six.

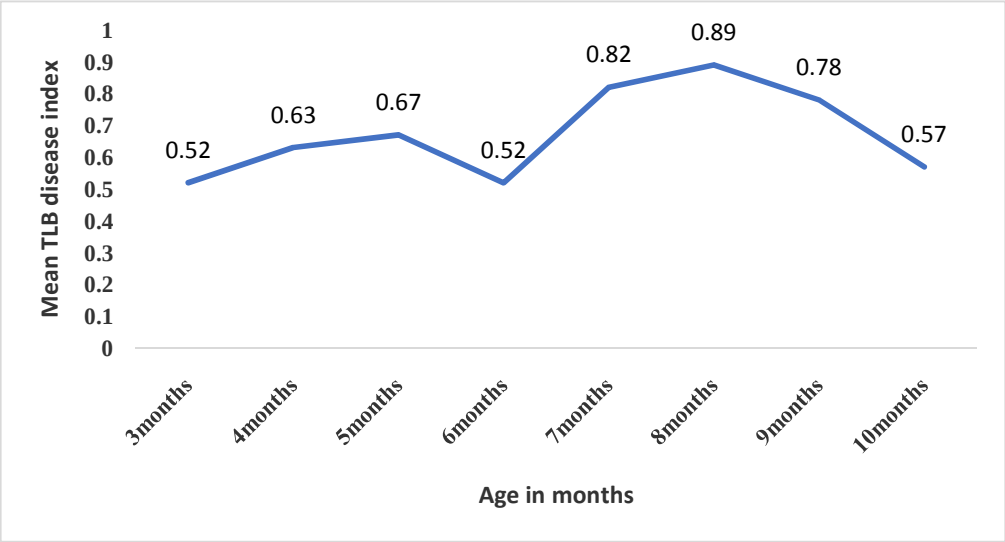


Figure 4.14: Mean TLB disease index of Pacific – Caribbean taro vis age under MMUST garden

4.1.3.1. Taro leaf blight disease index of Pacific- Caribbean field study-2 under Milimani garden

The result on monthly taro leaf blight disease index on various accessions of Pacific - Caribbean taro were as shown on table 4.8 below. Statistical evidence indicated that disease index was different according to region where the accessions came from and their age. The accessions themselves were significantly ($p<0.05$) different. The interactions between region and age also showed significant ($p<0.001$) effects on TLB disease index. The mean TLB disease index for the Pacific - Caribbean taro was 0.2 and that of Kenya was 0.78.

Table 4.8: Mean monthly TLB disease index of Pacific - Caribbean and Kenyan taro under Milimani garden

		Age in months			
Region	**Accession**	**05**	**06**	**07**	**Pooled m**
KENYAN	KNY/KIS/81	0.27	0.42	1.3	0.5
KENYAN	KMM/MM1/75	1.22	0.85	0.9	0.7
KENYAN	KMM/MM2/76	0.22	0.46	2.1	0.6
KENYAN	KNY/SYA/50	0.24	0.52	2.1	0.6
KENYAN	KNY/SYA/51	0.96	1.18	2.3	1
KENYAN	KNY/BSA/41	1.69	1.78	1.5	1.1
KENYAN	KNY/KIS/20	0.19	1.58	2.3	0.9
KENYAN	KNY/KIS/21	0.26	0.72	1.7	0.6
KENYAN	KNY/KIS/22	0.58	0.93	1.2	0.7
KENYAN	KNY/KAK/16	0.04	0.45	0.9	0.3
KENYAN	KNY/ELD/75	0.09	0.34	1.2	0.3
KENYAN	KNY/CTR/33	0.35	1.05	1.4	0.6
KENYAN	KNY/KTL/61	0.06	0.2	1.4	0.3
PACIFIC	CE/THA/7	0	0.06	1.3	0.3
PACIFIC	CE/THA/24	0.29	0.34	0.6	0.3
PACIFIC	BL/HW/8	0	0.07	0.8	0.2
PACIFIC	BL/HW/26	0.04	0.31	1.1	0.3
PACIFIC	CE/IND/1	0.06	0.52	1	0.3
PACIFIC	CE/IND/6	0	0.07	0.3	0.1
PACIFIC	CE/MAL/14	0.08	0.47	0.6	0.2
PACIFIC	CE/JP/3	0.22	0.25	0.8	0.3
PACIFIC	BL/HW/80	0	0.73	0.6	0.3
PACIFIC	BL/SM/28	0.11	0.11	0.4	0.1
PACIFIC	BL/SM/48	0.11	0.37	0.5	0.2
PACIFIC	BL/SM/111	0.64	0.41	0.3	0.3
PACIFIC	BL/SM/120	0.3	0.2	1	0.3
Mean		**0.36**	**0.55**	**1.1**	**0.4**
SD		**0.41**	**0.44**	**0.6**	**0.3**
CV		**114**	**80**	**52**	**58**
LSD (p<0.05)		**0.05**	**0.06**	**0.1**	**0**
Max		**1.69**	**1.78**	**2.3**	**1.1**
Min		**0**	**0.06**	**0.3**	**0.1**

Most Kenyan taro accessions recorded disease indices greater than the Pacific - Caribbean as shown in figure 4.15 below. The highest significant ($p<0.05$) disease index of 1.1 was recorded in Kenyan accession KNY/IND/06 while the lowest significant ($p<0.05$) index of 0.1 was obtained from Pacific - Caribbean taro accessions; CE/IND/06 and BL/SM/28. The lowest disease index among the Kenyan accessions of 0.3 included; KNY/KAK/16, KNY/ELD/75 and KNY/KTL/61. The highest disease index of 0.3 among the Pacific - Caribbean accessions was obtained from accessions; BL/SM/120, BL/SM/111, CE/THA/07, CE/THA/24, BL/HW/26, CE/IND/01, CE/JP/03, BL/HW/80.

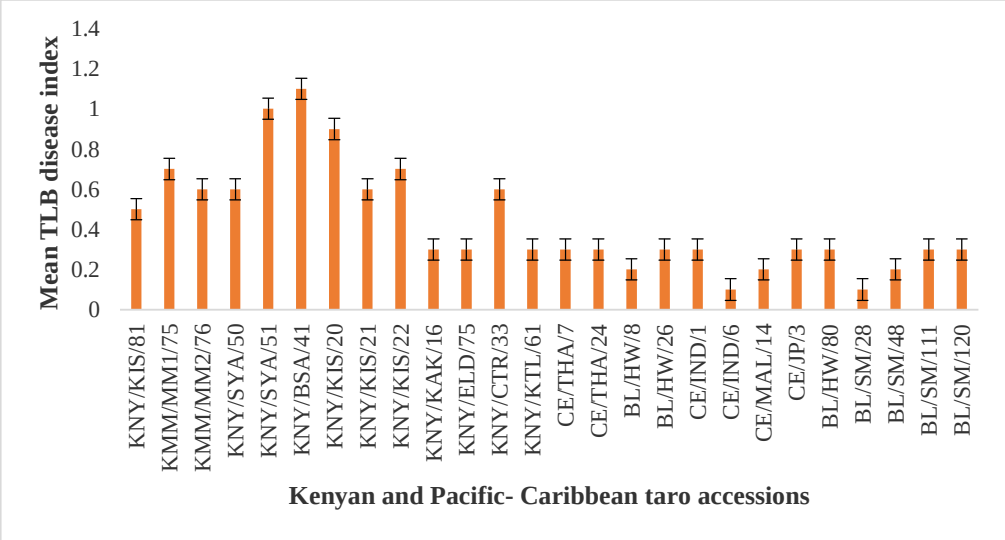


Figure 4.15: Mean TLB disease index of Pacific - Caribbean taro under Milimani garden

The disease showed progressive increase in disease index with plant age (From age five to seven) as shown in figure 4.16. Age seven had the highest significant ($p<0.05$) disease index of 1.1 and age five had the lowest significant ($p<0.05$) disease index of 0.36.

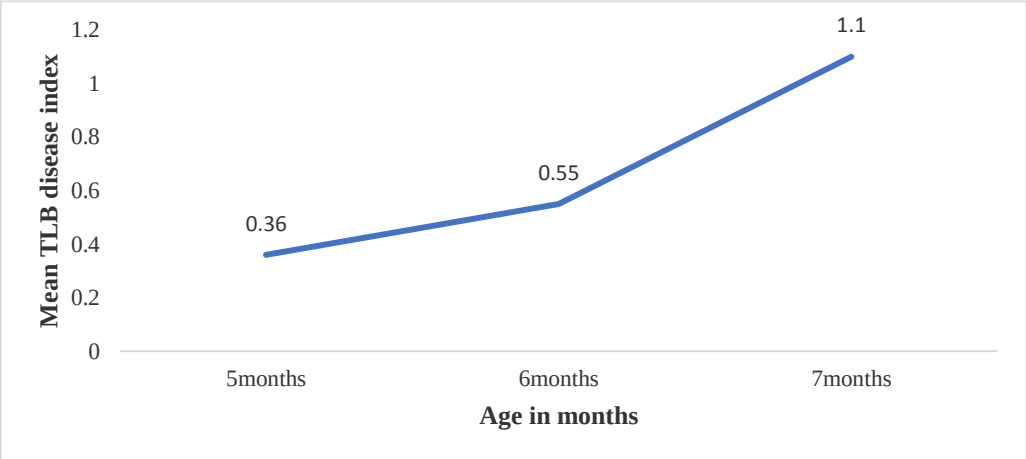


Figure 4.16: Mean TLB disease index of Pacific – Caribbean taro vis age under Milimani garden

4.1.3.2 Taro leaf blight disease index of Pacific - Caribbean and Kenyan taro under greenhouse study

Table 4.9 below gives a summary of mean monthly TLB disease index on Pacific - Caribbean and Kenyan greenhouse grown taro. There was significant ($p<0.001$) individual effects of region, age and accessions on TLB disease index. Interaction effects between region and age were equally significant. The highest significant ($p<0.05$) disease index of 2.26 was recorded with Kenyan accession KNY/SYA/51 and the lowest disease index of 0.8 with Pacific - Caribbean accession BL/HW/08 as shown in table 4.9. There was no significant difference ($p>0.05$) in disease index between accession KNY/SYA/51, KNY/SYA/50 and KNY/KSM/81 at age three months. The three accessions were obtained from the same and neighboring counties of Kenya. In the seventh month, accession KNY/MU/75, KNY/KAK/16, KNY/BSA/41, KNY/KTL/61, KNY/CNT/33 all from different counties of Kenya had varied TLB disease indices (Table 4.9). The mean TLB disease index for Pacific-Caribbean taro was 0.86 and that of Kenya was 2.08. All

the Pacific - Caribbean taro accessions had lower disease index than those of Kenya except the Kenyan Kakamega taro KNY/KAK/16 that was statistically ($p>0.05$) the same as the Pacific -Caribbean ones. The mean TLB disease index for the Pacific - Caribbean taro was 0.86 and the Kenyan was 2.08.

Table 4.9 *:* Summary of TLB disease index on Pacific - Caribbean and Kenyan greenhouse grown taro viz age.

		Age in months					
Region	**Accession**	**3**	**4**	**5**	**6**	**7**	**Pooled m**
KENYAN	KNY/SYA/51	1.36	1.86	2.59	2.58	2.91	2.26
KENYAN	KNY/SYA/50	1.27	1.6	2.06	2.28	2.98	2.038
KENYAN	KNY/KSM/81	1.28	1.92	2.35	2.73	2.98	2.252
KENYAN	KNY/MU/75	1.16	1.55	2.1	2.51	2.82	2.028
KENYAN	KNY/KAK/16	0.33	0.61	1.29	1.53	1.61	1.074
KENYAN	KNY/BSA/41	1.97	2.42	2.65	2.84	2.89	2.554
KENYAN	KNY/KTL/61	1.83	1.78	2.25	2.43	2.58	2.174
KENYAN	KNY/CNT/33	1.69	1.94	2.35	2.65	2.85	2.296
PACIFIC	CA/JP/O3	0.45	0.46	0.75	0.91	0.79	0.672
PACIFIC	BL/HW/26	0.39	0.36	0.55	0.55	0.54	0.478
PACIFIC	BL/SM/92	0.61	0.73	0.9	0.86	0.59	0.738
PACIFIC	BL/HW/08	0.42	0.71	0.96	1.03	0.88	0.8
PACIFIC	CE/THA/07	0.74	0.59	1.24	1.23	1.2	1
PACIFIC	BL/SM/80	0.71	0.9	1.25	1.16	1.13	1.03
PACIFIC	CE/IND/1	0.68	0.95	1.25	1.24	1.08	1.04
PACIFIC	CE/THA/24	0.7	0.89	1.35	1.49	1.08	1.102
Mean		**0.97**	**1.2**	**1.62**	**1.75**	**1.81**	**1.47**
SD		**0.52**	**0.63**	**0.68**	**0.77**	**0.96**	**0.69**
CV		**53.61**	**52.5**	**41.98**	**44**	**53.04**	**46.94**
LSD ($p<0.05$)		**0.09**	**0.11**	**0.11**	**0.13**	**0.16**	
Max		**1.97**	**2.42**	**2.65**	**2.84**	**2.98**	**2.554**
Min		**0.33**	**0.36**	**0.55**	**0.55**	**0.54**	**0.478**

The lowest disease index among the Kenyan accessions of 1.07 was obtained from KNY/KAK/16 and the highest index among the Pacific - Caribbean accession of 1.1 was obtained from CE/THA/24.

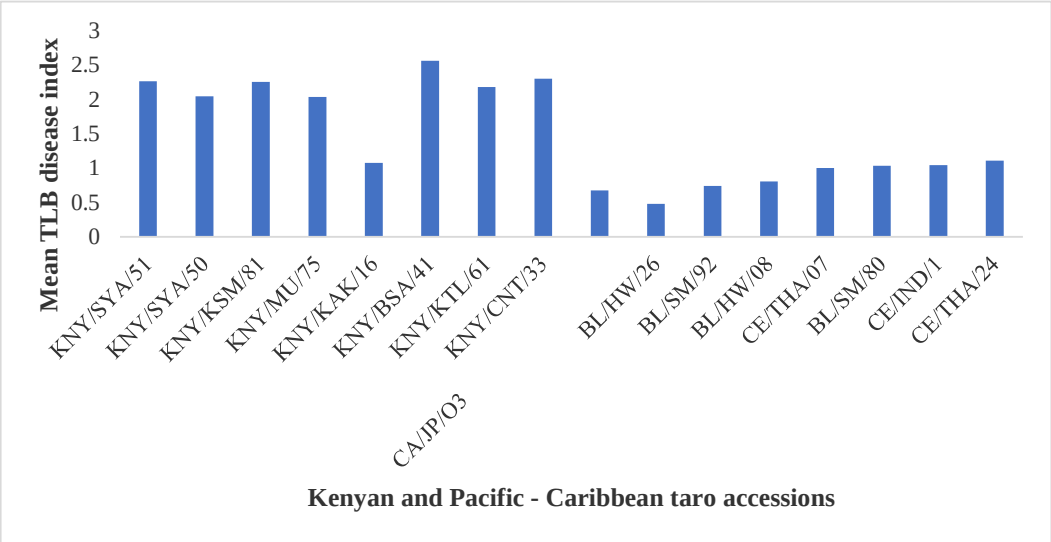


Figure 4.17: Mean TLB disease index of Kenyan and Pacific - Caribbean taro under greenhouse study.

There was a gradual increase in disease index with taro plant age. Age seven months had the highest significant ($p<0.05$) disease index of 1.81 and the lowest disease index of 0.97 was obtained at age three (Fig 4.18).

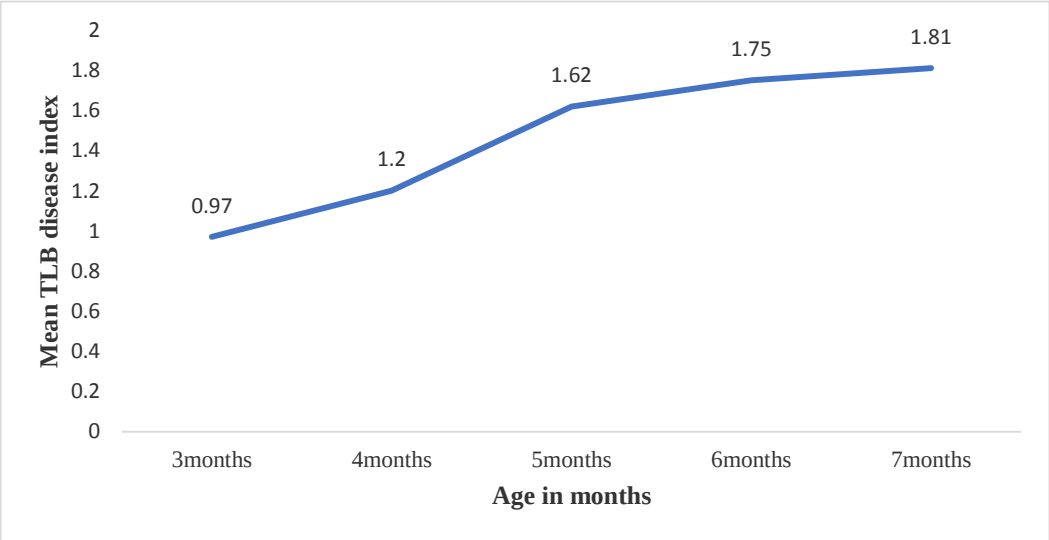


Figure 4.18: Mean TLB disease index of Kenyan and Pacific – Caribbean taro vis age under greenhouse study

4.2 Effect of mean monthly rainfall, temperature and relative humidity on TLB disease incidence on Pacific - Caribbean taro under MMUST Garden.

The result on field study performed on Pacific - Caribbean taro were as illustrated on table 4.10 below. There was no significant ($P>0.05$) effect of rainfall on TLB disease development on Pacific- Caribbean taro. No regular pattern of disease incidence to illustrate the effect of average temperature on the same. Disease incidence was at its highest of 20.75% when average temperature was 20.5^0 C, rainfall 16.1mm and R.H 69%. The lowest incidence of 19.1% was recorded at average temperature of 21.2^0C, rainfall of 7.7mm and average relative humidity of 68% (Table 4.10). The significantly ($p<0.05$) highest percentage disease incidence of 25.74% was obtained at a maximum temperature of 27.2^0C. The range of morning relative humidity for the period of study was 71-89%. There was no regular increase in disease incidence with increase in relative humidity within the months of study. At relative humidity 80% recorded in the morning

hours, in September, the percentage disease incidence was significantly ($p<0.05$) highest at 25.74% whereas at relative humidity 73% recorded in the morning in November, the percentage disease incidence was significantly ($p<0.05$) lowest at 19.1% as shown on table 4.10. There wasn't a regular pattern in the effect of relative humidity recorded in the afternoon on the mean taro leaf blight disease incidence on Pacific - Caribbean taro throughout the course of the study. However significantly ($p<0.05$) highest afternoon RH of 68% registered a disease incidence of 20.6% while relative humidity of 63% recorded significantly ($p<0.05$) lowest disease incidence of 19.1%.

Table 4.10. Summary of TLB disease incidence on Pacific - Caribbean taro under MMUST garden viz means monthly rainfall, temperature and relative humidity

Pacific accessions	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Pooled Mean
	Mean monthly TLB disease incidence								
BL/HW/08	20.1	20.3	15.5	12.3	14.3	19.3	13.8	10.2	15.7
BL/HW/26	23.3	23.9	17	11.6	15.5	14.6	12.3	9.6	16
BL/HW/37	22.1	25.8	24.4	17.9	22.6	18	16.8	12.8	20
BL/PNG/10	10.2	25.1	29.9	18.3	23.2	15.9	16.7	17.4	19.6
BL/SM/111	15.3	29.8	23.8	17.9	20	19.5	21.1	17.2	20.6
BL/SM/116	13.2	11.4	19.	18.6	24.4	26.1	22.8	18.6	19.3
BL/SM/120	18.6	38.8	24.7	22	20.2	16.6	15	13.6	21.2
BL/SM/128	31.4	24.7	24.6	24.3	20.9	23.9	17.2	13.7	22.6
BL/SM/132	37.1	45.2	28.7	24.6	25	27.7	22.6	18.1	28.6
BL/SM/143	16.9	22.6	19.6	14.7	20.9	23	25.2	18	20.1
BL/SM/149	23.2	23.1	18.4	18.3	21.7	28.4	26.1	18.8	22.3
BL/SM/151	11.3	11.5	10.8	12.2	20.7	19.7	21.4	18.9	15.8
BL/SM/152	27.6	40.4	26.3	38.7	25.6	28.7	32.9	20.3	30
BL/SM/158	20	18	19.8	21.7	23.5	29.3	27	25.8	23.1
BL/SM/80	19.9	30.4	26.5	25.4	34.1	36.9	29.2	24.9	28.4
BL/SM/92	12.5	12.9	11.8	8.9	11.9	14.7	13.2	9.5b	11.9
CA/JP/03	11.9	12.2	16	13.6	27.2	29.7	23.6	20.2	19.3
CE/IND/01	32.5	37.2	36.9	23.2	27.8	24.3	20.8	19.7	27.8
CE/IND/06	38.4	39.9	41.2	29	38.7	41.6	35.9	31.2	37
CE/MAL/12	19.2	27.9	27.1	24.4	26.3	26.8	25.1	21.5	24.8
CE/MAL/14	13.2	12	15.1	15.7	39	42.5	37	32.6	25.9
CE/THA/07	14.7	20.3	21	25.8	32.2	32.3	27.7	22.8	24.6
CE/THA/09	23.7	32.7	32.2	21.8	19.5	30.2	28.8	27.2	27
CE/THA/24	21.7	29	30.9	29.2	35.1	30.1	23.3	17.5	27.1
Mean	20.6	25.5	23.2	20.2	24.4	25.7	23.2	19.1	22.8
S.D	6.73	9.49	7.42	5.95	6.99	7.41	6.17	5.64	5.50
L.S.D ($p<0.05$)	0.64	0.9	0.7	0.56	0.66	0.7	0.58	0.53	
C.V	33.47	37.6	32.63	31.53	29.78	30.25	28.18	30.91	24.7
Max	34.2	46.3	40.47	29.27	37.78	41.67	36.57	31.87	35.43
Min	10	10.53	12.5	9.62	12.38	14.02	12.32	9.09	12.34

4.2.1 Effect of mean monthly rainfall, temperature and relative humidity on taro leaf blight disease incidence on Pacific – Caribbean and Kenyan taro under Milimani Garden

The result of the finding was as indicated on table 4.11 below. This study clearly portrayed the relationship between disease progression and rainfall amounts. Increase in rainfall led to an increase in TLB disease incidence on both categories of taro accessions. The highest amount of rainfall recorded during the period of study was 223.9 mm and the disease incidence for Kenyan taro was 29.859%. On the other hand, the Pacific-Caribbean taro had an incidence of 17.705%. The significantly lowest disease incidence of 3.023% for the Kenyan taro was recorded at rainfall amount of 65.5 mm while for the Pacific - Caribbean accession, the disease incidence was zero at the same amount of rainfall. The two highest recorded TLB disease incidence of 23.78% and 15.3% occurred during the month of April and March which also recorded the highest amount of rainfall of 223.9 mm and 174 mm respectively. Disease incidence was significantly ($p<0.05$) lowest at rainfall amount of 65.5 mm during the month of February. (Table 4.11). Pacific-Caribbean accessions; CE/THA/07, BL/HW/08, BL/HW/26, CE/IND/01, CE/IND/06, BL/HW/80/ BL/HW/48 increased in incidence with increase in amount of rainfall. CE/JP/03 was however constant between February and March then increased in incidence between March and April. Kenyan accessions; KMM/MM2/76, KNY/SYA/50, KNY/KIS/20, KNY/KIS/21, KNY/KAK/16, KNY/ELD/75, KNY/CTR/33 and KNY/KIS/61 also showed increase in disease incidence with increase in rainfall amount. Out of the twenty-six accessions investigated, ten showed inconsistent increase in disease incidence with increase in rainfall.

There was no clear and consistent effect of minimum temperature on TLB disease incidence contrary to the numerous findings of Charles *et al*. (2016), Asha (2006) and Omege *et al.* (2016) supporting a positive correlation between temperature and taro leaf blight disease incidence. At minimum temperature of 14.1°C, which occurred in April, highest disease incidence of 23.78 % was recorded. This finding disagreed with that of Hiraida (2016) that a minimum air temperature of 24.38°C was optimum for the development of taro leaf blight. Increase in maximum temperature however led to increase in disease incidence. At maximum temperature of 29.6^0C in March, disease incidence of 15.03% was recorded and at 29.1^0C in February, the incidence was 14.03% (Table 4.11). Average temperature increased with increase in disease incidence during the month of February and March. In April, the average temperature decreased from 22.35-15.05^0C as disease incidence increased from 21.25-23.78%.

The month of April recorded the highest average relative humidity of 59% and the highest morning R.H of 66%. (Table 4.11). Disease incidence was however significantly ($p<0.05$) lowest at average relative humidity 51%. The highest average relative humidity of 59% recorded for the period of study gave rise to the highest percentage disease incidence of 23.78% (Table 4.11). The findings generally revealed an increase in taro leaf blight disease incidence with increase in relative humidity. Similarly, Harplapur (2005) found a range of relative humidity 58.7-84.5% favorable for development of fungal leaf blight.

Table 4.11: Percentage of TLB disease incidence on Pacific - Caribbean taro under Milimani garden viz mean monthly rainfall, temperature and relative humidity

		Age in months			
		Feb	**March**	**April**	
Region	**Accession**	**05**	**06**	**07**	**Pd Mn**
Kenyan	KNY/KIS/81	18.18	16.67	21.28	15.23
Kenyan	KMM/MM1/75	47.06	25	17.65	22.84
Kenyan	KMM/MM2/76	13.64	15.15	35.56	18.20
Kenyan	KNY/SYA/50	13.64	14.71	40.54	18.22
Kenyan	KNY/SYA/51	27.27	23.53	42.11	23.73
Kenyan	KNY/BSA/41	38.89	33.33	29.63	27.04
Kenyan	KNY/KIS/20	9.52	33.33	45.16	22.05
Kenyan	KNY/KIS/21	11.54	19.23	32.35	15.12
Kenyan	KNY/KIS/22	16.67	23.33	21.95	22.39
Kenyan	KNY/KAK/16	3.23	16.13	21.28	8.13
Kenyan	KNY/ELD/75	5.71	11.43	25.58	8.54
Kenyan	KNY/CTR/33	14.71	21.95	28.30	12.99
Kenyan	KNY/KTL/61	3.92	7.84	26.79	7.71
Pacific	CE/THA/7	0	4	21.95	5.19
Pacific	CE/THA/24	14.29	9.09	15.79	7.83
Pacific	BL/HW/8	0	4.35	20.51	4.97
Pacific	BL/HW/26	2.78	12.19	23.69	7.73
Pacific	CE/IND/1	4	16	21.57	8.31
Pacific	CE/IND/6	0	4.76	8.62	3.73
Pacific	CE/MAL/14	5.26	15.79	14.29	7.07
Pacific	CE/JP/3	11.11	11.111	20.51	11.62
Pacific	BL/HW/80	0	20	16.13	7.23
Pacific	BL/SM/28	8.33	4.54	13.64	5.30
Pacific	BL/SM/48	6.67	10	20	7.33
Pacific	BL/SM/111	21.43	10.26	10.26	8.39
Pacific	BL/SM/120	10.71	7.14	23.21	8.21
Mean		14.03	15.03	23.78	12.12
SD		11.06	8.06	9.15	5.72
CV		78.83	53.63	38.48	47.19
LSD p<0.05		1.462	1.066	1.21	

4.2.2 Effect of mean monthly rainfall, temperature and relative humidity on taro leaf blight disease severity on Pacific - Caribbean taro grown under MMUST garden

Table 4.12 below summarizes the result on effect of mean monthly rainfall, temperature and relative humidity on TLB disease severity on Pacific - Caribbean taro (*Colocasiae esculenta*). The rainfall range during the period of study was 5.5mm - 24.9 mm in July and April respectively. The lowest amount of rainfall recorded for the period of study of 5.5 mm had disease severity of 12% while the highest rainfall amount recorded for the study of 24.9 mm registered disease severity of 10.2%. There was no positive correlation between rainfall and TLB disease severity. This could be due to the fact that Pacific - Caribbean was a high rainfall receiving country thus the plants had adapted means of resisting the infection even when rainfall condition was optimum.

The highest significant ($p<0.05$) disease severity of 25.1% was recorded at minimum temperature of 14^0C whereas the lowest significant ($p<0.05$) severity of 9.7% was recorded at minimum temperature of 15.5^0C (Table 4.12). The significantly ($p<0.05$) highest percentage disease severity of 25% was obtained at maximum temperature of 27.2^0C whereas the significantly ($p<0.05$) lowest severity of 9.7% was recorded at maximum temperature of 27.4^0C. However, the highest temperature recorded for the study of 27.5^0C recorded a disease severity of 24.3% and the lowest temperature recorded for the duration of the study of 26.4^0C obtained a lower mean disease severity of 23.6% (Table 4.12).

There was no regular trend on the effect of morning relative humidity on disease severity. contrary to the report by Manju *et al*. (2017) that high relative humidity favors TLB disease development and transmission. The highest significant ($p<0.05$) disease severity of 25.1% was recorded at morning relative humidity of 80% and the lowest significant ($p<0.05$) disease severity of 9.7% was obtained at relative humidity of 82%. The second highest disease severity obtained of 24.3% in October was recorded at afternoon R.H 59%. This was supported by the findings of Chothanil *et al.* (2017) that there was an increase in early blight severity at evening relative humidity of 30-58%. Contrary to this present finding, the lowest disease severity of 9.7% also occurred at R.H of 59% in the month of May. On the other hand, the highest afternoon R.H recorded for the study of 68% occurred in the month of April with disease severity of 10.2%. The afternoon relative humidity of 59% occurred both in the month of May and October with varied disease incidences of 9.7 and 24.3% respectively. Moreover , the month of June, August and September recorded equal afternoon relative humidity with varied disease incidences as 14.3, 23.6 and 25.1% respectively. The average relative humidity either did not show increase with increase in disease severity. At average R.H of 69%, disease severity was 25.1% whereas at RH of 72.5%. disease severity was 9.7%. This inconsistency could have been due to effect of other factors like rainfall and temperature variation.

Table 4.12: Summary of mean monthly rainfall, temperature and relative humidity on TLB disease severity on Pacific - Caribbean taro grown under MMUST garden

Month	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	
	3mths	**4mnths**	**5mths**	**6mths**	**7mths**	**8mths**	**9mths**	**10mths**	
Pacific taro	**Mean monthly TLB disease severity**								**pd m**
BL/HW/08	6.4	5.2	3.7	5.5	6.8	17.8	12	14.9	9
BL/HW/26	5.8	3.4	7.3	6.8	13.7	14.6	12.5	10	9.3
BL/HW/37	6.6	3.2	11.7	8.2	34.2	30.2	26.7	12.4	14.8
BL/PNG/10	7	14.1	9.8	6.8	14.9	14.9	17.6	15.5	11.2
BL/SM/111	3.8	9	10.4	8.9	16.1	13.4	13.1	6.7	9
BL/SM/116	20.9	5.8	7.5	5.8	22.4	26.9	17	15.8	13.6
BL/SM/120	8.8	6.2	13.3	11.8	17.5	10.7	14.6	11.3	10.5
BL/SM/128	15.3	8.5	7.3	10.7	14.6	24.2	20	13.7	12.7
BL/SM/132	9.2	3.2	16	14.6	29	29	27.2	10.8	15.4
BL/SM/143	4.1	4.7	6.4	4.5	14.5	14.7	15.7	12	8.5
BL/SM/149	11.8	7.9	5.4	5.8	19.1	17.4	16.8	14.5	11
BL/SM/151	1.8	1.8	3.8	3.8	27.8	23.9	19.5	15.8	10.9
BL/SM/152	6.8	3.3	12.9	14.7	26.9	32.3	30.2	10.2	15.3
BL/SM/158	3.1	4	8.9	8.5	20.2	25.1	25.7	18.4	12.7
BL/SM/80	7.3	9.1	23.3	20.1	40.9	36.2	40.3	28.3	22.8
BL/SM/92	10.3	4.1	10.4	3.5	13.8	15.9	15.9	5	8.8
CA/JP/03	3.1	7.3	8.8	9.6	26	32.2	25.6	14.5	14.1
CE/IND/01	22.3	30.3	31.1	12.1	22.8	16.2	21.7	15.8	19.1
CE/IND/06	35.8	42.5	48.2	34	45.8	50	56.2	39.2	39.1
CE/MAL/12	8.8	11.3	23.7	19.5	33.8	35.9	33.8	23.7	21.2
CE/MAL/14	5	3.8	6	5.2	26.5	35.2	38.6	24.7	16.1
CE/THA/07	26.1	22.2	21.9	22.8	29.5	29.5	29.5	29.5	23.4
CE/THA/09	11.4	11.4	26.3	24.5	26	29.9	27.8	22.4	20
CE/THA/24	8.8	14.8	27.3	27.8	33.4	35.5	33.7	18.3	22.2
Mean	10.2	9.7	14.3	12	23.6	25.1	24.3	16.6	15.1
CV	131	141	126	134	104	97.3	96.7	113	104.8
LSD	2.539	2.696	3.4	2.951	4.27	4.269	4.186	3.283	

4.2.3 Effect of mean monthly rainfall, temperature and relative humidity on taro leaf blight disease severity on Pacific - Caribbean and Kenyan taro grown under Milimani Garden

Result on effect of mean monthly rainfall on TLB disease severity on Pacific - Caribbean taro was given in table 4.13 below. Generally, TLB disease severity increased with increase in the amount of rainfall. The month of April which had the highest amount of rainfall of 223.9 mm gave the highest recorded disease severity of 47.94%. The least severity of 15.06% was recorded in February when rainfall amount was least (15.06 mm). Pacific-Caribbean accessions; BL/SM/28, CE/IND/01, CE/IND/06, CE/MAL/14, CE/THA/07 and Kenyan accessions; KMM/MM1/75, KMM/MM2/76, KNY/ELD/75, KNY/KAK/16, KNY/KIS/20, KNY/KIS/21, KNY/KIS/22, KNY/KIS/81, KNY/KTL/61, KNY/SYA/50, KNY/SYA/51 had their disease severity increase gradually with increase in rainfall. Harplapur (2005) reported similar result in his study that rainfall range of 47-104 mm were most favorable for development of most fungal diseases. The other accessions did not have consistent increase in severity with increase in rainfall. The highest significant ($p<0.05$) disease severity of 47.94% was recorded at minimum temperature of 14.1^0C, average temperature 21.25^0C and maximum temperature of 28.4^0C. These findings agreed with the earlier finding of Sahu *et al.* (2014) that the minimum temperature had a negative highly significant correlation with blight disease development. Ayogu *et al*. (2015) earlier stated that, epidemics generally flourish when night temperatures are in the range 17–20 °C. The cool temperatures stimulate the release of infective zoospores, promoting multiple infections (Fullerton and Tyson, 2003).

Increase in temperature therefore did not consistently lead to increase in TLB disease severity. This was contrary to the finding of Benzohra *et al*. (2018) that temperature was directly proportional to disease severity. It was also contrary to the report of Charles *et al.* (2016) that increase in maximum temperature could lead to increase in disease severity. The result also implied that age of plant has a major influence on disease severity.

The lowest disease severity of 15.06% was recorded at lower relative humidity in February. The result agreed with the findings of Nwanosike (2015) that relative humidity of 67 - 85.6 % favoured leaf blight development. Kenyan taro consistently recorded higher TLB disease severity than Pacific - Caribbean. could be as a result as a result of the fact that Pacific - Caribbean taro accessions were improved for tolerance to taro leaf blight. Mbong *et al.* (2015) supported this in his finding that there were spores and mycelia growth of *Phytophthora colocasiae* in all the cultivars both improved and local.

Table 4.13: Summary of TLB disease severity on Pacific - Caribbean and Kenyan taro field study -2 viz varied rainfall, temperature and relative humidity

		Age in months			
Region	**Accession**	**5 mths (Feb)**	**6 mths (Mar)**	**7mths (Apr)**	**Pooled Mn**
Pacific	BL/SM/28	1±1.7	6.7±5.8	25±43.3	6.5±19.3
Pacific	BL/SM/48	3.3±5.8	23.3±23.1	17.7±28	8.9±17.2
Pacific	CE/IND/1	2.5±5	21.3±21.7	43.8±23.9	13.5±21.8
Pacific	CE/IND/6	0±0	2.5±5	21.3±21.7	4.9±12.3
Pacific	CE/JP/3	12.5±25	8.8±11.8	26.3±32.5	9.8±19.5
Pacific	CE/MAL/14	2.5±5	15±12.2	30±30.8	9.5±17.9
Pacific	CE/THA/24	5±5.8	3.8±4.3	30±23.1	7.8±15,1
Pacific	CE/THA/7	0±0	2.5±5	38.8±12.5	14.3±28.5
Kenya	KMM/MM1/75	8.8±9.5	24±24.1	52±26.6	17.3±24.9
Kenya	KMM/MM2/76	1.8±1.6	16±19.5	66±28.2	17.1±29.2
Kenya	KNY/BSA/41	33.3±14.4	58.3±14.4	46.7±37.5	28.3±29
Kenya	KNY/CTR/33	10.6±13.2	49±35.6	47±23.3	21.3±29
Kenya	KNY/ELD/75	1.5±1.7	10±0	37.514.4	9.8±15.8
Kenya	KNY/KAK/16	0.6±1.3	20.6±26.9	35±22.4	11.2±20.4
Kenya	KNY/KIS/20	5±5.8	46.3±26.9	50±20.4	20.6±26.9
Kenya	KNY/KIS/21	13.3±24.5	31.3±23.9	56.3±12.5	20.3±26.2
Kenya	KNY/KIS/22	17.5±8.7	30±23.1	56.3±12.5	21.4±23.7
Kenya	KNY/KIS/81	1.5±1.7	7.5±5	75±0	17.1±29.9
Kenya	KNY/KTL/61	2.6±4.3	8±4.5	55±20.9	13.1±23.3
Kenya	KNY/SYA/50	3.3±4.7	27.5±26.3	56.3±23.9	17.7±26.5
Kenya	KNY/SYA/51	25±20.4	52.5±30.7	62.5±14.4	28.5±30.5
	Total	**6.6**	**21**	**44.4**	**14.5**
	CV	**96.02**	**82.77**	**49.4**	**84.01**
	LSD p<0.05	**3.03**	**5.98**	**6.5**	
	Mean	**15.06**	**28.73**	**47.94**	**31.09**

4.3 Relationship between TLB disease resistance and Agronomic traits of Pacific - Caribbean taro accessions under MMUST garden

4.3.1 Taro leaf blight disease resistance of Pacific - Caribbean taro accessions under MMUST garden

Table 4.14 below gives the disease resistance for the different taro accessions from Pacific - Caribbean. The overall range of TLB disease resistance was 56.16 - 93.45%. The accession BL/SM/14 from Samoa had the highest disease resistance of 93.45%. All

the accessions from Samoa recorded TLB disease resistance of at least 80% except accession BL/SM/80 which was 73.84%. The range of disease resistance for Samoan accessions was 73.84 - 93.45%. The resistance range for the Hawaian accessions was 73.84 - 90.54. The least resistance was obtained from Indonesian accession CE/IND/06 with 56.16%. The accessions from Indonesia and Thailand recorded below 80% resistance. The Samoan accessions seemed to exhibit superiority over the rest in disease resistance, followed by the Hawaian accesson. The finding of this study depicted an influence of location of origin on TLB disease resistance.

Table 4.14: Taro leaf blight disease resistance of Pacific - Caribbean taro accessions under MMUST Garden

Region	Accession	Resistance
PACIFIC	BL/HW/08	90.54
PACIFIC	BL/HW/26	90.6
PACIFIC	BL/HW/37	81.56
PACIFIC	BL/HW/80	73.84
PACIFIC	BL/PNG/10	86.73
PACIFIC	BL/SM/111	90.12
PACIFIC	BL/SM/116	86.5
PACIFIC	BL/SM/120	89.34
PACIFIC	BL/SM/128	84.55
PACIFIC	BL/SM/132	80.97
PACIFIC	BL/SM/143	93.45
PACIFIC	BL/SM/149	88.43
PACIFIC	BL/SM/151	85.85
PACIFIC	BL/SM/152	82.78
PACIFIC	BL/SM/153	87.46
PACIFIC	BL/SM/158	84.23
PACIFIC	BL/SM/80	73.84
PACIFIC	BL/SM/92	89.63
PACIFIC	CA/JP/03	84.77
PACIFIC	CE/IND/01	79.04
PACIFIC	CE/IND/06	56.16
PACIFIC	CE/MAL/12	74.55
PACIFIC	CE/MAL/14	80.87
PACIFIC	CE/THA/07	71.49
PACIFIC	CE/THA/09	75.97
PACIFIC	CE/THA/24	75.95
	Min	**56.16**
	Max	**93.45**

4.3.1.1 Agronomic traits in terms of number of leaves of Pacific-Caribbean taro under MMUST Garden

Mean monthly number of leaves of Pacific - Caribbean taro under MMUST Garden was given on Table 4.15 below. The highest number of leaves of 10 was obtained from

Hawaiian accession BL/HW/26 and the lowest of 6.55 leaves was from Samoan accession BL/SM/158. Age 10 months had the highest average number of leaves of 9.1 while age 5 months had the least number of leaves of 6.75 (Table 4.15). The Hawaiian accessions BL/HW/26, BL/HW/08 and BL/HW/37 had the highest number of leaves with an average of 9.6 leaves, Thailand followed with an average of 8.04, Papua New Guinea 7.8, Samoa 7.59, Indonesia, 7.49 and Malacia 7.13 respectively.

Table 4.15: Mean number of leaves from various accessions of Pacific - Caribbean taro under MMUST Garden

Mean number of leaves of various accessions of Pacific Caribbean taro									
Age	**3mnths**	**4months**	**5mnths**	**6mths**	**7mths**	**8mths**	**9mths**	**10mths**	
Pacific taro	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Pld M**
BL/HW/08	11.1±3.2	8.75±2.3	8.08±2.1	8.08±1.9	8.8±2.5	10±2.5	11±1.6	12±3.6	**9.79**±2.85
BL/HW/26	9.83±3.9	8.33±1.8	8.75±2	9.33±2.5	9.8±2.2	11±2	12±2.1	11±1.8	**10**±2.55
BL/HW/37	8.75±4.5	8.08±1.8	8.17±1.8	8.08±1.7	9.2±1.9	10±2.9	9.8±2.6	11±2.2	**9.11**±2.64
BL/PNG/10	7.82±1.4	5.42±1.7	5.18±1.9	6.18±1.9	7.2±1.7	10±1.7	10±1.7	10±1.7	**7.87**±2.71
BL/SM/111	9.08±3	7±2.1	7.08±2.2	7.33±2.6	8.2±2.8	8.2±2.8	8±2.8	8±2.7	**7.85**±2.63
BL/SM/116	8.67±3.3	7.92±2.2	7.33±2.5	6.75±2.1	6.9±2.2	6.9±2.2	7.2±2.3	8.3±1.8	**7.5**±2.38
BL/SM/120	12.8±3.1	7.5±1.7	7.5±1.7	7.42±1.6	8.9±1.6	8.9±1.6	9±1.7	9.9±1.8	**9**±2.49
BL/SM/128	6±1.7	6.42±1.9	6.33±1.8	6.42±1.9	7.8±1.5	7.8±1.5	7.5±1.4	8.8±1.5	**7.14**±1.83
BL/SM/132	10.3±6	6.83±1.5	7±1.7	7.17±1.9	8.3±1.8	8.3±1.8	8.3±1.7	8.8±1.8	**8.11**±2.78
BL/SM/143	6.33±1.7	7.25±2	7.17±2.4	7.5±2.2	9.1±1.9	9.1±1.9	8.7±1.8	8.9±1.8	**8**±2.17
BL/SM/149	6.5±1.5	6.25±1.5	6.42±1.4	6.42±2.4	7.1±2.4	7.1±2.4	7.2±2.4	8.8±2	**6.96**±2.11
BL/SM/151	5.75±2	5.25±1.8	5.33±1.7	5.42±1.7	6.6±1.7	6.6±1.7	6.4±1.7	6.8±2	**6.02**±1.82
BL/SM/152	11.4±5	7.33±1.8	7.08±1.7	6.67±2.5	8.4±2.2	8.2±2	7.7±2.9	8.1±2.3	**8.1**±2.97
BL/SM/153	8.67±2.4	5.92±1.6	5.83±1.8	5.67±1.8	7.1±2.4	6.2±1.5	6.1±1.6	8.2±1.3	**6.7**±2.07
BL/SM/158	6.58±4.3	4.75±1.6	5.25±1.9	5.67±2.2	7.5±1.6	7.5±1.6	7.3±1.7	7.8±1.7	**6.55**±2.41
BL/SM/80	8.83±5.2	6.42±1.7	6.33±1.8	6.33±1.8	7.4±2	7.4±2	7.8±1.7	9.4±2.2	**7.5**±2.66
BL/SM/92	7.92±1.4	9.08±2.1	8.67±1.7	8.67±1.7	9.4±1.4	9.4±1.4	9.9±1.2	11±1.6	**9.26**±1.77
CA/JP/03	5.83±2.9	5.92±1.8	6.08±1.9	6.17±2.3	7.6±2.4	7.6±2.4	7.7±2.4	9±1.9	**6.98**±2.44
CE/IND/01	8.08±3.5	6.17±1.5	6±1.4	6±1.3	7.9±1.2	7.9±1.2	7.8±1.3	8.2±.1.6	**7.25**±1.95
CE/IND/06	10.1±4.1	7.08±1.4	7±1.4	6.83±1.6	7.5±1.5	7.5±1.5	7.4±1.6	8.3±1.8	**7.72**±2.21
CE/MAL/12	9.92±5.1	6±1.9	6±1.9	7.08±2.4	7.9±2	7.9±2	7.9±2	8.4±2.7	**7.65**±2.87
E/MAL/14	6.08±2.5	6±1.5	5.75±1.4	6.67±1.4	7±1.5	7±1.5	6.8±1.3	7.6±1.4	**6.61**±1.65
CE/THA/07	9.75±4.2	6.25±1.6	6.42±1.8	6.42±1.8	7.3±1.9	7.3±1.9	7.5±1.7	9±1.7	**7.48**±2.45
CE/THA/09	9.75±4	6.5±1.8	6.67±1.7	6.75±1.6	7.8±1.6	7.8±1.6	8±1.8	8.7±1.8	**7.75**±2.31
CE/THA/24	13.1±5	8.09±2.1	7.08±1.8	6.25±2	6.8±2.2	9.5±2.4	9.5±2.4	11±1.9	**8.89**±3.36
Mean/month	**8.76**±4.1	**6.82**±2.1	**6.75**±2	**6.85**±2.1	**7.9**±2.1	**8.3**±2.3	**8.3**±2.3	**9.1**±2.3	**7.83**±2.63
CV	**46.3**	**30.1**	**29.6**	**30.8**	**26**	**28**	**28**	**25**	
LSD p<0.05)	**0.57**	**0.287**	**0.28**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	

4.3.1.2 Agronomic traits (in terms of leaf area) of Pacific - Caribbean taro under MMUST Garden in correlation with TLB disease resistance

There was a statistically significant weak correlation between resistance and average leaf area as shown in the figure 4.19 below. The coefficient of determination (R^2) (0.072) was positive indicating that there was more resistance in plants with greater leaf area. When the scattered graph was presented, the line of best fit had a positive slope as shown in figure 4.19 below.

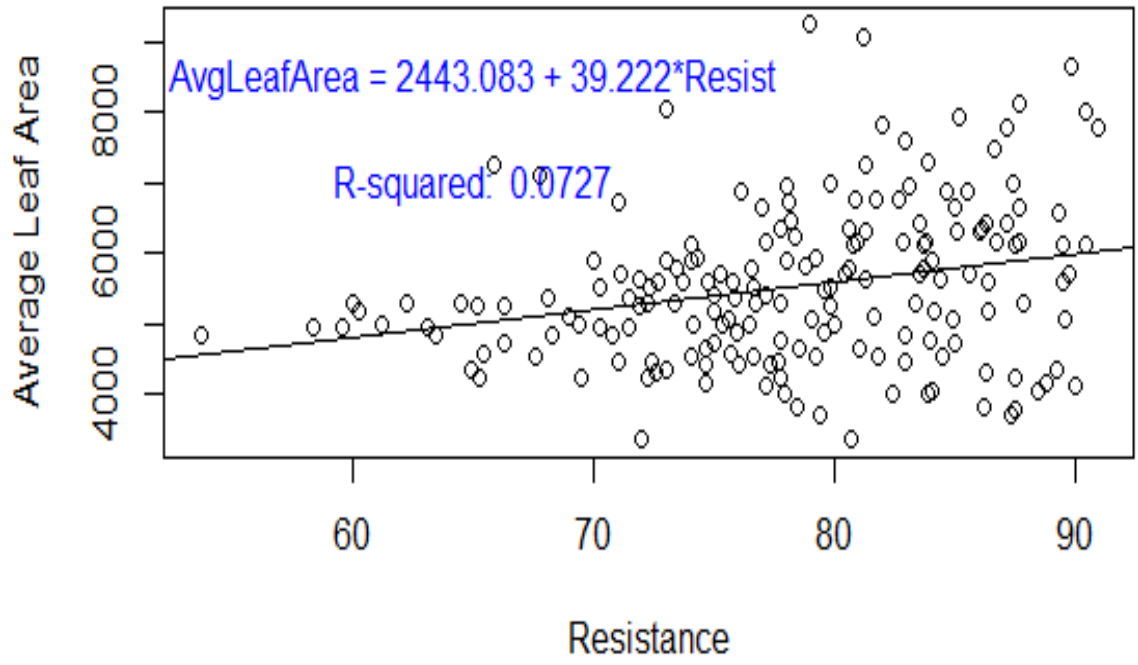


Figure 4.19: A scatter plot of leaf area in a month versus the resistance under MMUST Garden

4.3.1.3 Agronomic traits in terms of number of suckers of Pacific - Caribbean taro under MMUST Garden in correlation with TLB disease resistance

The number of suckers increased over time. Thus, the resistance improved as the plant matured. Correlation between TLB resistance and number of suckers shown on figure 4.2 revealed a positive but weak co-efficient of 0.0066 between the resistance and the

number of suckers. It showed that plants with more suckers tended to have higher resistance.

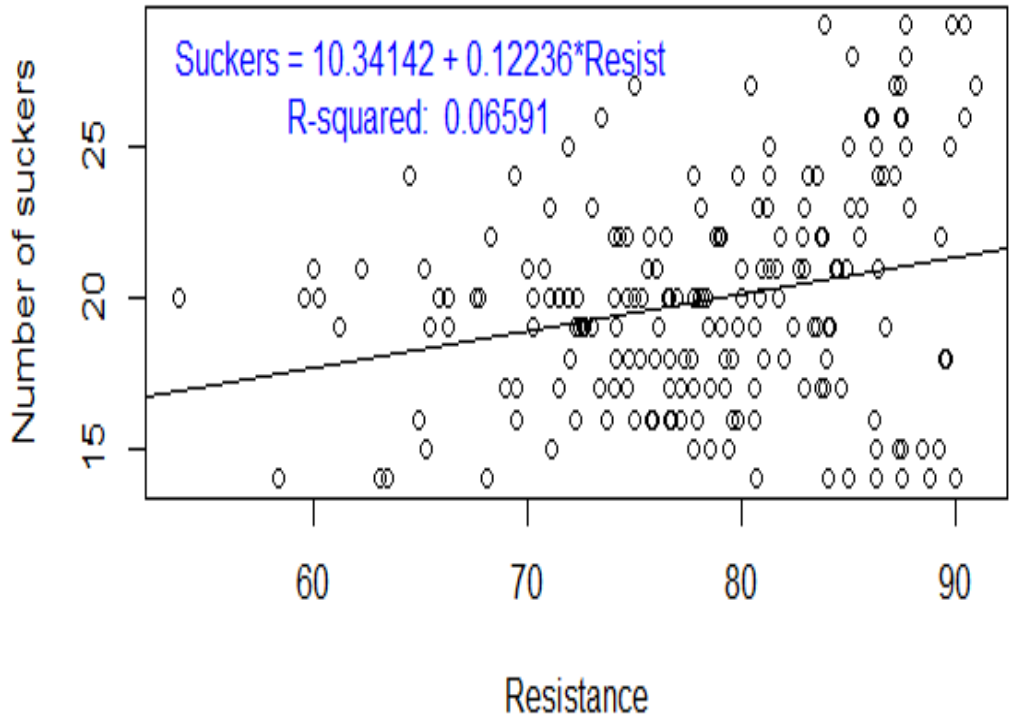


Figure 4.20: A scatter plot of the number of suckers in a month versus the resistance under MMUST Garden

4.3.1.4. Level of resistance of Pacific - Caribbean taro accession against TLB disease under MMUST garden

Generally, most of the Pacific - Caribbean accessions were moderately resistant. The resistant accessions were BL/SM/92, BL/SM/143, BL/SM/111, BL/HW/26 and BL/HW/08. Three of these were from Samoa and two from Hawaii. Only accession CE/IND/06 from Indonesia was found to be moderately susceptible to taro leaf blight (Table 4.16). None of the Pacific - Caribbean taro accessions was susceptible (Table 4.16).

Table 4.16: Level of resistance of Pacific - Caribbean taro accession against TLB disease under MMUST Garden

Scale identity	Range of disease severity	Level of resistance	No of accessions	Accessions
0-1	0-10%	R	5	BL/HW/08, BL/HW/26, BL/SM/111, BL/SM/143 BL/SM
1-2	10.1-25%	MR	19	BL/HW/37, BL/PNG/10, BL/SM/116, BL/SM/120, BL/SM/128, BL/SM/132, BL/SM/149, BL/SM/151, BL/SM/152, BL/SM/158, BL/SM/80, CA/JP/03, CE/IND/01, CE/MAL/12, CE/MAL/14, CE/THA/07, CE/THA/09, CE/THA/24, CE/IND/06
2-3	25.1-50%	MS	1	CE/IND/06
3-4	>50%	S	None	None

Host responses: R = Resistant; MR = Moderately resistant; MS = Moderately susceptible; S = Susceptible.

4.3.2 Taro leaf blight disease resistance of Pacific - Caribbean and Kenyan taro accessions under Milimani Garden

Table 4.17 below presents disease resistance for both Pacific - Caribbean and Kenyan taro accessions. The accession that had the highest disease resistance of 89.73% was Samoan BL/SM/128 and the lowest resistance was obtained from Kenyan- Siaya accession KNY/SYA/51 with 58.27%. All the Kenyan taro accessions had disease resistance of below 80% except accession KNY/KAK/16 from Kakamega county with 82.9% resistance and KNY/ELD/75 with 84.34% resistance from Uashin Gishu county. None of the Pacific - Caribbean taro accessions had below 73.81% resistance and six out of thirteen Pacific - Caribbean accessions had over 80% resistance. On average, the Pacific - Caribbean highest resistant accession was recorded on Indonesia and Japan with 82.49% resistance. Malacia, Hawaii, Samoa and Thailand had their average resistance at

82.25, 81.46, 80.44, and 80. 39% respectively. The Kenya's least resistant accession was obtained from Busia with a percentage of 64.02%. Siaya, Kisumu, Central Kenya, Mumias had their average disease resistance of 64.16, 67.24, 67.66 and 69.46% respectively. The result revealed generally higher TLB disease resistance with the Pacific - Caribbean taro accessions than the Kenyan taro.

Table 4.17: Taro leaf blight disease resistance of Pacific - Caribbean and Kenyan taro accessions under Milimani Garden

Region	Accession	Resistance
KENYAN	KMM/MM1/75	67.47
KENYAN	KMM/MM2/76	71.44
KENYAN	KNY/BSA/41	64.02
KENYAN	KNY/CTR/33	67.66
KENYAN	KNY/ELD/75	84.34
KENYAN	KNY/KAK/16	82.9
KENYAN	KNY/KIS/20	70.91
KENYAN	KNY/KIS/21	68.57
KENYAN	KNY/KIS/22	68.07
KENYAN	KNY/KIS/81	61.39
KENYAN	KNY/KTL/61	79.16
KENYAN	KNY/SYA/50	70.05
KENYAN	KNY/SYA/51	58.27
PACIFIC	BL/HW/08	88.65
PACIFIC	BL/HW/26	78.13
PACIFIC	BL/HW/80	77.59
PACIFIC	BL/SM/111	77.54
PACIFIC	BL/SM/120	76.91
PACIFIC	BL/SM/128	89.73
PACIFIC	BL/SM/80	77.59
PACIFIC	CA/JP/03	82.49
PACIFIC	CE/IND/01	75.28
PACIFIC	CE/IND/06	89.7
PACIFIC	CE/MAL/14	82.25
PACIFIC	CE/THA/07	73.81
PACIFIC	CE/THA/24	86.96
	Min	**58.27**
	Max	**89.73**

4.3.2.1 Agronomic traits in terms of number of leaves of Pacific - Caribbean and Kenyan taro under Milimani Garden

The result on number of leaves of Pacific - Caribbean and Kenyan taro under Milimani garden was given on table 4.18. The highest mean number of leaves of 8.1 was obtained from Samoan BL/SM/120 and the one with the lowest mean number of leaves of 4.7 was from accession CE/JP/3 from Japan. Age three had the lowest number of leaves of 2.05 while age seven had the highest mean number of leaves of 10.98. The average number of leaves for the Pacific - Caribbean taro was 6.2 while for Kenya was 5.85 leaves. There was steady increase in number of leaves with increase in age of plant as shown on table 4.18. Pacific - Caribbean taro hence produced more leaves than the Kenyan.

Table.4.18: Mean number of leaves of Pacific - Caribbean and Kenyan taro accessions under Milimani Garden

Mean number of leaves compared by region							
Age		**3mnths**	**4mnths**	**5mnths**	**6mnths**	**7mnths**	
Region	**Taro accession**	**M leaves**	**M. leaves**	**M leave**	**Mean leaves**	**Mean leaves**	**PD Mn**
Pacific	BL/HW/26	2.43±0.53	2.86±0.69	5.14±0.9	5.86±0.9	10.86±2.73	5.43±3.33
Pacific	BL/HW/8	2.25±0.5	2.25±0.5	5±0.82	5.75±1.71	9.75±1.71	5±3.03
Pacific	BL/HW/80	1.33±0.58	4±0	5±1	8.33±3.79	10.33±0.58	5.8±3.63
Pacific	BL/SM/111	2.33±0.58	2.67±1.15	4.67±0.58	13±2.65	13±2.65	7.13±5.25
Pacific	BL/SM/120	2±0	3.5±3	7±2.7	14±2.94	14±2.94	8.1±5.7
Pacific	BL/SM/28	2.67±0.58	3±0	4±0	14.67±2.52	14.67±2.52	7.8±5.98
Pacific	BL/SM/48	3±0	3.33±0.58	5±0	13.33±1.53	13.33±1.53	7.6±4.97
Pacific	CE/IND/1	2±0	4.25±1,26	6.25±1.7	6.25±1.71	12.75±3.77	6.3±4.12
Pacific	CE/IND/6	1.5±0.58	4.75±1.5	5.25±1.89	5.25±1.89	14.5±1.29	6.25±4.67
Pacific	CE/JP/3	1.5±0.58	3.25±0.5	4.5±1.29	4.5±1.29	9.75±3.3	4.7±3.21
Pacific	CE/MAL/14	2.25±0.5	3.75±0.5	4.75±1.26	4.75±1.26	14±2.71	5.9±4.46
Pacific	CE/THA/24	2.75±0.5	2.75±0.5	5.25±0.96	5.5±1.29	9.5±1.73	5.15±2.72
Pacific	CE/THA/7	2.25±0.5	2.25±0.5	6.25±2.06	6.25±2.06	10.25±1.71	5.45±3.36
Kenya	KMM/MM1/75	2.2±0.45	2.6±0.55	3.4±0.89	4.8±1.92	13.6±1.52	5.32±4.46
Kenya	KMM/MM2/76	2±0	2.4±0.55	4.4±1.82	6.6±0.89	9±0.71	4.88±2.83
Kenya	KNY/BSA/41	3±0	3±0	6±3	7±1.73	9±1.94	5.6±2.77
Kenya	KNY/CTR/33	1.8±0.45	2±0	6.8±1.3	8.2±1.48	10.6±1.95	5.88±3.72
Kenya	KNY/ELD/75	1.75±0.5	2±0	8.75±0.5	8.75±0.5	10.75±0.96	6.4±3.9
Kenya	KNY/KAK/16	1.4±0.55	2±0	6.2±1.64	6.2±1.64	9.4±0.55	5.04±3.19
Kenya	KNY/KIS/20	2.25±0.5	2.25±0.5	5.25±0.5	5.25±0.5	7.75±1.5	4.55±2.26
Kenya	KNY/KIS/21	1±0	2±0	6.5±1.29	6.5±1.29	8.5±0.58	4.9±3.06
Kenya	KNY/KIS/22	2±0	2±0	6±2.83	7.5±1	10.25±0.5	5.55±3.5
Kenya	KNY/KIS/81	2.25±0.5	2.5±0.58	2.75±0.5	4.5±2.38	11.75±2.75	4.75±3.97
Kenya	KNY/KTL/61	1.2±0.45	2±0	10.2±1.3	10.2±1.3	11.2±1.3	6.96±4.59
Kenya	KNY/SYA/50	2±0	2.25±0.5	5.5±2.08	8.5±2.08	9.25±1.98	5.5±3.41
Kenya	KNY/SYA/51	2.75±0.5	3±0	5.5±3	8.5±1.29	9.5±0.58	5.85±3.13
	Mean	2.05±0.64	2.75±1.03	5.64±2.09	7.45±3.17	10.98±2.6	5.77±3.89
	CV	31.2	37.5	37.1	42.6	23.7	
	LSD p<0.05	0.15	0.2405	0.488	0.74	0.607	

4.3.2.2 Agronomic traits (in terms of leaf area) of Pacific - Caribbean and Kenyan taro under Milimani Garden in correlation with TLB disease resistance.

There was a statistically significant correlation between resistance and average leaf area as shown in the figure 4.3 below. The coefficient was negative indicating that there was

less resistance in plants with greater leaf area. When the scattered graph was presented, the line of best fit had a negative slope as shown in figure 21 below.

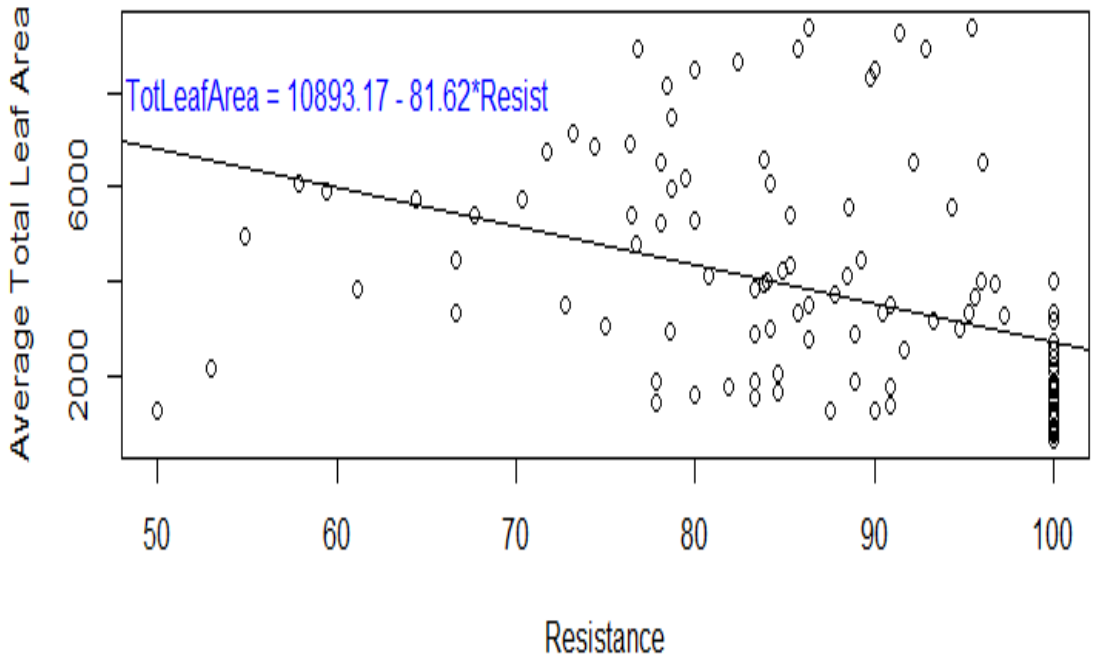


Figure 4.21: A scatter plot of leaf area versus TLB resistance under Milimani garden

4.3.2.3 Agronomic traits (in terms of number of suckers) of Pacific - Caribbean and Kenyan taro under Milimani Garden in correlation with TLB disease resistance.

The resistance had a statistically significant correlations with total number of suckers. The correlation was however negative with a coefficient 0.1106 in that increase in the number of suckers led to a decrease in disease resistance as shown in figure 22 below

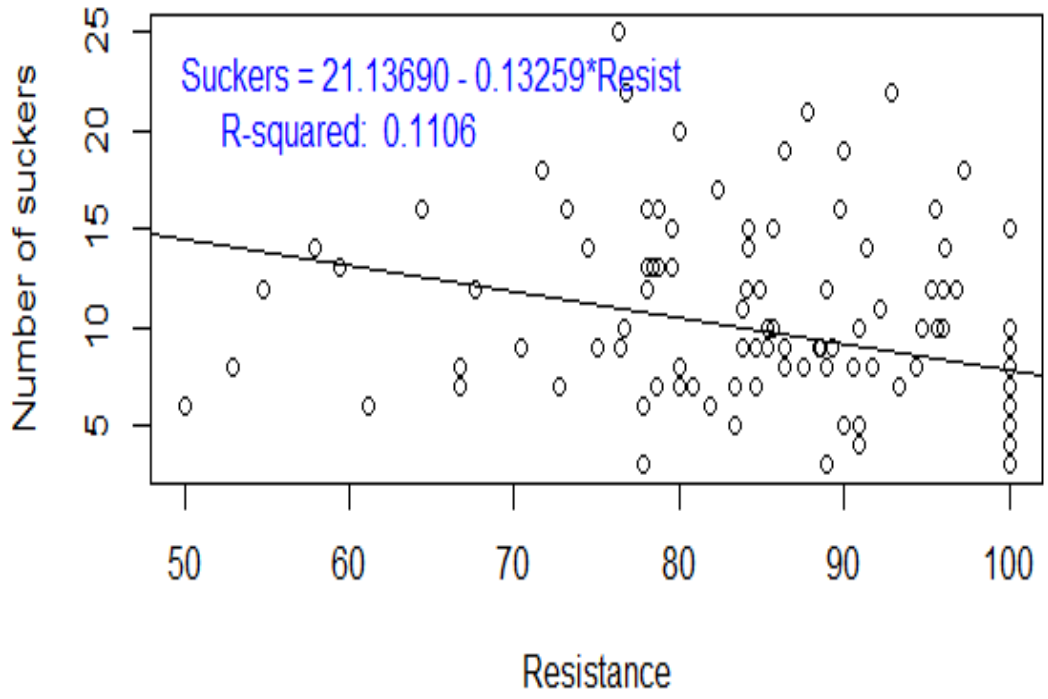


Figure 4.22: A scatter plot of the number of suckers in a month versus the resistance in the Second experiment

4.3.2.4 Level of resistance of Pacific - Caribbean taro accession against TLB disease under Milimani Garden

The result on investigation of taro leaf blight disease resistance in Kenyan and Pacific - Caribbean taro in experiment two are as outlined on table 4.19. The pooled average disease resistance of the accessions revealed that all the accessions except one (CE/THA/07) were moderately resistant. None of the accessions was resistant and none was susceptible (Table 4.19).

Table 4.19: Level of resistance of Pacific - Caribbean taro accession against TLB disease under Mililani garden

Scale	Level of resistance	No of accessions	Accession identity
0-1	R	None	None
1-2	MR	12	BL/SM/26, BL/HW/08, BL/HW/80, BL/SM/111, BL/SM/120, BL/SM/28, BL/SM/48, CE/IND/01 CE/IND/06, CE/JP/03, CE/MAL/14, CE/THA/24
2-3	MS	1	CE/THA/07
3-4	S	None	None

*Host responses: R = Resistant; MR = Moderately resistant; MS = Moderately susceptible; S = Susceptible.

4.3.2.5 Level of resistance of Kenyan taro accession against TLB disease under Milimani garden

The result on Kenyan taro accession varietal disease resistance under field study two was as illustrated on table 4.20 below. Ten of the accessions were moderately resistant, two, moderately susceptible and only one (KNY/ELD/75) was resistant. None of them was susceptible to taro leaf blight.

Table 4.20: Level of resistance of Kenyan taro accession against TLB disease under Milimani garden

Scale	Level of resistance	No of accessions	Accession identity
0-1	R	1	KNY/ELD/75
1-2	MR	10	KMM/MM1/75, KMM/MM2/76, KNY/CTR/33, KNY/KAK/16, KNY/KIS/20,KNY/KIS/21,KNY/KIS/22,KNY/KIS/81, KNY/KTL/61, KNY/SYA/50
2-3	MS	2	KNY/BSA/41, KNY/SYA/51
3-4	S	None	None

Host responses: R = Resistant; MR = Moderately resistant; MS = Moderately susceptible; S = Susceptible

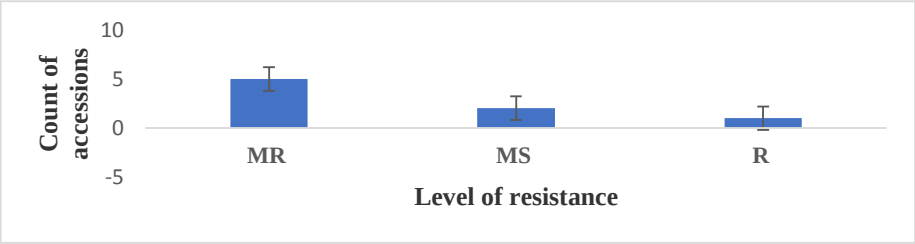
4.3.3. Relationship between TLB disease resistance and agronomic traits of Pacific - Caribbean and Kenyan taro accessions under greenhouse study

The greenhouse experiment result on TLB disease resistance is presented on table 4.21 below. The highest disease resistance of 89.69% was obtained from Hawaii accession BL/HW/26 and the lowest resistance of 55.06% was recorded from Kenyan accession from Busia county KNY/BSA/41. Of the eight Pacific - Caribbean accessions examined, three had over 83.32% resistance. None of the Kenyan accessions observed recorded more than 73.47% resistance. The average TLB disease resistance for Pacific - Caribbean taro accessions were 78.59% and for Kenya was 67.95%. The result revealed low disease resistance on Kenyan taro than the Pacific - Caribbean.

Table 4.21: Taro leaf blight disease resistance of Pacific - Caribbean and Kenyan taro accessions under greenhouse experiment

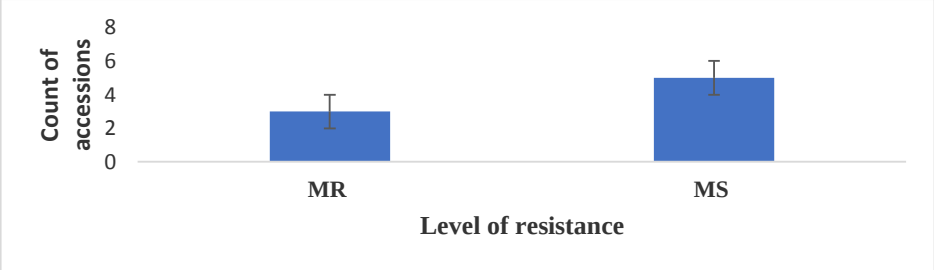
Region	Accession	Resistance
KENYAN	KNY/BSA/41	55.06
KENYAN	KNY/CNT/33	63.95
KENYAN	KNY/KAK/16	78.14
KENYAN	KNY/KSM/81	66.44
KENYAN	KNY/KTL/61	67.34
KENYAN	KNY/MU/75	73.47
KENYAN	KNY/SYA/50	72.74
KENYAN	KNY/SYA/51	66.42
PACIFIC	BL/HW/08	78.73
PACIFIC	BL/HW/26	89.68
PACIFIC	BL/SM/80	74.38
PACIFIC	BL/SM/92	85.53
PACIFIC	CA/JP/03	83.32
PACIFIC	CE/IND/01	75.32
PACIFIC	CE/THA/07	73.54
PACIFIC	CE/THA/24	68.28
	Min	**55.06**
	Max	**89.68**

Summary of the level of resistance to taro leaf blight of Pacific - Caribbean and Kenyan taro is shown on figure 4.23 and 4.24 below. Difference in disease resistance among the two categories of accessions inoculated in this study indicated that there was difference in varietal reaction to TLB pathogen and also aggressiveness of the pathogens used for inoculation.



Host responses: R = Resistant; MR = Moderately resistant; MS = Moderately susceptible; S = Susceptible.

Figure 4.23: Count of Pacific- Caribbean taro accessions by level of resistance to taro leaf blight under greenhouse experiment of September 2015 to January 2016



Host responses: R = Resistant; MR = Moderately resistant; MS = Moderately susceptible; S = Susceptible.

Figure 4.24: Count of Kenyan taro accessions by level of resistance to taro leaf blight under greenhouse experiment of September 2015 to January 2016

4.3.3.1. Number of leaves of Pacific-Caribbean and Kenyan taro under greenhouse study

The result on mean monthly number of leaves of Pacific-Caribbean and Kenyan taro under showed that the highest number of leaves of 5.5 at age seven, the last month of study. The lowest mean number of leaves of 3.4 occurred at age three which was also the first month of data recording. The accession with significantly ($p<0.05$) highest mean number of leaves of 4.7 was Pacific Hawaiian accession BL/HW/26 and the one with the lowest mean number of leaves of 4.2 was Kenyan Kakamega accession KNY/KAK/16. The number of leaves of Pacific - Caribbean and Kenyan taro was statistically the same

with Pacific - Caribbean taro accessions recording an average of 4.48 and Kenyan accessions 4.45 leaves.

Table 4.22: Mean number of leaves compared between Pacific - Caribbean and Kenyan taro accessions on greenhouse experiment

Mean number of leaves compared by region							
	Age	**3mnths**	**4mnths**	**5mnths**	**6mnths**	**7mnths**	
Region	**Accession**	**Mean**	**Mean**	**Mean**	**Mean**	**Mean**	**Pled mean**
Pacific	BL/HW/08	3.3±0.5	4±0.9	4.3±0.5	4.7±0.5	5.7±0.5	4.4±1
Pacific	BL/HW/26	3.6±0.5	4.7±0.5	4.7±0.5	4.9±0.6	5.8±0.7	4.7±0.9
Pacific	BL/SM/80	3.8±0.4	4.4±0.7	4.4±0.7	4.8±0.4	5.2±0.4	4.5±0.7
Pacific	BL/SM/92	3.4±0.5	3.9±0.8	4.2±0.4	4.6±0.5	5.6±0.7	4.3±0.9
Pacific	CA/JP/O3	3.3±0.5	4.3±0.5	4.3±0.5	4.3±0.5	5.7±0.7	4.4±0.9
Pacific	CE/IND/1	3.4±0.5	4.2±0.8	4.4±0.5	4.8±0.4	5.7±0.7	4.5±0.9
Pacific	CE/THA/07	3.3±0.5	4±0.9	4.3±0.5	4.7±0.5	5.6±0.7	4.4±1
Pacific	CE/THA/24	3.7±0.5	4.7±0.7	4.7±0.7	4.8±0.7	5.3±0.9	4.6±0.9
Kenya	KNY/BSA/41	3.3±0.5	4±0.7	4.2±0.4	4.6±0.5	5.3±0.8	4.3±0.9
Kenya	KNY/CNT/33	3.5±0.5	4.6±.0.7	4.6±0.6	4.9±0.7	5.5±0.9	4.6±0.9
Kenya	KNY/KAK/16	3.2±0.4	3.9±0.7	4.2±0.5	4.6±0.6	4.9±0.7	4.2±0.8
Kenya	KNY/KSM/81	3.3±0.4	4.1±0.7	4.4±0.5	4.8±0.4	6±0.8	4.5±1.1
Kenya	KNY/KTL/61	3.3±0.5	4.2±1	4.4±0.7	4.7±0.7	5.7±1	4.5±1.1
Kenya	KNY/MU/75	3.5±0.5	4.4±0.7	4.4±0.5	4.8±0.5	5.4±0.9	4.5±0.9
Kenya	KNY/SYA/50	3.6±0.5	4.3±0.8	4.4±0.5	5±0.5	5.7±0.7	4.6±0.9
Kenya	KNY/SYA/51	3.3±0.5	4±0.7	4.3±0.5	5±0.7	5.5±0.9	4.4±1
	Mean	3.4	4.2	4.40.6	4.8	5.5	4.5
	CV	14.7	16.7	13.6	12.5	14.5	20
	LSD	0.11	0.07	0.09	0.08	0.08	0.12

Figure 4.25 below showed that the number of leaves of Pacific - Caribbean and Kenyan taro had a steady but slow increase in number of leaves from month three to month seven. The error bars indicated significant difference in number of leaves only between age three in September and age seven in January. Age four to six number of leaves were statistically the same.

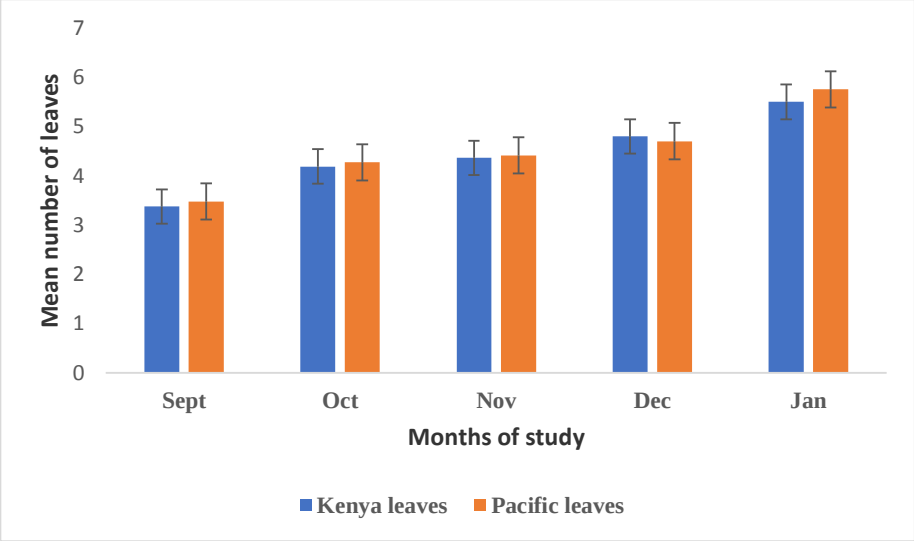


Figure 4.25. Comparison of number of leaves of Pacific - Caribbean and Kenyan taro

4.3.3.2 Plant height of Pacific - Caribbean and Kenyan taro under greenhouse study

The plant height was compared by region and the result was given on model table 4.23. The average height for the accessions from Kenya was 65.45cm. This was taller than the accessions from the Pacific-Caribbean by 3.43 cm. According to the model, Kenyan varieties under the 2R1 treatment had an average height of 43.91 cm. The height increased by 8.55 units each month for the five months, irrespective of the region from which the accession came from. There was statistical evidence to indicate that the accession from Pacific-Caribbean were 3.43 units shorter than the Kenyan ones. The

accessions under the other treatments were also shorter than those under the 2R1 treatment as indicated in model table 4.23.

Table 4.23: Mean leaf height compared between Pacific - Caribbean and Kenyan taro accessions on greenhouse study

	Estimate	Std Error	t-value	Pr (> t)	
Intercept	43.9076	0.4515	97.256	<2e-16	***
Category pacific	-3.4266	0.3933	-8.713	<2e-16	***
Treatment 3R1	-3.1207	0.3966	-7.869	6.39-15	***
Treatment water	-9.1495	0.3966	-23.071	<2e-16	***
Age in months	8.5456	0.1145	74.647	<2e-16	***

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

4.3.3.3 Corm weight of Pacific-Caribbean and Kenyan taro under greenhouse study.

The result on corm weight comparison between Pacific - Caribbean and Kenyan taro were given on a model table 4.24. The accessions from the Pacific - Caribbean had heavier corm weights compared to the Kenyan ones with statistical significance as shown in the model. Further, there was enough statistical evidence to indicate that plants in the 3R1 taro leaf blight pathogen and water treatments had a heavier corm than those under the 2R1taro leaf blight pathogen treatment as shown in the model table 4.24. There was not enough statistical evidence to indicate that the corm diameter and corm length between accessions from the Pacific - Caribbean and Kenya differed.

Table 4.24: Mean corm weight compared between Pacific - Caribbean and Kenyan taro accessions on greenhouse experiment

	Estimate	Std Error	t-value	Pr(>t)	
			-		***
Intercept	-61.4528	3.6305	16.927	<2e-16	
Category	10.1859	3.1626	3.221	0.0013	**
Treatment3R1	2.8759	3.1891	0.902	0.3673	
Treatment water	9.9703	3.1891	3.126	0.0018	**
Age In months	27.4842	0.9206	29.854	<2e-16	***

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

4.3.3.4 Level of resistance of Pacific - Caribbean taro accession against TLB disease under greenhouse study

The result on greenhouse experiment is shown on table 4.25. Compared to the experiment one of April-November 2013, more Pacific - Caribbean accessions became susceptible or moderately susceptible to taro leaf blight as shown on table 4.25. The disease reaction of the eight accessions of taro showed differences in resistance to isolates of *Phytophthora colocasiae*. In the pooled response of taro to TLB disease, accession BL/HW/26 emerged resistant while CE/THA/24 and BL/SM/80 were moderately susceptible (Table 4.25). This variation could indicate that there existed differences in resistance levels and degree of response of various taro accessions to inoculated blight pathogen. This is because the genetic makeup of taro may promote the growth and spread of the pathogen or resist and eliminate it altogether. Cadle-Davidson *et al.* (2011) investigated the resistance level of some Vitis species to different strains of *Uncinula necator*, the causal agent of powdery mildew. They determined resistance level differences amongst accessions similar to this current study. Furthermore, the findings of Atak (2016) was consistent with this study that resistance levels in cultivars can differ for different isolates. The finding further

stated that while species were important in resistance breeding, the resistance level of each accession should be determined.

Table 4.25: Level of resistance of Pacific - Caribbean taro accession against TLB disease under greenhouse study

Scale	Level of resistance	Number of accessions	Accession identity
0-1	R	1	BL/HW/26
1-2	MR	5	BL/HW/08, BL/SM/92, CA/JP/03, CE/IND/01, CE/THA/07
2-3	MS	2	CE/THA/24, BL/SM/80
3-4	S	NONE	

Host responses: R = Resistant; MR = Moderately resistant; MS = Moderately susceptible; S = Susceptible

4.3.3.2 Resistance of Kenyan taro accession against TLB disease under greenhouse study

Table 4.26 below illustrates the summary of Kenyan taro accession disease resistance under greenhouse study. For the Kenyan taro accessions, moderate susceptibility was observed. It was evident that none of the Kenyan accessions evaluated in the greenhouse was resistant to taro leaf blight and that accessions belonging to the same species differed in their resistance to pathogens. Similar to the findings in this study, Atak (2016) reported that *V. vinifera* cultivars generally had low disease resistance, but it was also reported that resistance level of cultivars varied. It agreed with Shakywar *et al.* (2013) who evaluated ninety taro accessions in India and observed that none was resistant to taro leaf blight. In the pooled taro disease reaction, KNY/KAK/16, KNY/MU/75 and KNY/SYA/50 were moderately resistant. Mishra (2010) supported this finding in his report that *Phytophthora colocasiae* pathogen usually produce an elicitor which is recognized by its host taro, so that once it is detected the taro plant can limit the spread of pathogens through a

hypersensitive response that induces apoptosis. This makes the unaffected tissue to develop a systemic acquired resistance which renders the entire plant more resistant to pathogen attacks (Lam *et al*., 2001).

Table 4.26: Level of resistance of Kenyan taro accession against TLB disease under greenhouse study

Scale	Level of resistance	Number of accessions	Accession identity
0-1	R	NONE	
1-2	MR	3	KNY/KAK/16, KNY/MU/75, KNY/SYA/50
2-3	MS	5	KNY/BSA/14, KNY/CNT/33, KNY/KIS/81, KNY/KTL/61, KNY/SYA/51
3-4	S	NONE	

Host responses: R = Resistant; MR = Moderately resistant; MS = Moderately susceptible; S = Susceptible

4.3.4 Progress of taro leaf blight disease infestation on tolerant Pacific - Caribbean accession CE/IND/06 and susceptible Busia accession KNY/BSA/41 leaves

Plates 4.1 to 4.4 below showed the progress of taro leaf blight on a Pacific - Caribbean accession CE/IND/16 known to be moderately tolerant to taro leaf blight. Plate 4.1 showed a healthy leaf, 4.2 showed lesion spots developing on leaves, 4.3 indicated enlarged lesion surrounded by yellowish discoloration on leaf while 4.4, the dark brown halo was then concentrated at the apex. The disease progress was slow and localized, an indication of resistant accessions. The finding was in concurrence with the following symptoms used to determine resistant variety by Jugurnauth *et al. (*2001); no leaf showing symptoms of taro leaf blight, mild symptoms on one or less than half of the leaves and ability to hold in the field after it is ready for harvesting without rotting.

Wilson (1990) finding was consistent with this finding that in a resistant plant, a diseased tissue falls away from spots (short holes symptoms).

Stages of development of symptoms of TLB disease of taro on a moderately resistant taro

Plate 4.1: Healthy tolerant leaf

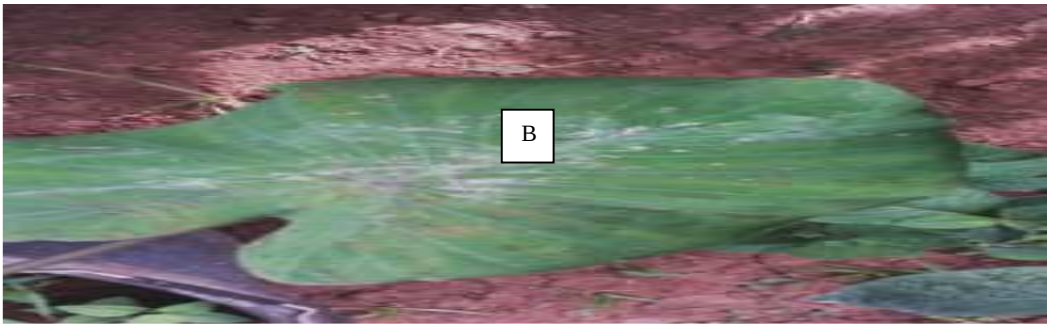


Plate 4.2: Lesion spots on lamina

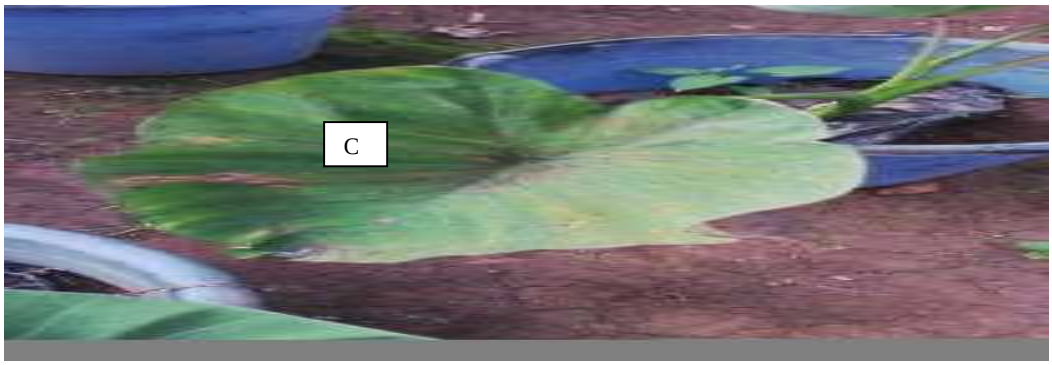


Plate 4.3: Lesion spots surrounded by yellow halo on lamina

Plate 4.4: Dark brown halo concentrated at the leaf apex

Stages of development of symptoms of TLB disease of taro on a susceptible taro

Plates 4.5 to 4.8 given below showed stages of development of symptoms of TLB disease on a susceptible taro. 4.5, was an indication of a healthy leaf, 4.6, yellowing covering entire leaf margin, 4.7, yellowing covering entire leaf and finally plate 4.8 shows browning and defoliation of leaf. According to the Jugurnauth, *et al.* (2001), the following symptoms indicated susceptible varieties; brown to olive green spots on leaf, edge of the spots diffuse, lesions becoming tan/ brown or dark brown/ black edge. Highly susceptible cultivars were expected to produce smaller leaves on shorter petioles. The leaves could be completely destroyed by the blight just as indicated on plate 4.8 of KNY/BSA/41.

Plate 4.5: Healthy susceptible leaf

Plate: 4.6: Yellowing spread throughout leaf margin

Plate 4.7: Yellow patches covering the entire leaf

Plate 4.8: Browning / blackening of and defoliation of leaf

4.3.5 Cluster analysis for populations on incidence, severity, leaves and suckers for MMUST Garden (Experiment - 1)

Figure 4.26 from cluster analysis below groups the accessions when considering the percent incidence, the severity of the disease, the average total leaves per month and the average total suckers per month. The closer the distance, the closer the clustering. Cluster three formed the major group of 11 taro accessions while cluster one had only six taro accessions. As the figure below shows, the clustering of accessions in the dendrogram was not correlated with geographical origin. The accessions from the same region did not behave in a similar fashion for instance, the accessions HW/37 and SM/120 were from Hawaii and Samoa respectively. The origins were different but were closely matched with regard to disease incidence, its severity, the total number of leaves and the total number of suckers.

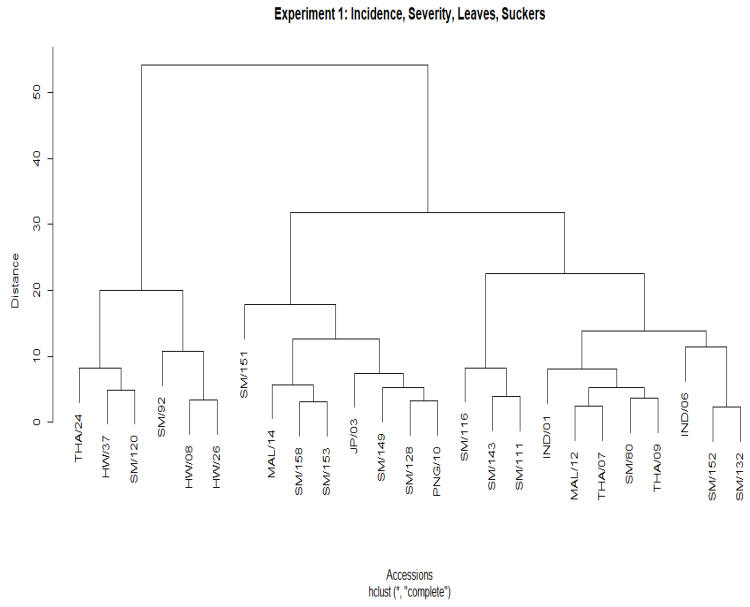


Figure 4.26: UPGMA dendogram indicating relationship among 25 accessions of taro Pacific-Caribbean under MMUST garden (experiment 1)

4.3.5.1. Cluster analysis for Pacific - Caribbean taro populations on incidence, severity, leaves and suckers for Milimani Garden (Experiment 2)

There was a lot of variability when the Pacific - Caribbean accessions were used under Milimani Garden. Further, the same experience as with the first experiment was not visibly seen. In the first experiment, the accession from Japan (JP/03) was closely clustered with two from Samoa (SM/149 and SM/126) and a third from PNG (PNG/10). On the contrary, under different experiment environmental condition in the second, the Japan accession (JP/03) was closely clustered with a Hawaiian (HW/80). Hawaii and Samoa were generally distant in terms of their reaction to TLB disease and agronomic traits.

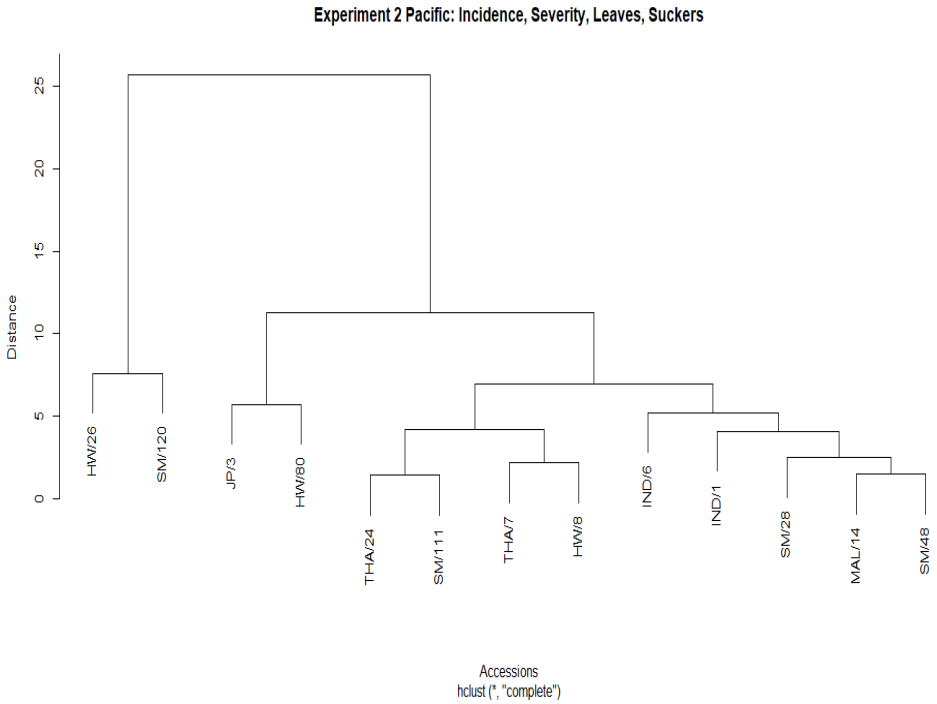


Figure 4.27: UPGMA dendogram indicating relationship among 13 accessions of taro of Pacific-Caribbean under milimani garden (experiment 2)

4.3.5.2. Cluster analysis for Kenyan taro populations on incidence, severity, leaves and suckers for Milimani Garden (Experiment - 2)

The same cluster analysis was conducted for the Kenyan varieties. In figure 4.10 below, two main clusters are visible. The one to the left has matched accessions from Kitale, Central and Kakamega. The one to the right has matched varieties from Kisumu, Siaya, Mummias and Busia. This could have been attributed to similar weather conditions in areas with matching qualities. The clustering was with respect to the disease incidence, its severity, the total number of leaves and the total number of suckers.

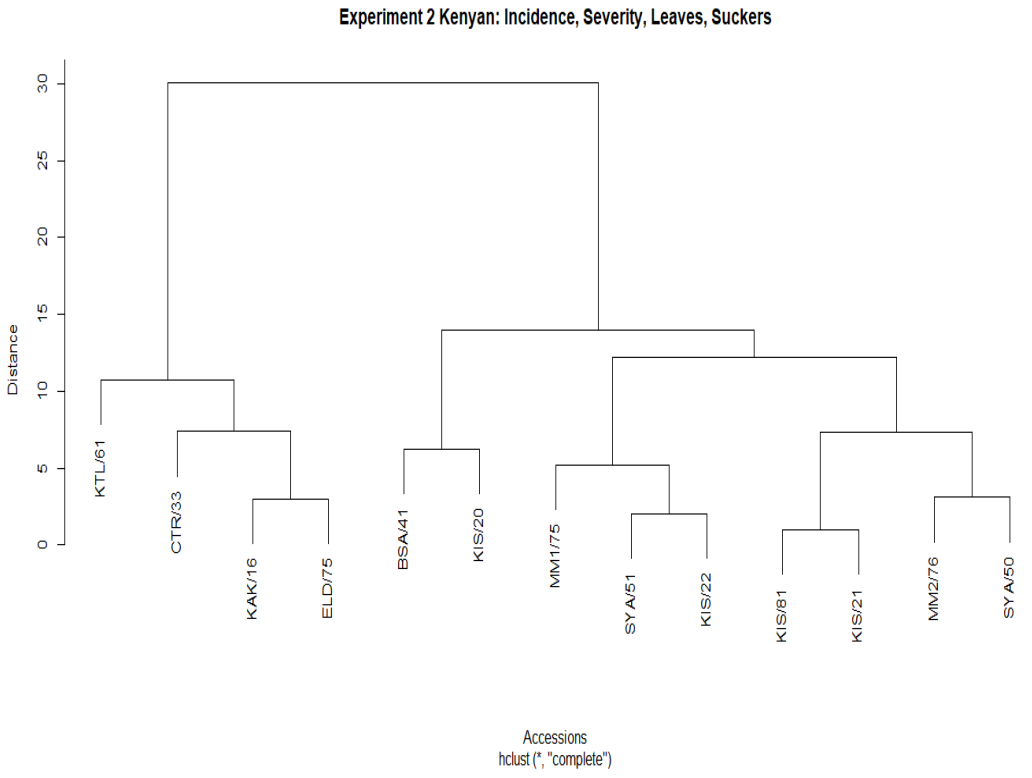


Figure 4.28: Cluster analysis for Kenyan taro accessions based on percentage disease incidence under Milimani Garden (Experiment 2)

4.3.5.3. Cluster analysis for both Kenyan and Pacific - Caribbean taro accessions on percentage disease incidence under Milimani Garden (Experiment 2)

There was no clear distinction from the clustering of Kenyan and Pacific -Caribbean accessions. Kenyans featured in all clusters and were closely linked to all the clusters (Figure 4.11). Only one sub-cluster had accession from Samoa (SM/28, SM/48, SM/111), Malaysia (MAL/14), Thailand (THA/24, THA/7) and Hawaii (HW/08) but excluded any Kenyan accession (Figure 4.11). The dendogram also showed clustering within related locations. There were KIS/21; KIS/81 and BSA /41; KIS/20 respectively clustering very closely. This could also confirm genetic similarity and relatedness among taro from same region.

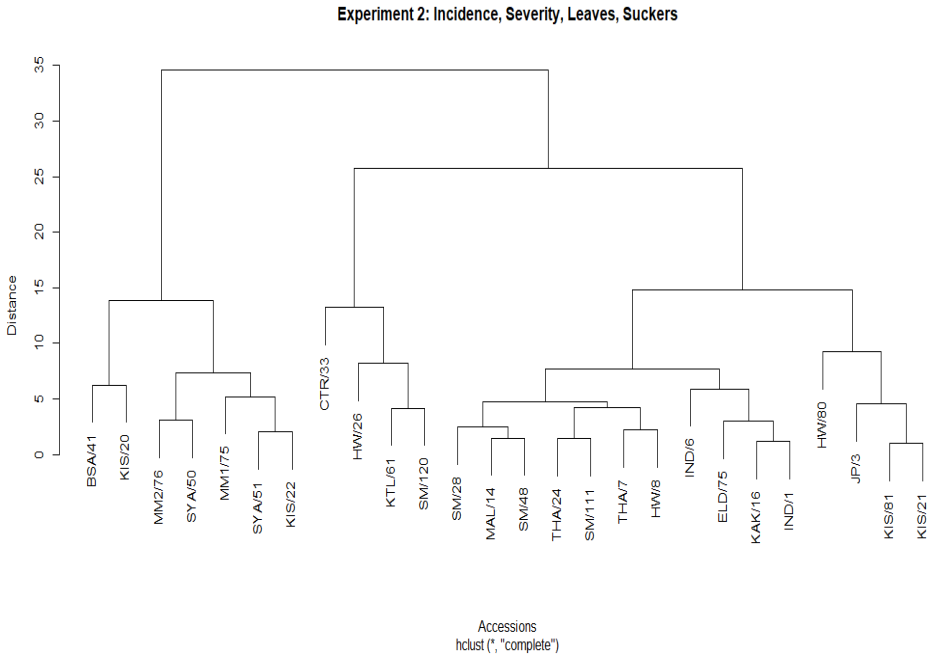


Figure 4.29: UPGMA dendogram indicating relationship among 26 accessions of taro of Pacific - Caribbean and Kenya under Milimani Garden (Experiment 2)

Whereas no direct estimation for gene flow was taken during this study, indirect deductions could be made from the phenetic analysis. The incidence, severity and agronomic performance data provided evidence of gene flow between populations obtained from different localities. This is because accessions from different origins frequently clustered together. However, the high similarity among accessions from same locality leads to low genetic variation among them.

4.3.5.4. Cluster analysis for Pacific - Caribbean and Kenyan taro accessions based on percentage disease incidence and agronomic traits under greenhouse study

Figure 4.30 below gives the cluster analysis for the accessions from the Pacific - Caribbean when infected in the green house. The clustering showed very short distances between clusters (a distance of about 5 units and below). This meant that the clusters were very close together hence it is difficult to distinctly differentiate them.

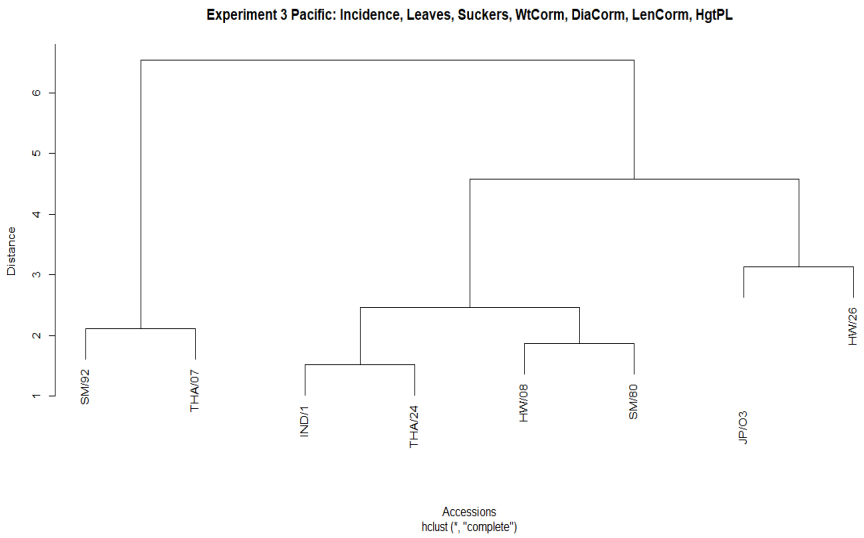


Figure 4.30: Cluster analysis for Pacific - Caribbean taro accessions based on percentage disease incidence and agronomic traits under greenhouse study

4.3.5.5. Cluster analysis for Kenyan taro accessions based on percentage disease incidence and agronomic traits under greenhouse study

Figure 4.31 below gives the cluster analysis for the accessions from Kenya when inoculated in the green house. The clustering showed long distances between clusters (a distance of up to 50 units and below). This meant that the clusters were widely apart hence they could easily be differentiated. Central Kenya accession (CNT/33) was distantly related from the rest of the accessions. Siaya and Kitale taro accessions were closely related. Kakamega, Kisumu, Mummias and Busia also clustered closely

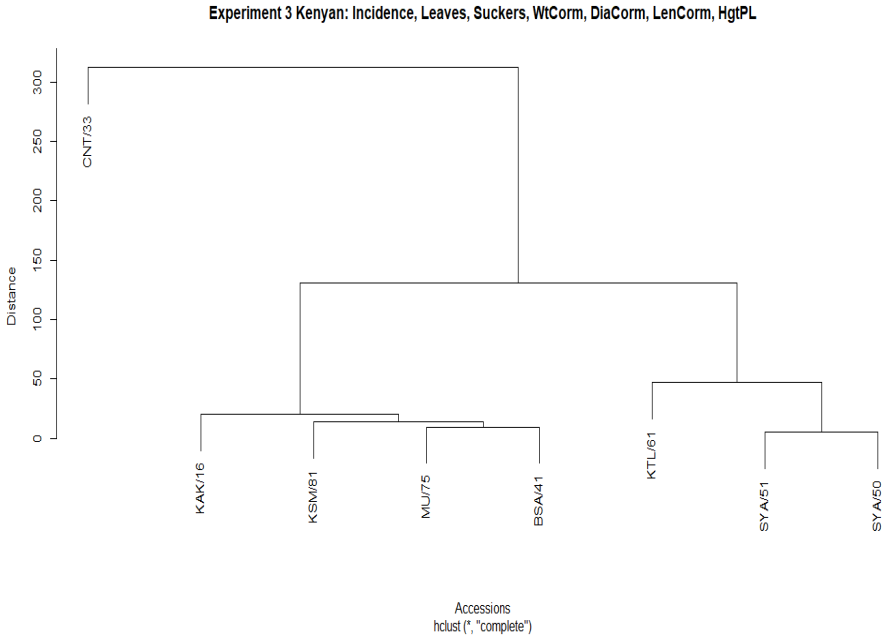


Figure 4.31: Cluster analysis for Kenyan taro accessions based on percentage disease incidence and agronomic traits under greenhouse study

4.3.5.6. Cluster analysis for both Kenyan and Pacific- Caribbean taro accessions on percentage disease incidence under greenhouse

Figure 4.32 below shows that there was a clear disparity between some Kenyan accessions and those from the Pacific - Caribbean when they were all introduced to TLB pathogen in the greenhouse. All the Kenyan accessions clusters closely together while all the Pacific -Caribbean accessions were in different clusters**.** Siaya accession SYA/50 and SYA/51 appeared to be closely related

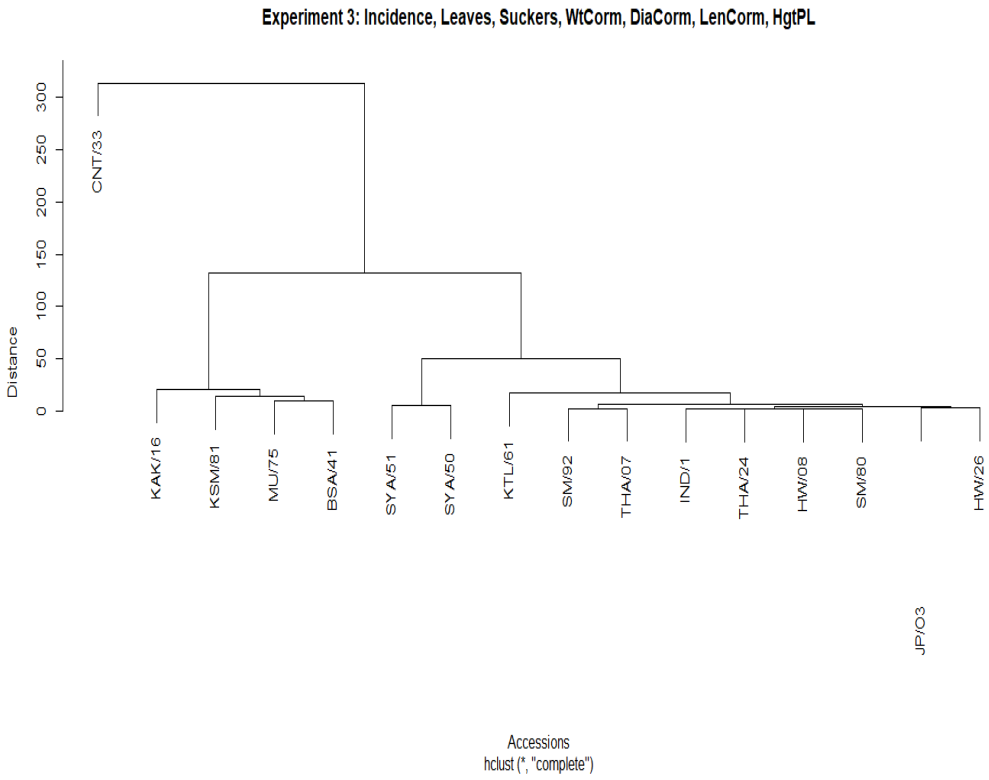


Figure 4.32: Cluster analysis for both Kenyan and Pacific - Caribbean taro accessions under greenhouse study

CHAPTER FIVE

DISCUSSION

5.1. Taro leaf blight disease incidence on Pacific-Caribbean taro accessions under MMUST field

The Pacific - Caribbean taro accessions did not show uniform TLB disease incidence. The varied level of disease incidence could be as a result of genetic differences among the taro accessions and it concurred with the findings of Miyasaka *et al*. (2012) that taro cultivars differed in their incidence to TLB and corm rot. The inconsistence increase in disease incidence in taro accession CE/IND/01, CE/MAL/12, BL/SM/143 among others which showed irregular progress in disease incidence could probably be as a result of the accession showing tolerance to the pathogen. It could also be as a result of weather influence such as increase or decrease in the amount of rainfall. This has been observed in April which received high amount of rainfall hence registered high mean disease incidence for most taro accessions yet they were just 3 months old (Kakamega-data.org.Https://en.climate-data.org). Campbell and Benson, (1994) reported similar results that factors involved in plant fungal epidemic included; favorable environment, susceptibility of host and virulent pathogen. Sarkar *et al*. (2017) in a study on field management of TLB using promising germplasm also observed that taro leaf blight disease incidence correlated with meteorological parameters.

The presence of the disease on young leaves of three months and rapid development of the disease on the leaves suggested that TLB was a strong fungus which was able to attack the leaves at all developmental stages. The earlier expression of the disease symptoms on the younger leaves may also be due to the tenderness of the cuticle

membrane of the younger leaves than the older ones (Chaube and Pundhir 2005). Plumbley and Sweetmore (1994) in a study concurred with results of this study that the susceptibility of some yam cultivars to a fungal disease was due to low resistance factors that reduce disease infection.

5.1.1 Taro leaf blight disease incidence on Pacific - Caribbean and Kenyan taro accessions under Milimani Garden

The difference in disease incidence among the Pacific - Caribbean and Kenyan taro accessions could be due to different host and pathogen predisposing situations just as earlier reported by Cardoso *et al.* (2004) that conditions might be conducive for infection of a disease but not for its spread depending upon the host and pathogen. The findings of the present study that showed variability in TLB disease incidence were at slight variance with the results of Chiedina and Ugwuja (2013) who reported that the taro accessions studied were all susceptible to TLB disease. There was progressive increase in disease incidence with age of plant in most accessions studied which could be attributed to leaf senescence and reduced immunity normally increasing with age. This fact was supported by the findings of Nwanosike *et al*. (2015) that most fungal diseases depended on stage of plant growth and they tended to increase with age. The consistent increase in disease incidence in these taro accessions was as a result of continued multiplication of the disease due to the prevailing favorable weather conditions of high rainfall, relative humidity and temperature during the respective months. Similar results were reported by Chikkaswamy and Rabin (2014) that powdery mildew disease caused by fungus *Phyllactinia corylea* commonly occurred during September to March in tropical region.

The accessions could also be susceptible to the pathogen or may have had reduced immunity as they approached senescence.

The high mean TLB disease incidence in Busia KNY/BSA/41 accession was indicative of the prevalence of the disease in that location. This fact was supported by the earlier findings of Chiedina and Ugwuja (2013) who attributed variation in disease incidence from one location to another to differences in inoculum potentials across these locations. The genetic makeup of the particular accessions could also have contributed to high disease incidence. The increase in disease incidence with increasing age was supported by the earlier work of Shakywar *et al*. (2013) that increasing disease levels usually occur in the late growing season as a result of increasing age of the susceptibility of plant tissues. The results were also supported by the work of Tyson and Fullerton, (2015) who reported that older taro leaves were more susceptible to TLB than young leaves. The results were in agreement with the findings of Charles *et al.* (2016) that TLB leaf incidence increased with age after planting. It stated that as the plant aged, there seemed to be more cell death than cell division that increased the susceptibility of the plant to diseases. Moreover, the increased accumulation of wastes as plant ages and increase in population of plant pathogen with time could increase susceptibility to diseases.

The reason for lower disease incidence among the Pacific - Caribbean taro was because they were improved cultivars developed for resistance to TLB in Pacific - Caribbean. This result was in support of the findings of Charles *et al*. (2016) who argued that improved cultivar BL/SM/132 from Samoa did not show any symptom of taro leaf blight disease hence low incidence and severity. The percentage incidence differences exhibited between the two locations also suggested that each distinct location of origin influenced

the disease in a unique manner probably due to other factors like climate peculiar to each environment of origin. The present results have shown that the effect of region of origin of taro on disease incidence varied from one location to another. Chiejina and Ugwuja (2013) observed that some farmers planted their crops long before the outbreak of the infection which minimized disease incidence while others planted just before the infection or after the infection. These practices could affect the subsequent progenies.

5.1.1.1 Taro leaf blight disease incidence on Pacific - Caribbean and Kenyan taro accessions under greenhouse study

The lower disease incidence in Pacific - Caribbean taro could be due to genetic properties developed by the accessions to reduce the effect of the pathogen. This could have been attributed to the tendency of the plant getting rid of infected leaves due to hypersensitivity reaction. This study was in concurrence with the findings of Haelapur (2005) that TLB disease incidence increased gradually later became stable. It was also in tandem with the findings of Chowdhury and Hossain (2011) that decrease in disease incidence could be brought about by growth and flashes of new leaves which were not attacked by the pathogen due to the plant gaining tolerance as a result of increased immunity.

The greenhouse results also indicated differences in percent incidences found to be consistent with a previous study by Nath *et al*. (2016) who stated that virulence tests showed a significant difference ($p<0.05$) in the rate of infection on the green house plants thought to be attributed to their differences in morphology. Age seven which was the last month of data collection registered significantly ($p<0.05$) low mean disease incidence. This indicated that the pathogen slowly progressed from initial stages of growth and then

decreased in incidence with the age. This study disagreed with that of Haelapur (2005) that age of plant affected the extent of disease susceptibility and that susceptibility increased with age of plant. The Pacific - Caribbean taro disease incidence increased from age three to five then started decreasing from age five to age seven which was indicative of disease tolerance.

5.1.2 Taro leaf blight disease severity on Pacific - Caribbean taro accessions under MMUST garden

The generally low severity exhibited among the Pacific – Caribbean taro accessions could be due to accession's low susceptibility to TLB disease. Hiraida (2016) in his study, linked low disease severity of a cultivar to the cultivar being less prone to diseases. Adamako, *et al.* (2016) findings supported the current research in reporting that low TLB disease severity was linked to clean planting materials and good agricultural practices. It could also be as a result of external factors like temperature, rainfall and relative humidity being unfavorable to the pathogen. This fact was supported by the report of Hiraida (2016) that weather conditions such as high rainfall, temperature and humidity influenced infection rates in all plants, including those with a degree of genetic resistance**.**

5.1.2.1 Taro leaf blight disease severity on Pacific - Caribbean and Kenyan taro accessions under Milimani garden

This present finding that indicated lower disease severity at initial stages of growth and increased with age could be due to increase in inoculums and increasing age of plant. The result corroborated the report by Hiraida (2016) that during the first stages of TLB infection, taro uses non-specific mechanisms to eliminate pathogens by increasing

antifungal levels which protects cells from oxidation and accelerate recovery during inflammation. Harplapur (2005) reported a similar result that high susceptibility of plants to fungal diseases mostly occurred at a later age after flowering. The higher increase in disease severity among Kenyan taro than the Pacific - Caribbean suggested that a number of Pacific - Caribbean accessions investigated were tolerant to taro leaf blight. Contrary finding by Brook (2008) indicated a decrease in TLB lesion diameter with increasing plant age. The varied levels of disease severity among the taro accessions showed that there were different levels of inherent properties to reduce disease severity in the accessions. Different taro accessions exhibited different levels of disease resistance. Location of origin of the accessions could also play a role in determining the level of disease susceptibility although contrary to the study by Hunter *et al*. (1996) that the disease severity levels of the taro accessions studied were significantly ($p<0.05$) the same**.**

5.1.2.2 Taro leaf blight disease severity on Pacific - Caribbean and Kenyan taro accessions under greenhouse study.

Kenyan accessions had generally higher disease severity than the Pacific - Caribbean taro revealing that different locations from which taro were obtained influenced TLB disease severity. This was consistent with the report of Charles *et al*. (2016) that improved Samoan accession BL/SM/132 from Pacific - Caribbean neither showed tissue collapse even after TLB pathogen inoculation nor symptom of taro leaf blight disease compared to other taro accessions which showed high severity rates. Differences in disease severity was also portrayed among the different Pacific - Caribbean and Kenyan taro accessions. This could be attributed to genetic and environmental differences as described by

Miyasaka *et al*. (2012). Omege *et al*. (2016) attributed the differences in disease severity to genetic differences among taro plants. Nath *et al*. (2013) reported in support of this finding that there was a differential degree of response against taro leaf blight disease among different taro accessions. The result showed increase in TLB disease severity with increase in age as described by Shakywar *et al.* (2013) that late growing periods of taro revealed higher TLB disease levels than early periods**.** In the TLB-Kenya pathosystem, there was evidence of physiological adaptation of *Phytophthora Colocasiae*. This finding was also in concurrence with the report of Ramadhani (2010) that the role of pathogen variability and adaptation cannot be precluded and may in fact account for the observations.

5.1.3 Taro leaf blight disease index on Pacific - Caribbean taro accessions under MMUST Garden

Pacific - Caribbean taro generally indicated low disease index. The evidence of low TLB disease index in this study could have been due to pre and post- infection defense related factors in the tolerant accessions. There was no regular increase in disease index throughout the growing period. There could have been an influence of a fluctuating external factor such as rainfall, relative humidity and temperature as indicated on Kakamega-data.org.Https://en.climate-data.org. Sarkar *et al*. (2017) in his study on field management of taro leaf blight reported that maximum percent disease index was observed when mean average temperature was 30.17^{o}C, maximum relative humidity 93.12% and mean rainfall 95.43mm.

5.1.3.1 Taro leaf blight disease index on Pacific - Caribbean and Kenyan taro accessions under Milimani garden

The initially low disease index could have been attributed to the fact that plants had just grown and had not yet been attacked by the pathogen or the pathogen had not reached exponential phase. This could also be due to dry weather conditions which was evident from the early months of growth not favourable for the pathogen, however when weather condition once again became congenial for the disease development, disease index increased (Rai *et al.,* 2002) **(**Kakamega-data.org.Https://en.climate-data.org). Nwanosike *et al*. (2015) attributed low disease index of 0.143-0.265 to relatively high minimum temperature (16°C), maximum temperature (27°C) and moderate humidity. Kenyan taro consistently conveyed higher TLB disease index than the Pacific - Caribbean. Two Kenyan accession, KNY/KAK/16 and KNY/ELD/75 had disease index of TLB that did not differ significantly ($p<0.05$) from disease indices exhibited in some Pacific - Caribbean accessions. This was an indication of inherent tolerance to TLB that could also be found in non-improved taro.

5.1.3.2 Taro leaf blight disease index on Pacific - Caribbean and Kenyan taro accessions under greenhouse study.

The application of artificially prepared *Phytophthora colocasiae* (taro leaf blight) pathogen performed in the greenhouse exhibited increased TLB disease index as compared to the natural inoculation observed in the field. The disease index continued to increase month by month in some accessions which was directly correlated with age of plant. The high TLB disease index could be due to secondary inoculum followed by released conidia in the air during saturation period (Ramadhani, 2010). It could further be

attributed to background contamination or proximity to inoculum source (Takan *et al.*, 1994). Some accessions did not show continued increase in disease index with age. This finding was consistent with report of Brooks (2008) that inoculated leaves of all taro hybrids showed a decrease in lesion diameter with increasing plant age. Misra *et al.* (2008) showed that infection on taro plant tissue increased peroxidase, PR-proteins, and decreased sugar 11 production to induce tissue death, reducing the spread of disease. Nwanosike *et al.* (2015) attributed increase in disease index to available pathotypes of the pathogen.

5.1.3.3 Taro leaf blight disease index on Pacific - Caribbean and Kenyan taro accessions under greenhouse study

The result was indicative of location relatedness of the accessions in terms of disease index. Similarly, Chiejina and Ugwuja (2013) attributed variation of disease index from one location to another, to differences in inoculum potential across the locations of origin.

5.2. Mean monthly rainfall, temperature and relative humidity on taro leaf blight disease incidence on Pacific - Caribbean taro grown under MMUST garden.

The relative TLB disease tolerance exhibited among the Pacific - Caribbean taro accessions could have been attributed to the fact that Pacific - Caribbean region was wetter than Kenya and the accessions easily adapted a way to reduce TLB disease incidence even under high rainfall amounts. The result of this study disagreed with the report by Harlapur (2005) that the period of rainy season could also be a period of pests and diseases attack from other crops therefore increase in incidence. The result also disagreed with that of Van der Puije *et al.* (2015) that wet season recorded the highest

incidence of 99% whilst the dry season recorded the lowest incidence of 92% in most fungal plant diseases.

This result was contrary to the report by Trujilo (1965) that taro leaf blight disease was much related to temperature condition and that increase in minimum temperature promoted taro leaf blight development. Harlapur (2005) similarly in his study, revealed that the most favorable maximum temperature in relation to most plant blight development was (26.3-29.4°C). The result was in concurrence with several reports by Van der Puije *et al*., 2015, Carnot, *et al*. (2016) and Askaru, (2010) that high relative humidity promotes taro leaf blight disease incidence.

Dipa (2017), reported that the *Colocasiae* blight disease increased at temperatures between 25 and 28^0 C. This finding corroborated those of Omege *et al*., (2016) that taro leaf blight disease occurred when night temperatures are 21-22^0C and day temperature are 25-28^0C. The finding stated further that taro leaf blight resulted to temperature related growth of causal organism *Phytophthora colocasiae L. Rac* with the rapid growth during warm day followed by slow growth during cooler night. The present investigation was also consistent with that of tarogen annual report 2001/2002 that the growth rate of taro leaf blight pathogen and the rate of lesion development were strongly influenced by temperature and fungal disease incidence often increase with increase in temperature. The report continued to state that most TLB pathogen survived within a temperature range of 25^0C-30^0C and that at temperature above 35^0c, the pathogen stopped to grow. This was also consistent with the report by Trujilo (1965) that taro leaf blight disease had a positive correlation with temperature**.**

Askaru (2010) reported similar result that taro plants growing in extremely hot and humid environments showed higher susceptibility to blight disease than those growing under cold and dry conditions. This could be because asexual reproduction by taro leaf blight pathogen, occurred mainly during wet weather and moderate temperature promoted sexual reproduction and also governs physiological processes. The findings of Onyeka (2014), further stated that taro leaf blight disease level differ according to temperature with an increase in incidence with increase in temperature. The result was also consistent with that of Charles *et al*. (2016) that high temperatures increased *Phytophthora colocasiae* incidence. Hiraida (2016) reported in support of this current study that infection of all crops was positively correlated with temperature up to 29°C.

This finding revealed that high humidity had a great influence on the development of the *Phytophthora colocasiae* fungus which could lead to disease epidemic development. This study also revealed that taro leaf blight disease increased with increase in relative humidity such that susceptible accessions were completely devastated when the conditions were of very high relative humidity. This positive correlation between TLB disease development and relative humidity agreed with the report by Van der Puije *et al*. (2015) that high humidity of 90-100% favoured TLB disease progress. Similarly, Rahman *et al.* (2003) reported a high influence of high humidity on the development of leaf spot caused by *Colletortrichum gloeosporioides* on leaves of most fruits.

5.2.1 Mean monthly rainfall, temperature and relative humidity on *Phytophthora colocasiae* disease incidence on Pacific - Caribbean and Kenyan taro grown under Milimani garden.

The present result indicated some relationship between the pathogen and weather changes. Relatively high rainfall, temperature and humidity were conducive for TLB pathogen and it was consistent with the findings of Chowdhury and Hossain (2011) that higher incidence of leaf spot of jackfruit fungal pathogen increased during the month that experienced highest rainfall amount. Similar leaf spot caused by *Colletortrichum gloeosporioides* on leaves of other fruit species had also been reported to be influenced by excessive rainfall (Rahman *et al*., 2003). The finding was also supported by that of Mbong *et al*. (2013) who observed that symptoms suggestive of TLB were observed on taro plants in southern States of Nigeria followed by disappearance of the same with onset of dry periods. The result further corroborated that of Adinde *et al*. (2016) that taro leaf blight grows very rapidly in areas with high humidity and heavy rainfall that aids the spread through rain splash on the free leaves. This finding was in tandem with the report by Hiraide, (2016) that higher fungal disease incidence would result from higher rainfall recorded during production season. Further, Manju *et al.* (2017) supported this present report in his finding that TLB disease incidence was high in fields during rainy seasons and that as dry season approached, disease incidence reduced. He further indicated on his field reports that early leaf infection often took place where rainfall, dew or guttation droplets accumulated. Mbong *et al*. (2013) further reported that rain wash off sporangia and zoospores from leaves into the soil or splash on to other leaves and petiole of plants causing infection. Hiraide (2016) reported a similar result that rainfall with a maximum

of 198.20 mm positively correlated with TLB disease infection. The present finding also concurred with the result of Carnot *et al*. (2016) which stated that the interaction number of watering and percentage of attacks proved highly significant (P<0.05%) and that increased watering contributed to increased disease incidence.

The effect of minimal manifestation of disease symptoms on young plants could also have played a role in this study (Omege *et al*., 2016) and (Askaru, 2010). Minimum temperature seemed not to have influenced disease incidence as it was almost constant throughout the study yet there was continued increase in disease incidence among both Kenyan and Pacific - Caribbean taro. This finding was in slight variance with the report of Hiraida (2016) that TLB infection of all crops was positively correlated with temperature up to 29°C. Tarogen annual report of 2001/2002 reported that cool wet conditions promoted the development of taro leaf blight symptoms. It further stated that in hot dry conditions, lesions developed slowly, fail to expand or the fungus completely died. Age as a factor that increases susceptibility of taro plants to TLB pathogen might also have taken effect. Rainfall was 65.5 mm when the plants were just three months old when least disease incidence was recorded.

Kenyan taro was higher in disease incidence than the Pacific - Caribbean taro. The result indicated an increase in disease incidence with increase in rainfall. Rainfall was known to aid the spread of the fungus and to provide moisture required for its development (Van der Puije *et al.,*2015). The result of this research indicated support for positive correlation between taro leaf blight disease incidence and temperature. The result corroborated that of Charles *et al*. (2016) that high temperatures increased *Phytophthora colocasiae* incidence. He further noted that *Phytophthora colocasiae* was a warm weather pathogen

growing most rapidly at temperature between 27-30^{0}c and that optimum minimum and maximum temperature for the growth of TLB was 10^{0}C and 35^{0}C respectively. This result was also supported by Van der Puije *et al. (*2015) that taro leaf blight was favoured by high temperatures ranging from 15^{0}C - 35^{0}C with an optimum of 28^{0}C. Similar reports were noted by Chowdhury and Hossain (2011) that *Colletortrichum gloeosporioides* fungal pathogen on leaves of guava and mango fruit species, were influenced by excessive temperature. This result was also consistent with the report made by Asha (2006) that temperature of 28^{0}C was best for taro leaf blight pathogen growth. The result further corroborated the report by Jugurnauth *et al*. (2001) that the level of taro leaf blight infection was higher (20-30%) with increased temperature. The findings of Dipa (2017) that at temperatures of 20 to 22^{0}C during the night, the *Phytophthora blight* disease would increase supported this current report. The finding was however contrary to the other findings of Omege *et al.* (2016) that high temperatures normally hinder taro blight disease manifestation. Disease incidence increased in both taro categories irrespective of maximum temperature. The interactive effect of the different categories of accessions and maximum temperature on the blight disease showed that the disease was more variety dependent than maximum temperature dependent. This probably suggested that there were higher levels of genetic differences between Kenyan and Pacific - Caribbean taro. The implication of this was that the Pacific - Caribbean taro would have greater chances of resisting the pathogen if there was an epidemic.

The present research revealed support of high humidity on TLB development. It agreed with the findings of Brooks (2015) that warm humid days and cool wet nights were ideal for the reproduction and spread of *Phytophthora colocasiae*. This finding was also

supported by the findings of Charles *et al*. (2016) that 100% incidence of taro leaf blight was observed when relative humidity was high. Moreover, Tarogen annual report (2001/2002) stated that cool wet conditions promoted rapid *Phytophthora colocasiae* symptom development in taro. The report also stated that in hot dry conditions, lesions developed slowly, fail to expand or the fungus dried off. The result indicated that high humidity promoted pathogen development just as supported by Askaru (2010) that high humidity and water availability increased TLB incidence and severity. The study also agreed with that of Brooks (2015) that warm humid days and cool wet nights were ideal for the reproduction and spread of taro leaf blight disease. Dipa (2017) further supported this finding in his report that relative humidity at or below 65% during the day and R.H of 100% during the night would promote taro leaf blight disease. In a study by Manju *et al*. (2017) on TLB disease incidence, the finding revealed that the fungus depended on free surface water and high relative humidity during the wet seasons and that the incidence was determined by the duration of surface moisture. The results were in support of the earlier study of Shakywar *et al*. (2013) who reported that maximum sporangia germination, penetration of taro leaves by taro leaf blight and zoospores formation were recorded at relative humidity 90 -100%. The result also corroborated the report by Jugurnauth *et al*. (2001) that the level of taro leaf blight infection was higher (20-30%) in the super-humid conditions (humidity 75-82%) which in their case, occurred in January, February and May. In this present study, the 'super humid' conditions occurred in April and August which revealed similar trends for the level of taro leaf blight incidence in relation to relative humidity.

This difference in incidence rate between Pacific - Caribbean and Kenyan taro could be due to the inherent susceptibility to attack by TLB pathogen on Kenyan taro since there was no prior screening done on Kenyan taro unlike the Pacific - Caribbean taro which were screened. This comparison was in concurrence with the report by Graham (2012) that most accessions from the Pacific - Caribbean had been improved through breeding for resistance to taro leaf blight.

5.2.2 Mean monthly rainfall, temperature and relative humidity on *Phytophthora colocasiae* disease severity on Pacific - Caribbean taro grown under MMUST Garden

Rainfall and relative humidity did not show any consistent effect on TLB disease severity, other factors of fungal disease epidemiology could have had effect. Increase in minimum temperature also did not increase taro leaf blight disease severity. Many reports have been published on positive correlation between temperature and TLB disease severity but this study indicated no relationship. Effects of other factors like age of plant and other weather factors such as sunshine, leaf wetness and cloud cover could have played a role. This finding corroborated the report by Chothani *et al.* (2017) that some unknown factors might be involved in early blight development on tomato apart from the known weather factors.

5.2.3 Mean monthly rainfall, temperature and relative humidity on *Phytophthora colocasiae* disease severity on Pacific - Caribbean and Kenyan taro grown under Milimani garden

The percentage disease severity on Kenyan taro increased steadily after the third month of growth with increase in the amount of rainfall. The results of present findings were comparative with those of Dadarum (2016) who reported that disease was in epidemic form in the rainy season. There was low disease severity whenever monthly rainfall was low as supported by the study done by Jugurnauth *et al*. (2001), the same occurred in August and December. Gadre and Joshi (2003), also reported that the survival of the *P. Colocasiae* fungus under field conditions was favoured by flooding conditions. Nwanosike *et al.* (2015) reported higher Northern leaf blight in maize severity in the highlands as compared to relatively dry lowland regions. This was to mean that high rainfall and high relative humidity of highlands would favour the blight. He further reported in support of this finding that rainfall range of 325.3-679.2 mm during the growing seasons would favour the fungal blight disease. The disease severity increased with increase in rainfall such that by April (which received the highest amount of rainfall) the susceptible accessions had already been highly infected.

The highest amount of rainfall recorded during the period of study was 223.9 mm and severity for Kenyan taro was 54.5%. On the other hand, the TLB disease severity on Pacific - Caribbean taro was 33.2%. According to the severity scale of Omege *et al*. (2016) at high rainfall amount, in this case 223.9mm, the severity inference for the Kenyan taro was high infection, falling between 51-75% severity scales. The severity of Pacific - Caribbean taro on the other hand was between 26%-50% which is moderate

infection. The result of this study indicated that heavy rainfall promoted the occurrence of taro leaf blight and it was consistent with the findings of Adinde *et al*. (2016) which stated that taro leaf blight grew very rapidly in areas with high humidity and heavy rainfall that aids the spread through rain splash on the free leaves. High moisture content seemed to favour the pathogen increasing severity during heavy rainfall.

There was no disease severity at temperature 14.5^0C probably because the plants were just three months old and had not yet been infected or had not yet shown symptoms of TLB disease. This was in partial support of the report by Nwanosike (2015) on northern maize blight that minimum temperatures of 13.7-15.9°C favored the blight disease severity. At 15.1^0C minimum temperature, disease severity was 13.56%. The result indicated increase in disease severity with increase in minimum temperature. This was in concurrence with the findings of Fullerton and Tyson (2003) that TLB epidemics generally flourished when night temperatures were in the range of 17–20 °C and that the cool temperatures stimulate the release of infective zoospores, promoting multiple infections. Chothanil *et al*. (2017) reported that increase in tomato early blight severity was higher at minimum temperature range of $17.1–24.4^0$C. It was well known that temperature governed the rate of reproduction of fungi in that reproduction increased with temperature (Benzohra *et al*., 2018).

Temperature also affected the growth and aggressiveness of pathogens together with expression of disease symptoms in plants. Moreover, it had been demonstrated that inoculum density was closely related with temperature and disease development (Singh *et al* .2014). The present result was in support of the findings by Pan and Ghosh (1997) that

studied the relationship of various environmental factors with blight severity and showed positive relationship of severity with maximum temperature. Asha (2006) also suggested that temperature played an important role in disease development. The current study also corroborated the findings of Charles *et al*. (2016) that *Phytophthora colocasiae* is a warm weather pathogen growing most rapidly at temperature between 27-30^{0}C. Charles *et al*. (2016) further stated that optimum minimum and maximum temperature for the growth of TLB was 10^{0}C and 35^{0}C respectively. It was however contrary to the finding of Chothanil *et al.* (2017) on tomato early blight that increase in the blight disease severity was comparatively higher at maximum temperature range 35.2 – 38.3^{0}C. The present finding disagreed with that of Ramadhani (2010) that severity of *E. turcicum* blight of maize was lower in warmer areas. The present finding supported that of Benzohra *et al.* (2018) that most mycelial growth, pycnidia formation and sporulation declined above 22^{0}C with absence of sporulation at 26 and 30^{0}C.

Fernandez *et al*. (2014) found out that temperature highly affected the mycelial growth of *B. cinerea* isolates and that temperature discriminated isolates based on their temperature optima. Benzohra *et al.* (2018) and Pefaura *et al*. (2007) further reported that *Trachysphaera fructigena* radial growth decreased to minimum at higher temperatures. Similarly, Sehajpal and Singh (2014) noted that temperature of 20±1°C was the best for mycelial growth *Botrytis gladiolorum* and the least was observed at 30±1°C and that no conidial and sclerotial production was recorded at lower and extreme temperatures. The rate of mycelial growth of *Sphaeropsis pyriputrescens* increased as temperature increased up to 20°C and then decreased rapidly as temperature increased. In the latter finding, increase in temperature led to an increase in disease severity. Benzohra *et al.* (2018) and

Fernando *et al*. (2012) also reported that *Corynespora cassiicola* sporulated freely on PDA at 10 to 35 °C with a peak at 30 °C. However, no sporulation or growth of the colonies of the isolates was observed at temperatures below 5^0C and above 35°C. The present result however contradicted the earlier finding of Sahu *et al.* (2014) in his epidemiological studies on early blight disease of tomato that minimum temperature had a negative highly significant correlation with early blight disease development.

This finding indicated support on an increase in relative humidity with increase in disease severity. Mbong *et al.* (2015) in his study on mycelia growth and sporulation of *Phytophthora colocasiae* isolates supported the finding in his report that under optimum conditions of relative humidity approaching 100%, there was greatest sporulation in TLB pathogen. Harplapur (2005) similarly reported that in Georgia, Russia, the most favourable relative humidity for development of maize leaf blight was 75 to 90%.

5.3 Relationship between TLB disease resistance and agronomic traits of Pacific - Caribbean taro accessions under MMUST Garden

The Pacific - Caribbean taro accessions did not show uniform TLB disease resistance which could have been due to genetic variability. Miyasaka (2010) reported that oxalate oxidase homologs abundant in some taro genotypes could be involved in disease resistance. Similar findings were noted in the reports of Graham (2012) that most Samoan accessions were tolerant to taro leaf blight. Graham (2012) further reported that some Indonesian taro accessions such as CE/IND/24 and CE/IND/14 were susceptible to taro leaf blight.

The variation in number of leaves with age could have been attributed to the effect of weather elements which varied each month. The result was in support of the findings by Ogbonna *et al*. (2013) who stated that the differences in yield parameters could be due to climatic factors such as relative humidity, temperature and rainfall. Mare (2009), reported that temperature was the most important factor affecting growth and development of taro plant. Referring to the Kakamega-data.org.Https://en.climate-data.org, this present finding indicated that high temperature was not favorable for sucker formation and in most cases, increase in sucker usually led to increase in number of leaves. This present finding corroborated the report by Timlin *et al*. (2006) that end of season tuber mass decreased with increase in temperatures above 24^0C in potatoes. This finding contradicted the report by Omege *et al*. (2016) that high temperatures favoured more leaf production in taro fields. The finding was also contrary to the report of Mare (2009) that higher temperatures sped up development between emergence and tuber initiation, whereas total tuber dry mass and leaf area decreased with increasing temperatures in potatoes.

The number of leaves seemed to increase with age of plant. This could be due to the proportional increase in tubers. In correlating resistance between number of suckers and disease resistance, there was positive but weak correlation. Plants with more suckers tended to have higher resistance. This was the same for leaves since the proportion of leaf to leaf area was 1:1.

5.3.1 Relationship between TLB resistance and agronomic traits of Pacific - Caribbean and Kenyan taro accessions under Milimani Garden

The generally high TLB disease resistance observed in this particular study could have been attributed to the fact that the study area had previously not been used for taro or any related crop hence low disease prevalence. The variation in disease resistance between the Pacific - Caribbean and Kenyan taro could be due to the varied environmental conditions exhibited in regions of plant collection. Atak, (2016) reported in concurrence to this present finding that cultivars from different regions of Spain collected to determine their fungal disease resistance, had generally high sensitivity to the pathogen except for some collected from the humid regions of Spain. These cultivars showed more resistance than those from other regions. Varied reaction to TLB exhibited between Pacific - Caribbean and Kenyan taro accession was similar to the result reported by Padmaja, (2013) on his studies on TLB disease that disease reaction of 37 accessions of taro showed differences in disease resistance. The results also suggested that Pacific-Caribbean accessions did exhibit qualitative and quantitative (rate-reducing) resistance which limit the spread of TLB disease.

The results further suggested that the level of resistance within genotypes also affected the disease development over time. The close to similar resistance between Pacific - Caribbean and Kenyan taro disease resistance during early stages of development could be attributed to conditions being less conducive for TLB disease development during the period of study. Pataky *et al.* (1998) reported from his study on disease severity and yield of sweet corn hybrid that the reactions of the most resistant cultivars could not be

differentiated when conditions were less conducive for the development of Northern leaf blight. Further improvement of resistance to TLB in taro would then require evaluation of breeding materials in environments that are least conducive to taro leaf blight. The result that indicated high TLB disease resistance among some Kenyan taro accessions was in accordance with reports of Ackah *et al*. (2014) that some reasonable resistance to taro leaf blight could be found in local germplasm just has been reported in Kakamega and Eldoret taro accessions of Kenya.

Increase in number of leaves with age could have been attributed to high rainfall amount in April (223.9mm) (Kakamega-data.org.Https://en.climate-data.org). In contrast, lowest yield was scored at rainfall amount of 65.5mm. High rainfall amount accorded to this study, promoted leaf formation and when there was water stress, the number of leaves reduced due to premature senescence of leaves. This would go along with reduced leaf surface area as a means of the plant to cope with reduced water availability. Reduced leaf area would lead to reduced photosynthesis limiting corm development. Limited water availability according to the report by Mabhaudhi (2012) was found to reduce plant growth due to reduced cell division and expansion. Misra *et al*. (2008) reported that taro growth was favored by high amounts of rainfall throughout the year. He further reported that under cloudy weather conditions with intermittent rains, taro plant grew at a faster rate. This study was also in support of the findings by Mare (2009) that water availability influenced the yield and tuber size of taro coupled with increased tuber number and mean weight. Similar results were reported by Miyasaka *et al. (*2001) that in taro, inadequate rainfall during the time of greatest water need (just before corms develop) resulted in

lower yield and percentage corm dry matter. Mare (2009), also discovered an increase in total fresh and marketable tuber yield with increasing amount of irrigation water.

The present finding observed high levels of variability for plant growth habit in terms of yield. This could have been attributed to the inherent cultivar variation and climatic factors. The findings of this study support those of Aigbewi *et al*. (2013) who stated that variation of cultivars had effect on the sprout and establishment of yam. The study also agreed with the report of Omege *et al*. (2016) that significant variation in number of leaves among cultivars could be due to climatic factors and genetic cultivar difference in growth habits. Ogbonnaya *et al*. (1983) and Ogbonna *et al*. (2013) further reported the varietal differences across the cultivars and that some cultivars would not produce much suckers and long petiole, even when the essential growth environments had been provided. The Kenyan most yielding accession in terms of number of leaves was found to be KNY/KTL/61 with mean leaves of 6.96. The scatter plot of leaf area versus resistance showed negative coefficient and that indicated less resistance in plants with greater leaf area. This was the same for leaves since the proportion of leaf to leaf area was 1:1.

5.3.2 Relationship between TLB disease resistance and agronomic traits of Pacific - Caribbean and Kenyan taro accessions under greenhouse study.

The wide variation of resistance to TLB between the Pacific - Caribbean and Kenyan taro alludes to long term co-evolution of *Phytophthora colocasiae* and taro within the Kenyan taro. It is thus conceivable that among both host and pathogen, there was a wide array of pathogenicity and resistance genes respectively. Strains of the fungal pathogen could also have produced excessive anti resistance factors in the susceptible cultivars to breakdown their resistance**.** This study showed that more Pacific - Caribbean taro accessions could be

used as sources of resistance to TLB infection. Tsatsia and Jackson (2015) in a leaflet produced by the Ministry of Agriculture and Livestock, Solomon Islands, with support from IPPSIT reported that breeding programs in Papua New Guinea and Samoa had produced plants resistant to taro leaf blight. In Solomon Islands, a hybrid, LA16, had been found to be resistant to taro leaf blight. Kenyan accessions were neither screened nor were known to be resistant to taro leaf blight. The number of leaves of Pacific-Caribbean and Kenyan taro were statistically the same. Those of Pacific - Caribbean taro accessions recorded an average of 4.48 and Kenyan accessions 4.45 leaves. This could have been due to the fact that greenhouse was controlled and therefore very minimal environmental effects were realized. It was important to note that no significant correlation was obtained between TLB disease resistance and agronomic traits.

CHAPTER SIX

CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

6.1. CONCLUSION

Incidence, severity and disease index of the taro leaf blight was comparatively lower in Pacific - Caribbean taro accessions than in Kenyan taro accessions. The time of taro planting and location influenced TLB disease incidence, severity and disease index.

In MMUST Garden study on Pacific - Caribbean taro alone, the mean TLB disease incidence was 21.88. At Milimani Garden study, mean disease incidence for Pacific - Caribbean taro was 7.14% and that of Kenya was 13.19%. The greenhouse study obtained far much higher disease incidence as a result of pathogen inoculation, with Pacific - Caribbean accession recording a lower mean incidence of 28.08% than the Kenyan, 59.04%.

The mean TLB disease severity for the Pacific - Caribbean taro under MMUST Garden was 17%, the mean severity for Pacific - Caribbean taro at Milimani Garden was 7.14% while the Kenyan tar under the same study was 13.19%. The greenhouse study had higher disease severity with Pacific - Caribbean accession recording a lower mean severity of 20.47% than the Kenyan, 29.64%.

The mean TLB disease index for the Pacific - Caribbean taro under MMUST Garden was 0.68, the mean index for Pacific - Caribbean taro at Milimani Garden was 0.2 while the Kenyan taro under the same study was 0.78. The greenhouse study had higher disease

index with Pacific - Caribbean accession recording a lower mean disease index of 0.86 than the Kenyan, 2.08.

The weather parameters had profound effect on the prevalence of the disease and the effect differed significantly in different weather conditions. When rainfall was high, the temperatures high and relative humidity favourably high during the period of study, the incidence, severity and disease index of TLB increased. The experiment revealed that the disease spread very fast particularly when conditions were favourable and could be very destructive. The two peak rainfall amounts of 174mm and 223.9mm, minimum temperature of 24.38°C, maximum temperature of 28.6°C and a range of R.H of 56-66% yielded the highest disease incidences and severity in both Pacific - Caribbean and Kenyan taro.

Pacific - Caribbean taro having been screened from their location of origin, yielded higher disease resistance than the Kenyan taro. The highest disease resistance of 89.73% was obtained from Pacific - Caribbean taro BL/SM/128 and the lowest of 58.27% from KNY/SYA/51. None of the Pacific - Caribbean taro had below 73.81% resistance. The disease is therefore a major constraint to taro production in Kakamega county of Kenya. However, sources of resistance to TLB of taro possibly do exist within the Kenyan taro accessions; Kakamega KNY/KAK/16 with 82.9% and Uashin Gishu KNY/ELD/75 with 84.34% resistance. However, the identified accessions needed further evaluations under more disease pressure as well as under diverse environments.

The identification of some Kenyan taro accessions to be moderately resistant to TLB was a plus to our country as the accessions could be considered possible candidates for further

breeding purposes although some of them were low yielding. The moderate resistant accessions such as; CE/IND/0, BL/SM/92, BL/SM/80, BL/SM/151, BL/SM/83, BL/SM/25, BL/SM/120, BL/SM/136, BL/SM/13, KNY/KAK/16 with multiple comparisons with the most resistant cultivars can be used to produce source of resistance to taro leaf blight caused by the fungus *Phytophthora colocasiae* for better yield

The quality and yield of taro was found to be affected by weather parameters and taro leaf blight disease infection. Taro leaf blight incidence and severity negatively correlated with yield with Kenyan taro accessions recording lower yield in terms of number of leaves and weight of corm than the Pacific - Caribbean taro. Pacific – Caribbean Hawaian accessions had highest mean no of leaves of 9.6 followed by Papua New Guinea (PNG) with a mean of 7.8. and the lowest mean of 4.6 was from KNY/KSM/20. Kenyan accession KNY/KTL/61 from Kitale was found to be most high yielding and BL/SM/110 from Samoa Pacific - Caribbean.

6.2 Recommendations

The taro accessions that experienced low TLB disease incidence, severity and disease index should be investigated further for future breeding

Weather pattern needed to be monitored in relation to time of planting as it has effects on disease incidence, severity and index. There is also need for further evaluations of the identified taro under more disease pressure, diverse environments and for longer duration in order to understand disease pattern in terms of incidence and severity. This will help to

establish appropriate time to combat the disease at minimum effort and to design for sustainable management strategy for the disease.

Based on the present results, the identified resistant and moderately resistant taro accessions could be suggested for future breeding however, artificial screening of them with most virulent isolates of *Phytophthora colocasiae* should be conducted to enhance production of resistant taro in Kenya.

The resistant and moderately resistant accessions especially under greenhouse conditions such as; BL/HW/26 CE/IND/01, BL/HW/08, BL/SM/25, BL/SM/92,CA/JP/03,, CE/THA/07 KNY/KAK/16 KNY/MU/75 and KNY/SYA/50 require multiple comparisons with other resistant cultivars from other countries who have produced resistant accession like China in order to produce source of resistance to TLB.

6.3 Suggestions for Further Research

The parameters of epidemiology viz. total amount of rainfall in the growing period, leaf wetness period, vapor presser deficit, sunshine hour, and microclimatic parameters and canopy temperature should be critically evaluated so as to be able to correlate between the disease and weather factors.

Kenyan taro accessions found to be moderately resistant should be evaluated further in taro leaf blight endemic areas to authenticate the durability of their moderate resistance.

The knowledge about the genetic diversity of taro in terms of disease resistance and agronomical traits should be pursued in all taro growing regions of Kenya for potential mitigation of leaf blight of taro. Agronomical evaluation conducted will assist in the recommendation of best varieties for farmers

Critical study should be conducted on host-pathogen system to find out the most appropriate time to combat the disease at minimum effort. This will help in the integrated management of the disease in the surveyed areas.

Molecular characterization of a greater number of TLB pathogen isolates should be conducted and their genetic diversity together with their pathogenicity be studied in detail for effective realization of sustainable prevention of the blight disease and for combating taro leaf blight menace.

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APPENDICES

APPENDIX 1: Two-way ANOVA comparing effect of Accession and Age of plant on the incidence of disease for MMUST Garden

	Df	Sum sq	Mean sq	F value	Pr (>F)	
Accession	24	5842	243.41	12.71	<2e-16	***
Age	1	58	58.43	3.05	0.0828	
Accession: Age	24	2381	99.22	5.18	1.06e-10	***
Residuals	150	2873	19.15			

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX 11: Three-way ANOVA comparing effect of Region, Accession and Age of plant on the incidence of disease for Milimani Garden

	Df	Sum Sq	Mean Sq	F-Value	Pr(F>)	
Region	1	2313	3213	53.685	1.87e-10	***
Accession	25	2727	114	1.898	0.0183	*
Age	1	6808	6808	113.736	<2e-16	***
Region: Age	1	143	143	2.383	0.1267	
Accession: Age	25	796	33	0.554	0.948	
Residual	78	4669	60			

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX 111: Three-way ANOVA comparing effect of Region, Accession and Age of plant on the incidence of disease for Experiment three

	Df	Sum Sq	Mean sq	F-Value	Pr(>F)	
Region	1	19166	19166	1254.56	<2e-16	***
Accession	15	4039	289	18.886	6.84E-15	***
Age	1	625	625	40.888	6.24E-08	***
Region: Age	1	411	411	26.929	4.22E-06	***
Accession: Age	15	335	24	1.566	1.24E-01	
Residuals	48	733	15			

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX 1V Two-way ANOVA comparing effect of Accession and Age of plant on the disease severity for MMUST Garden

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX V: Three-way ANOVA comparing effect of Region, Accession and Age of plant on disease severity for Milimani Garden

	Df	Sum Sq	Mean Sq	F-Value	Pr (>F)	
Region	1	2338	2338	16.441	0.000118	***
Accession	25	2520	105	0.738	0.796845	
Age	1	29926	29926	210.443	<2e-16	***
Region: Age	1	1964	1964	13.811	0.000378	***
Accession: Age	25	1646	69	0.482	0.976843	
Residuals	78	11092	142			

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX V1: Three-way ANOVA comparing effect of Region, Accession and Age of plant on disease severity for greenhouse experiment

	DF	Sum Sq	Mean Sq	F Value	Pr(>F)	
Region	1	1680	1680	131.668	2.32E-15	***
Accesson	15	3472	248	19.435	3.91E-15	***
Age	1	7415	7415	581.17	<2e-1	***
Region: Age	1	196	196	15.379	0.000279	***
Accession: Age	15	531	38	2.975	0.002482	**
Residuals	48	612				

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX V11: Two-way ANOVA comparing effect of Accession and Age of plant on the Disease Index for MMUST Garden

	Df	Sum Sq	Mean sq	F-value	Pr(>F)	
Accession	24	17.294	0.7206	17.541	<2e-16	***
Age	1	0.6426	15.642	0.000118		***
Accession: Age	24	3.748	0.1562	3.802	2.40E-07	***
Residual	150	6.162	0.0411			

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX V111:Three-way ANOVA comparing effect of Region, Accession and Age of plant on the Disease Index for Milimani Garden

	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Region	1	4.833	4.833	48.106	1.04E-09	***
Accession	25	4.089	0.17	1.696	0.0428	*
Age	1	17.99	17.99	179.075	<2e-16	***
Region: Age	1	2.264	2.264	22.539	9.18E-06	***
Accession: Age	25	2.241	0.093	0.929	0.5638	
Residuals	78	7.836	0.1			

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1

APPENDIX 1X: Three-way ANOVA comparing effect of Region, Accession and Age of plant on disease index for greenhouse experiment

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)	
Region	1	30.111	30.111	1165.561	<2e-16	***
Accession	15	8.488	0.606	23.47	<2e-16	***
Age	1	7.828	7.828	303.01	<2e-16	***
Region: Age	1	2.321	2.321	89.838	1.42E-12	***
Accession: Age	15	0.672	0.048	1.859	0.0565	
Residuals	48	1.24	0.026			

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1

APPENDIX X: Agro-metrological data used for the interpretation of effect of weather on TLB disease incidence, severity and index.

Mean environmental condition at different age crop (month)

Year 2013	Rainfall(mm)	Min temp (^{0}C)	Aver temp (^{0}C)	Max temp (^{0}C)	R.H 1200 (%) at 4pm	Aver RH	R.H 0600Z (%) at 10am
April	24.9	15.4	16.25	17.1	68	75	82
May	13.2	14.5	21.35	27.4	59	72.5	86
June	9.2	14.5	20.75	26.8	58	73.5	89
July	5.5	13.6	20.5	26.7	53	69.5	86
Aug	17.2	13.9	20.5	26.4	58	70	82
Sept	16.1	14	20.6	27.2	58	69	80
Oct	12.4	14.7	20.45	27.5	59	65	71
Nov	7.7	14.8	21.2	27.3	63	68	73

Kakamega meteorological station (2013)

APPENDIX XI: Agro-metrological data used for the interpretation of effect of weather on TLB disease incidence, severity and index.

Mean environmental condition at different age crop (month)

Year 2013	Rainfall (mm)	Min temp (^{0}C)	Ave temp (^{0}C)	Maxi temp (^{0}C)	R.H 1200 (%) at 4pm	Average R.H	R.H 0600Z (%) at 10am
December	65.5	14.5	21	27.5	55	56.9	58.8
Year 2014	**Rainfall (mm)**	**Min temp (^{0}C)**	**Ave temp (^{0}C)**	**Max temp (^{0}C)**	**R.H 1200 (%) at 4pm**	**Average R.H**	**R.H 0600Z (%) at 10am**
January	45.2	13.7	21.5	29.3	43	49.75	56.5
February	102.2	14.4	21.75	29.1	43	51	59
March	174	15.1	22.35	29.6	46	55	64
April	223.9	14.1	21.25	28.4	52	59	66

Kakamega meteorological station (2013-2014)

APPENDIX X1I: ANOVA table for the best models regressing disease severity to weather elements and the age of plant

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	265.145	6	44.191	86.691	.000[b]
	Residual	164.651	323	.510		
	Total	429.796	329			
a. Dependent Variable: Severity						
b. Predictors: (Constant), Age of Plant, R.H at1200, Rainfall, RH at 0600, MINTEMP, MAX.TEMP						

APPENDIX X1I1:Linear model comparing number of leaves by region under Milimani Garden

	Estimate	Std, Error	t-value	Pr(>t)	
Intercept	-1.28521	0.24075	-5.339	1.39E-07	***
Category	0.60056	0.19038	3.155	0.0017	**
Age	2.25701	0.06724	33.568	<2e -16	***

Significance. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

APPENDIX X1V: Corm yield data for greenhouse taro

Region	Accession	Wtcorm in gms	Diacorm in cm	Lengcorm in cm
KENYAN	KNY/BSA/41	160.97	6.2	9.08
KENYAN	KNY/CNT/33	154.04	5.49	9.48
KENYAN	KNY/KAK/16	212.34	7.46	10.42
KENYAN	KNY/KSM/81	156.94	5.69	9.26
KENYAN	KNY/KTL/61	158.63	5.94	9.12
KENYAN	KNY/MU/75	172.73	6.31	9.9
KENYAN	KNY/SYA/50	168.16	5.42	9.49
KENYAN	KNY/SYA/51	150.84	5.19	9.04
PACIFIC	BL/HW/08	218.19	6.1	8.66
PACIFIC	BL/HW/26	217.13	6.22	9.11
PACIFIC	BL/SM/80	215.84	6.36	8.64
PACIFIC	BL/SM/92	195.6	5.84	8.94
PACIFIC	CA/JP/O3	219.86	6.29	8.37
PACIFIC	CE/IND/1	223.13	6.27	8.92
PACIFIC	CE/THA/07	200.72	6.43	8.82
PACIFIC	CE/THA/24	221.23	6.07	8.5

APPENDIX XV: ANOVA table testing the relationship between disease incidence and the total leaves and number of suckers for the first experiment

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	974.816	2	487.408	9.432	.000[b]
	Residual	10179.828	197	51.674		
	Total	11154.643	199			
a. Dependent Variable: Incidence						
b. Predictors: (Constant), Total suckers Total Plant Leaves						

APPENDIX XVI: ANOVA table testing the relationship between disease incidence and the total leaves and number of suckers for the second experiment

Model		Sum of Squares	df	Mean Square	F	Sig.
2	Regression	3139.882	1	3139.882	26.415	.000[c]
	Residual	15214.905	128	118.866		
	Total	18354.787	129			
a. Dependent Variable: Incidence						
b. Predictors: (Constant), suckers Total, Plant Leaves Total						
c. Predictors: (Constant), Plant Leaves Total						

Appendix XV11: Comparison of number of leaves of Pacific-Caribbean and Kenyan taro under greenhouse study

	Estimate	Std Error	t-value	Pr(>t)	
Intercept	3.06996	0.04555	67.404	<2e-16	***
Category					
Pacific	0.03477	0.03968	0.876	0.381	
Treatment3R1	0.03784	0.04001	0.946	0.344	
Treatment					
Water	-0.11532	0.04001	-2.882	0.004	**
Age in months	0.46907	0.01155	40.614	<2e-16	***

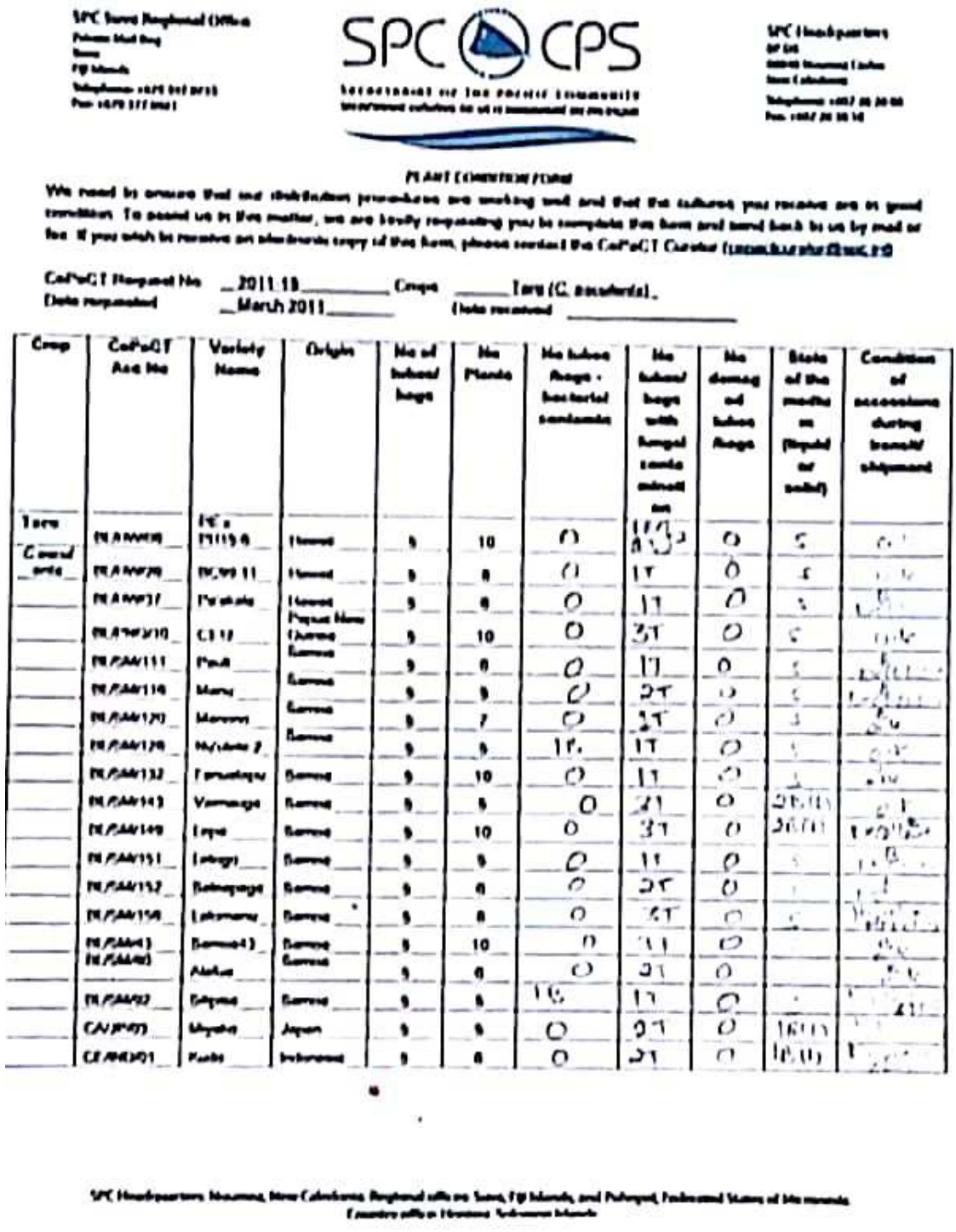
Statistically significant differences* =P ≤ 0.05, ** P≤0.01, and *** = P≤ 0.001.

Appendix XV111: Comparison of corm weight of Pacific-Caribbean and Kenyan taro under greenhouse study

	Estimate	Std.Error	t-value	Pr(>t)	
	-				***
Intercept	61.4528	3.6305	-16.927	<2e-16	
Category					**
Pacific	10.1859	3.1626	3.221	0.0013	
Treatment3R1	2.8759	3.1891	0.902	0.3673	
Treatment					**
Water	9.9703	3.1891	3.126	0.0018	
Age in months	27.4842	0.9206	29.854	<2e-16	***

Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘’ 1

Appendix XIX: The secretariat of the Pacific Community (SPC/CPS) Suva Regional office-plant condition form



SPC Suva Regional Office
Private Mail Bag
Suva
Fiji Islands
Telephone: +679 337 0733
Fax: +679 337 0021

SPC
Secretariat of the Pacific Community

SPC Headquarters
BP D5
98848 Noumea Cedex
New Caledonia
Telephone: +687 26 20 00
Fax: +687 26 38 18

PLANT CONDITION FORM

We need to ensure that our distribution procedures are working well and that the cultures you receive are in good condition. To assist us in this matter, we are kindly requesting you to complete this form and send back to us by mail or fax. If you wish to receive an acknowledgement copy of this form, please contact the CePaCT Curator (

CePaCT Request No: 2011.18 Crops: Taro (C. esculenta)
Date requested: March 2011 Date received:

Crop	CePaCT Acc No	Variety Name	Origin	No of tubers/ bags	No Plants	No tubers /bags - bacterial soft rot	No tubers/ bags with fungal conta minati on	No damag ed tubers /bags	State of the medium (liquid or solid)	Condition of accessions during transit/ shipment
Taro										
Cocoyam	[illegible]	[illegible]	Samoa	5	10	0	[illegible]	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	8	0	17	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	8	0	17	0	5	[illegible]
	[illegible]	[illegible]	Papua New Guinea	5	10	0	37	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	8	0	17	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	5	0	27	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	7	0	27	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	5	17	17	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	10	0	17	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	5	0	27	0	25/11	[illegible]
	[illegible]	[illegible]	Samoa	5	10	0	37	0	26/11	[illegible]
	[illegible]	[illegible]	Samoa	5	5	0	17	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	8	0	27	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	8	0	27	0	5	[illegible]
	[illegible]	[illegible]	Samoa	5	10	0	17	0		[illegible]
	[illegible]	[illegible]	Samoa	5	8	0	27	0		[illegible]
	[illegible]	[illegible]	Samoa	5	5	16	17	0	5	[illegible]
	CAV [illegible]	[illegible]	Japan	5	5	0	27	0	16/11	[illegible]
	CE [illegible]	[illegible]	Indonesia	5	8	0	27	0	16/11	[illegible]

SPC Headquarters, Noumea, New Caledonia; Regional offices: Suva, Fiji Islands, and Pohnpei, Federated States of Micronesia
Country offices in Honiara, Solomon Islands

Crop	CePaCT Acc. No	Variety Name	Origin	No of tubes/ bags	No Plants	No tubes /bags - bacterial contamin	No tubes/ bags with fungal contamination	No damaged tubes /bags	State of the medium (liquid or solid)	Condition of accessions during transit/ shipment
	CE:INDO06	IND 133	Indonesia	5	5	0	3T	0	L	[illegible]
	CE:MAL/12	Klang	Malaysia	5	6	2	2T	0	[illegible]	[illegible]
	CE:MAL/14	Kluang	Malaysia	5	12	0	1T	0	[illegible]	[illegible]
	CE:THA:07	Srisaket 8	Thailand	5	5	0	1T	0	[illegible]	[illegible]
	CE:THA:09	Ta Daeng	Thailand	5	9	2T	3T	0	[illegible]	[illegible]
	CE:THA:24	Rayong	Thailand	5	7	0	2T	0	[illegible]	[illegible]
	TOTAL			125	179					

Have any accessions survived the period in transit better than others, if yes, please give accession numbers.

[illegible]

Was the documentation/information accompanying the cultures useful? Have you any suggestions as to what other information could be provided that would be of benefit to you.

N/A

Were you satisfied overall with the service provided by the CePaCT? Have you any suggestions as to how this could be improved.

N/A FUNGAL [illegible]

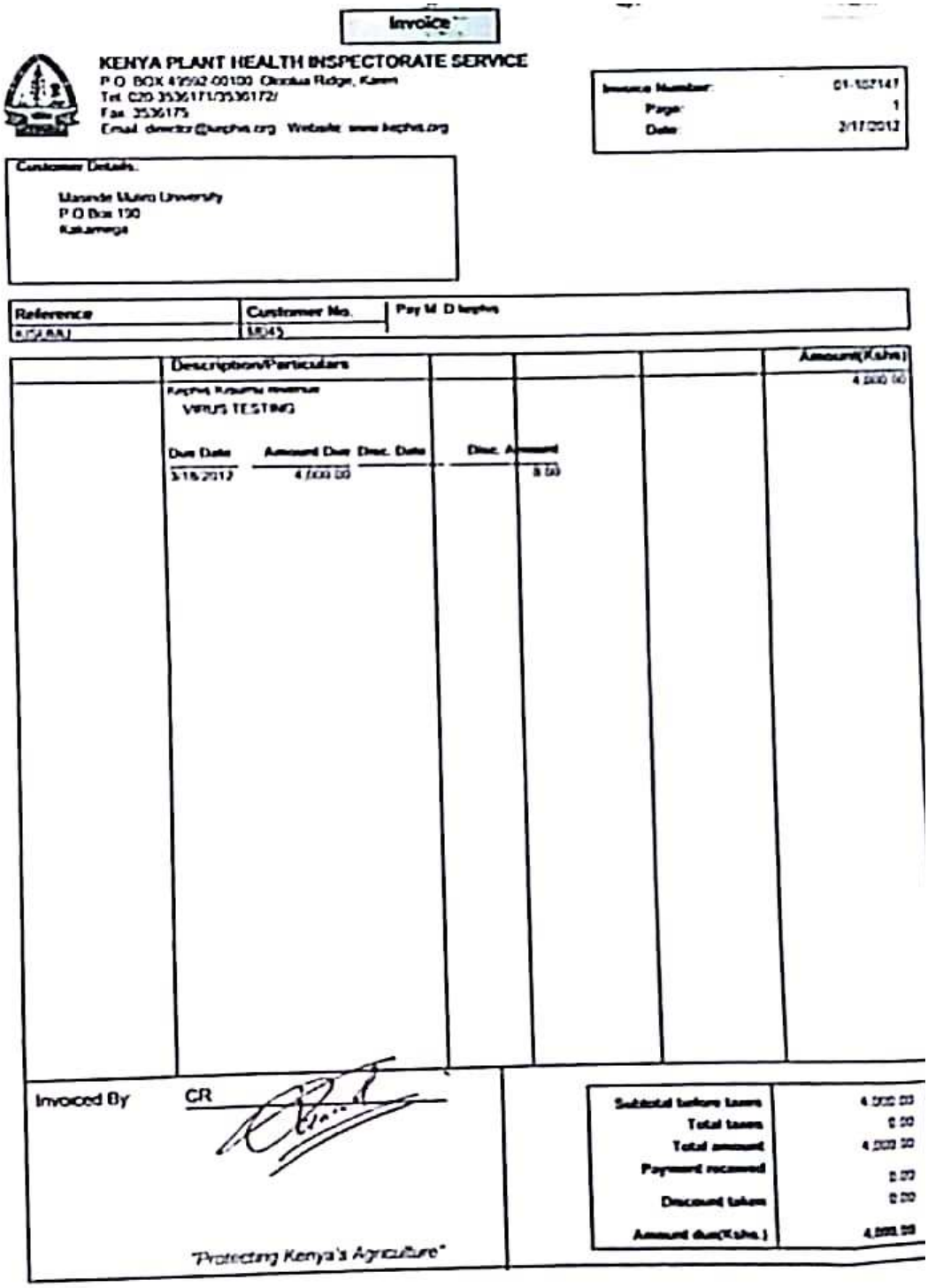
Name of Importing Agency/Institute:

Name of Importer/Curator:

Position: Researcher

Signature: _____

Appendix XX: Kenya Plant Health Inspectorate Service (KEPHIS) -Pest Diagnosis Report



Invoice

KENYA PLANT HEALTH INSPECTORATE SERVICE
P O BOX 49592-00100 Olkaluo Ridge, Karen
Tel: 020 3536171/3536172/
Fax: 3536175
Email: director@kephis.org Website: www.kephis.org

Invoice Number: 01-107141
Page: 1
Date: 3/17/2012

Customer Details:
Masinde Muliro University
P O Box 190
Kakamega

Reference	Customer No.	Pay Id: D kephis
KPS/RAU	1845	

	Description/Particulars				Amount(Kshs)
	Kephis Routine revenue VIRUS TESTING				4,000.00
	Due Date: 3/18/2012	Amount Due: 4,000.00	Disc. Date:	Disc. Amount: 0.00	

Invoiced By: CR

"Protecting Kenya's Agriculture"

Subtotal before taxes	4,000.00
Total taxes	0.00
Total amount	4,000.00
Payment received	0.00
Discount taken	0.00
Amount due(Kshs.)	4,000.00

PROPOSED CHECKLIST FOR AN OPEN QUARANTINE FACILITY/SITE

1. The area should be isolated and well fenced with only one entrance into the facility. One entrance to also serve as an exit.
2. The entrance must have a secure gate, which must be locked at all times.
3. A concrete trough to be constructed to hold disinfectant solution to be used for dipping the shoes or feet when entering and coming out of the quarantine. This should cover entire entrance.
4. No unauthorized person should gain access to the area.
5. The personnel who will be manning the site must be aware of the technical knowledge of the operations of the trial site.
6. No plant of the same family as the ones on the quarantine should be grown near the crop. They should be at least 400 meters away.
7. Nobody should take or carry away any plant part from the open quarantine.
8. All implements used in the open quarantine facility should be cleaned and stored in a designated store.
9. There should be no exchange of working tools to avoid contamination or be thoroughly disinfected before transferring elsewhere.
10. Ensure the crop performance is monitored and maintain a hard cover book on the site and record any pests, disease and weeds observed.
11. Provide guards' shade at quarantine site.
12. Provide running water tap at the site.
13. Inspection visits by KEPHIS plant inspectors shall be organized regularly during active growth period of the plants under quarantine. KEPHIS has the right to inspect the facility without NOTICE.
14. The occupation health and safety measures should be put in place. The safety of the neighbors should also be assured. Provide personal protective equipment (PPE) for the workers.