UNIVERSITY OF CAPE COAST

MANAGEMENT OF TARO LEAF BLIGHT DISEASE CAUSED BY PHYTOPHTHORA COLOCASIAE IN THE EASTERN REGION OF GHANA

BY

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere

Candidates Signature..... Date 19/03/19

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Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

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ABSTRACT

Studies on the management of leaf blight disease on taro by *Phytophthora colocasiae* were conducted in the Eastern District of Ghana. The studies comprised a survey to assess the prevalence of the disease, production practices of farmers and perception of the disease in ten selected districts of the region. It also included characterisation of isolates of *Phytophthora colocasiae* from the ten districts and the evaluation of twenty-one taro accessions both *in vitro* and on the field for resistance to the taro leaf blight disease (TLBD). Five different fungicides (Carbendazim, Agro Comet, Chemoliette, Mancozeb and TOPS-M) were evaluated *in vitro* to determine their effectiveness against *P. colocasiae* as well as evaluation of different plant distances (1.0 m x 1.0 m, 0.75 m x 0.75 m and 0.6 m ×0.9 m) for the management of TLBD. It was observed that majority of the farmers were male (75%), relatively young (< 50%) with age range of 20 to 49 years and low level of education (JHS/MSL). Most farmers produced taro on small pieces of land (0.5 acres to 1.44 acres) and in river plains as sole crop. Majority of the farmers had observed the TLBD on their farms and revealed that it mostly occurred in the rainy season and high in marshy areas with stagnant water. The results revealed that majority of the farmers used insecticides instead of fungicides to manage the disease. Few farmers practiced pruning as and when the disease appeared and admitted that it was very effective in managing the disease. The disease was observed to be very high in the districts with incidence of 62.2% to 92.2% in wet season and 69.9% to 78.9% in dry season with New Juabeng and Fanteakwa district recording the highest. The studies revealed that all the isolates were *P. colocasiae*, but showed differences in their length and width of sporangia, varying from 36 µm to 61.67 µm and 20 µm to 28 µm respectively and also a pedicel length of 3.667 µm to 12.333 µm. Amongst the 21 taro accessions evaluated, 4 exotic ones were resistant to the TLBD and only one local accession was tolerant. Carbendazim and Agro Comet (Metalaxyl + Copper (1) oxide) were identified to be most effective in reducing the growth of *P. colocasiae* at a rate of 300 ppm to 500 ppm. The combination of wider spacing (1.0m x 1.0m and 0.75m × 0.75) and pruning reduced the severity of the disease significantly.

KEY WORDS

Colocasiae

Eastern Region

Fungicide

Incidence

Leaf Blight

Management

Phytophthora

Pruning

Severity

Spacing

Taro

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DEDICATION

This work is dedicated to my family, especially my lovely wife and daughter.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
FAO	Food and Agriculture Organisation
GLM	Generalized Linear Model
GoG	Government of Ghana
LSD	Least Significant Difference
MoFA	Ministry of Food and Agriculture
PDA	Potato Dextrose Agar
RCBD	Randomised Complete Block Design
SPSS	Statistical Package for Social Science
SRID	Statistics, Research and Information Directorate
TLBD	Taro Leaf Blight Disease
USDA	United State Department of Agriculture

CHAPTER ONE

INTRODUCTION

Worldwide it is believed that crop diseases reduce agricultural productivity by more than 10% which is the equivalent of 500 million tonnes of food per year (Anon, 1998). Not only does the farmer have to cope with reduced levels of production, he or she is also faced with the additional costs involved in trying to control the problem. In the Pacific region, the impact of taro leaf blight and the threat it poses to countries not yet affected by the disease illustrate this point clearly (Gurr, 1996).

Taro leaf blight disease (TLBD) was reported in Ghana in 2012 and has spread to most of the taro growing areas in the country causing yield losses of between 25 to 50% (Omane *et al.*, 2012, Ackah, 2014). Until the problem of yield loss caused by this disease is solved, the aim of this country in reducing the poverty of taro farmers is going to be a mirage. It is therefore important that the state of the taro leaf blight disease in all the growing areas in the Eastern region of Ghana be known including the possible information on the causative organism as well as its management so as to save the crop in the country. This will lead to an increase in taro production in the region with a consequent reduction in the poverty rate. The result of the study will contribute to improving taro production in the region. The study will involve surveys to identify the intensity of the disease in the study area and the socioeconomic impact of the disease in the region. There will be field germplasm collection and evaluation. In addition some

fungicides and cultural practices in the management of the disease will be evaluated.

It is expected that a comprehensive knowledge of the disease will help taro farmers manage the disease better both on the field and in storage. It is also envisaged that the results obtained from the study, will improve the income of farmers, encourage the youth and farmers in general to cultivate taro on commercial basis and thus increase their income.

Background of the Study

Taro (*Colocasia esculenta* (L.) Schott) is an important staple crop for several hundred million small-scale farmers in Asia and the Pacific, the Americas and Africa (Jackson, 1999; Bandyopadhyay, 2012; Ackah *et al.*, 2014). There is a general consensus that taro was most likely domesticated in different locations throughout an area that stretches from India to Southern China, Melanesia and northern Australia (Taylor & Iosefa, 2013). The crop ranks fourteenth worldwide among staple vegetable crops with about 12 million tonnes produced globally and annually from about 2 million hectares of land with an average yield of 6.5 t ha^{-1} (FAOSTAT, 2010).

Most of the global taro production comes from developing countries, characterized by smallholder production systems relying on minimum external resource inputs. This makes this food crop very important for food security, especially among subsistence farmers in developing countries (Singh *et al.*, 2012). The world production as at 2016 ranked Nigeria as the highest with a production quantity of 3,273,000 tons among the first ten countries. China (1,868,590 tons),

Cameroon (1,637,900 tons), Ghana (1,299,000), Papua New Guinea (272,770 tons), Madagascar (234,820 tons), Japan (166,000 tons), Fiji (154,150 tons), Central African Republic (132,740 tons) and Egypt (115,950 tons) also ranked among the first ten in descending order (FAOSTAT, 2016). Producing countries in West Africa include Nigeria, Ghana, Cote d'Ivoire, Togo, Benin, Chad, Sierra Leone, Liberia and Guinea. Outside of West Africa, other African producers are Gabon, Egypt, Rwanda, Burundi, Zaire, Central African Republic, Comoros Island, Sao Tome and Principe, Madagascar and Mauritius (FAO, 2010).

It is the most important edible species of the monocotyledonous family Araceae (Kay, 1987). Almost all parts of a taro plant are utilized (Singh *et al.*, 2012). Its corms are baked, roasted, or boiled and the leaves are frequently eaten as a vegetable. The blades and petioles of leaves can be preserved or dried, and used as food in times of scarcity. Petioles and stolons are also eaten fried or pickled. The inflorescence is a delicacy in some food cultures of Asia and the Pacific. The corms and leaves are also used for medicinal purposes. Taro in many cultures is a sacred plant with high prestige and strong cultural and symbolic importance. It may be presented on formal occasions, in domestic or agricultural rituals, in religious and other feasts, and as bride price or compensation (Ramanatha, Matthews, Eyzaguirre & Hunter, 2010).

Taro is an important source of vitamins (A and C), protein, calcium, and phosphorus. Moreover, it is 98.8% digestible because of its small starch grains (FAO, 2008).

Despite the importance of taro as a food security crop, its production is affected by a number of diseases and pests. Taro is affected by at least ten major diseases and pests in different parts of the World (Kohler, Pellegrin, Jackson, & MacKenzie, 1997). Of the various taro diseases, taro leaf blight (TLB) caused by the fungal-like Oomycete, *Phytophthora colocasiae* Raciborski is of prime importance (Gurr, 1996; CMI, 1997; Jackson, 1999).

Phytophthora colocasiae is primarily a foliar pathogen, but it also affects the petioles and corms of its hosts. The first symptoms of the disease on the upper leaf surface are small, dark brown flecks or light brown spots which often occur at the tips and margins of leaves where water accumulates. The spots enlarge rapidly, becoming circular, zonate, and purplish brown to brown in colour. The spots on the lower leaf surface have a water-soaked or dry gray appearance and hard globules of plant exudates. These spots eventually coalesce and become blighted reducing photosynthesis and hence yield of the crop (Nelson *et al.*, 2011).

The disease can reduce corm yield by up to 50% (Jackson, 1999) and leaf yield by 95% in susceptible varieties (Nelson, Brooks, & Teves, 2011). It can also deteriorate corm quality (Sar, Wayi, & Ghodake, 1998; Paiki, 1996). In addition to corm yield losses that occur as a consequence of the reduced leaf area in diseased plants, a corm rot caused by *P. colocasiae* may also occur (Jackson, 1999; Brunt, Hunter, & Delp, 2001). The fungus also invades harvested corms and causes heavy losses during storage (Jackson 1999).

In recent years, observations and reports indicate that taro production is fast declining in Ghana (Omane *et al.*, 2012; Ackah *et al.*, 2014 & van der Puije *et al.*, 2015). The once flourishing taro fields that characterized several wetland ecologies in Ghana are fast disappearing. Critical observations indicate that taro leaf blight is largely responsible for the decline in most taro producing zones (Jackson, 1999; Omane *et al.*, 2012; Singh et al., 2012 & Ackah *et al.*, 2014).

The first report of the disease in Ghana occurred in 2009 in the Eastern region (Omane *et al.*, 2012). Since then, it has rapidly spread to other taro-growing regions in the country. Van der Puije *et al*, (2015) had observed the devastating effect of taro leaf blight disease in the Aowin-Suaman district of the Western region with a record of an average incidence of 92% in the dry season and 99% in the wet season (van der Puije *et al.*, 2015). The occurrence of TLB in Ghana therefore threatens food security and a cursory observation in the Eastern Region indicates that some farmers have abandoned their farms. Management strategies are urgently needed.

Management strategies suggested to be useful include the application of fungicides, sanitation, resistant varieties, plant spacing, drainage, intercropping, and fertilizer application (Jackson, 1999; Nelson *et al.*, 2011 & Ackah, *et al.*, 2014). The highly infectious nature of the disease may exclude the use of a single cultural or physical management practice. Hence several complimentary practices may be required to reduce the incidence and severity of the TLBD to tolerable levels (Ackah *et al.*, 2014). It is therefore quite important to develop management strategies that can best be used to manage the TLBD in order to improve yields and production of taro in the Eastern region of Ghana.

Statement of Problem

In some places like Bososo, Kwawu Bepong, Begoro, Koforidua and Oda in the Eastern Region, the crop could previously be found in almost every marshy area but due to the outbreak of this disease (Taro leaf blight) the crop has disappeared from most of these areas. The disappearance of the crop in these communities is likely to affect biodiversity. This disease has made production difficult as it attacks the crop right from the emergence of the first leaf. This affects the growth of the plant and consequently the yield. Taro was one of the most popular food crops on the market, but now can rarely be seen among the food stuffs being sold in the region. Consequently, as a result of its role as a hunger crop, the level of poverty in the region has increased significantly. Though the disease has been reported to be caused by *Phytophthora colocasiae,* other *Phytophthora* species have also been reported to infect taro, therefore there is the probability that the disease could be caused by different strains.

Justification

Taro is an important food crop in Ghana. It is a hunger crop and widely cultivated in the Eastern Region. A lot of the village folks depend on this crop for their livelihood. The farmers get a source of income from its production as well as food for the family. While a lot of taro is produced and consumed on a subsistence basis, quite a considerable amount is produced as a cash crop. In addition, surpluses from the subsistence production manage to find their way to the market, thereby playing a role in poverty alleviation. Farmers in the region

have been complaining bitterly about the disease, because they depended a lot on this crop for their livelihood. It is therefore envisaged that the results obtained from the study, will improve the income of farmers, encourage the youth and farmers in general to cultivate taro on commercial basis and thus increase their income and alleviate poverty.

General objective

The study is designed to improve taro production in the Eastern Region of Ghana through management of Taro Leaf Blight Disease (TLBD).

Specific objectives were to:

- Determine the prevalence of TLBD; taro production activities; perception of farmers; and management (pesticide and rouging/pruning) of the disease in the Eastern region.
- Characterize the pathogen that causes the disease in the study area.
- Collect germplasm and evaluate against TLBD for resistance or tolerance.
- Evaluate the effectiveness of pruning and spacing in the management of TLBD.
- Assess the effectiveness of fungicides for the control of the disease.

Hypothesis

- Taro leaf blight is not a major constraint to taro production, and also farmers have knowledge of the disease and its management in the Eastern region.
- There are no differences between the isolates of *P. colocasiae* from the different districts.

- There is no resistant accession for the management of the disease
- There is no effective fungicide for the control of the disease.
- Plant spacing and pruning are not effective in managing the disease

Significance of the Study

The project therefore seeks to improve the productivity of taro by developing management strategies that would reduce the incidence and severity of taro leaf blight disease in the Eastern Region of Ghana to acceptable levels. If the disease management strategies are effective, they may be implemented in other taro-growing regions to ensure food security and reduce poverty levels in Ghana.

CHAPTER TWO

LITERATURE REVIEW

Origin and Distribution of Taro

Various lines of ethno-botanical evidence suggest that taro (*Colocasia esculenta*) originated in South Central Asia, probably in India or the Malay Peninsula. Wild forms occur in various parts of South Eastern Asia. From its centre of origin, taro spread eastward to the rest of South East Asia, and to China, Japan and the Pacific Islands (Purseglove, 1979; USDA, 2001). From Asia, taro spread westward to Arabia and the Mediterranean region. By 100 B.C., it was being grown in China and in Egypt. It arrived on the east coast of Africa over 2,000 years ago; it was taken by voyagers, first across the continent to West Africa, and later on slave ships to the Caribbean (Purseglove, 1979; Wagner *et al.*, 1999).

Today, taro is pan-tropical in its distribution and cultivation. The greatest intensity of its cultivation, and its highest percentage contribution to diet, occurs in the Pacific Islands. Significant quantities of taro are also grown in the Caribbean, and virtually all humid or sub-humid parts of Asia. It has been suggested that the eddoe type of taro was developed and selected from cultivated taro in China and Japan several centuries ago, and was later introduced to the West Indies and other parts of the world (Purseglove, 1979; Revill *et al.*, 2005). As such, it is now cultivated in more than 65 countries worldwide (USDA, 2001). However, in Africa the largest area of cultivation is in the West, where production is dominated by Nigeria and Ghana, (FAO, 2013). In Ghana, taro is mostly grown

in regions and areas with high rainfall exceeding 2200 mm mostly to be used as food and source of income (Agyekum, 2004).

Importance of Taro

Colocasia esculenta is a major food staple and food security crop and it remains an important crop to many cultural and agricultural traditions worldwide (Ooka and Brennan, 2000). It serves both as a vegetable crop and a root tuber. The entire plant can be eaten. The corm is eaten fried, boiled, baked, or converted into breadstuffs.

Nutritionally, taro corms contain 63-85% water, 1.3-3.0% protein, 0.2-0.4% fat and appreciable quantities of Vitamins B and C. The leaf of taro contains 87.2% water, 3.0% protein, 0.8% fat and 6.0% carbohydrates (Onwueme, 1994). The protein is richer in total sulphur-bearing amino acid than that of other root tubers (Parkinson, 1984). The crop is also a good source of thiamin, riboflavin, iron, phosphorus, and zinc (Coursey, 1968; Onwueme, 1994) as well as vitamin B6, vitamin C, niacin, potassium, copper, and manganese which are important for the body immune system, protecting the body against chronic diseases including cardiovascular diseases and diabetes (Englberger *et al.*, 2003).

Juice from the corms is used externally for treatment of baldness, internally as a purgative and an antidote to wasp stings. Some species of taro are used as food plants by the larvae of some Lepidopteran species (Stephens, 1994).

Globally, taro is the fourteenth most consumed vegetable, with 12 million tonnes (~13 million US tons) produced from about 2 million hectares (5 million acres);

yielding on average 6.5 tonnes/ha (2.8 US tons/acre) (FAO, 2010; Ramanatha *et al.*, 2010).

Most taro produced is consumed locally and never reached the international market but where taro can be exported, its production not only provides cash to the farmers but also valuable foreign exchange to the country. This is precisely what had happened in Fiji, Tonga, Cook Islands, Tuvalu, and Thailand and, up till 1993, in Samoa. These countries have been able to earn substantial foreign exchange from the taro export trade, mainly to Australia and New Zealand. Many other countries would like to participate in taro exportation, but they are deterred by quarantine regulations against one or other of the taro diseases and pests (Revill *et al.*, 2005).

Taro in Food System

Taro plays a major role in the life of the Pacific islands and Africa. It is a major component of socio-cultural, dietary and economic livelihood (Lebot & Aradhya 1991). Mere production figures do not convey the full picture of the importance of the crop in producing countries, since production and utilization figures have been combined for taro and tannia (*Xanthosoma sagittifolium*) (Onwueme, 1994. In the Pacific very little of tannia is utilized for food but in West Africa, however, the situation is reversed with more tannia utilized than taro, except in Nigeria. Nevertheless, taro is always listed among the staple food crops of coastal West African countries from Nigeria to Guinea (Onwueme, 1994; Robin, 2008). Most of the crop is produced in Nigeria, Ghana and Cote d'Ivoire but outside of West Africa, other African producers are Gabon, Egypt, Rwanda,

Burundi, Zaire, Central African Republic, Comoros Island, Sao Tome and Principe, Madagascar and Mauritius (FAO, 2001). Taro contributes significantly to food security in producing countries in both West Africa and the Pacific. It serves as an important food during the dry season or before yam and cassava harvest in West Africa (Onwueme, 1994).

Socio-Cultural Value

Beside its food value, taro is important in the social and cultural life of the people. The crop features prominently in folklore, during traditional feasting and as a valuable gift in the Pacific Islands (Onwueme, 1994). In West Africa, such prestige is attached to yam. Various parts of the taro plant are used in traditional medicine and hence has a certain amount of reverence attached to it (Robin, 2008). This cultural attachment is largely responsible for the existence of the export market of taro in Australia, New Zealand and United States of America, where many Pacific islanders live (Onwueme, 1994; Robin, 2008). Taro from West Africa is exported mostly to Europe, where again the consumers are migrants from Africa, who see themselves maintaining their culture through traditional food (Robin, 2008).

Development Economy of Taro

Taro production generates income for several subsistence farmers in both West Africa and the Pacific. Market avenues for surpluses from subsistence production are more widespread in the Pacific, compared to West Africa, where production and consumption are rather peculiar to specific ecological zones

(Robin, 2008). Taro contributes significantly to poverty alleviation for several vulnerable groups in producing regions. For some Pacific countries, taro exports form a substantial part of foreign exchange earnings. In West Africa, however, other traditional export products such as cocoa, coffee and timber exist and hence taro is classified under the non-traditional export commodities (Robin, 2008).

Production Systems of Taro

There are two main production systems used in taro cultivation: flooded or wetland taro production and dryland or upland taro production (De la Pena, 1998). Dryland taro production implies that the taro is not grown in flooded or marshy conditions and is essentially rain-fed (Onwueme 1994). Flooded taro cultivation occurs in situations where water is abundant. The water may be supplied by irrigation, by the swampy nature of terrain, or from diverted rivers and streams and there is no need for irrigation (Robin, 2008). Despite its advantages, flooded taro is restricted only to certain locations where the economics of production and water availability permit the system to thrive. By far the largest area and production of taro in the Asia and Pacific region occurs under dry-land conditions. This is also true of global taro production (Robin, 2008).

There are essentially four types of planting materials that are used in taro production: side suckers produced as a result of lateral proliferation of the main plant in the previous crop, small corms (unmarketable) resulting from the main plant in the previous crop; huli which is the apical 1-2 cm of the corm with the basal 15-20 cm of the petioles attached; and corm pieces resulting from larger corms (De la Pena, 1998).

Three strategies are currently available for the rapid multiplication of planting material. The first is to use a minisett technique analogous to the same technique used for yams (*Dioscorea* spp.. The second rapid method of generating planting material is through meristem tissue culture, which, starting from a single plant, thousands of plantlets can be generated in a few months. A third method is the use of the true seed of taro for planting (Onwueme, 1994).

Propagation and Growth Conditions of Taro

Propagation

Colocasia esculenta is grown in all parts of the tropics and subtropical regions and has long been propagated vegetatively with planting distance of 60 by 90 cm or 90 by 90 cm (Onwueme, 1978; Raynor & Silbanus 1993).

Growth Conditions

Temperature

Growth is best at temperatures between 20°C and 30°C (Onwueme, 1978, Silva *et al.*, 1990; Manrique, 1994). Temperatures below or above this range have been reported by Manrique (1994) to reduce plant growth and yield while accelerating taro leaf blight disease and other fungal and bacterial diseases such as bacterial leaf spot.

Soil and Water requirements

Taro can be grown in a well-drained soil if supplied with abundant water which exceeds 2500 mm. It is able to tolerate heavy soils on which flooding and

waterlogging can occur (Onwueme, 1978; Raynor & Silbanus, 1993). Dry conditions could result in reduced corm yields. They do best in moist or wet soil, rich in organic material or compost with soil pH of 5.5-6.5 (Onwueme, 1978; Raynor & Silbanus, 1993). Macronutrients such as nitrogen, phosphorus and potassium and micronutrients such as calcium, sulphur, manganese, boron, iron and chlorine have been reported to be essential for normal growth of taro either in upland or wetland conditions but their imbalances could reduce growth and yeild (Silva *et al.*, 1990; Manrique, 1994). One particular useful characteristic of taro is that some cultivars are able to tolerate salinity and in Japan and Egypt, taro has been used satisfactorily as a first crop in the reclamation of saline soils (Kay, 1973). Taro is also able to form beneficial associations with vesicular-arbuscular mycorrhizae, which facilitates nutrient absorption (Kay, 1973).

Light requirement

It has been reported that highest yields of taro are obtained under full intensity sunlight (Raynor & Silbanus, 1993; Manrique, 1994). However, they appear to be most shade-tolerant than most other crops. This means that reasonable yields can be obtained even in shade conditions where other crops might fail completely. This is a particularly important characteristic which enables taro to fit into unique intercropping systems with tree crops and other crops. Daylight also affects the growth and development of taro. Formation of corms is promoted by short-day conditions while flowering is promoted by long-day conditions (Raynor & Silbanus, 1993; Manrique, 1994).

Cultivation Practices

Weed control

Weed control may vary in various production systems. For flooded taro, weed infestation is minimal, but some aquatic weeds do occur. Some of these are pulled out manually, although in high-technology production systems, herbicides may be added to the irrigation water. In Hawaii, Nitrofen at 3-6 kg/ha has been found to be effective (Hunter *et al.*, 2001). For Dryland taro, weed control is necessary only during the first three months or so, if crop spacing has been close enough. Thereafter, the crop closes canopy and further weed control is not necessary (Hunter *et al.*, 2001). In the last two months of the crop's field life, average plant height diminishes and spaces open up again between plants. Weeds may re-appear but their potential for economic damage is very low. Weed control with hand tools is the most prevalent practice in Dryland taro and it helps reduce incidence and severity of pest and diseases (Jackson *et al.*, 1980, Hunter *et al.*, 2001).

Fertilizer application

The majority of taro growers in the Asia, Pacific region and Africa (Nigeria and Ghana) especially those producing taro to be used as food, do not use any fertilizer. Some even believe that fertilizers reduce the quality and storability of their taro (Onwueme, 1978). Generally, taro has been found to respond well to fertilizers and to manures and composts. Kay (1973) had earlier reported that taro is able to form mycorrhizal associations which promote phosphorus uptake. Also, in some flooded taro fields, *Azolla* is deliberately or

inadvertently cultured in the field water, to improve the nitrogen supply to the taro. This is quite common in flooded taro fields (Kay, 1973).

Dryland and wetland taro respond to N fertilisation (Silva *et al.*, 1990, Manrique, 1994). They reported that plant growth foliar N concentration and yield increases as a result of N fertilization with maximum yield at N ratio of 560 and 1120 kg/ha for upland and lowland conditions, respectively. They also reported on the response of taro to manure such as animal droppings and compost as well as mulching with plants parts.

Harvesting

For dryland taro, maturity for harvest is signalled by a decline in the height of the plants and a general yellowing of the leaves (Onwueme, 1994; Chan, 1997). These same signals occur in flooded taro, but are less distinct. Due to continuous and abundant water supply, the root system of flooded taro remains alive and active, and leaf senescence is only partial. The time from planting to harvesting ranges from 5-12 months for dryland taro and 12-15 months for flooded taro. Much depends on the cultivar and the prevailing conditions during the season (Chan, 1997).

Harvesting is most commonly done by means of hand tools (Onwueme, 1994). The soil around the corm is loosened, and the corm is pulled up by grabbing the base of the petioles. For flooded taro, harvesting is more tedious because of the need to sever the living roots that still anchor the corm to the soil. Even in mechanised production systems, harvesting is still mostly done by hand, thereby increasing the labour and cost of production (Onwueme, 1994).

Constraints to Production in West Africa

Generally, the yield of taro extensively cropped in West Africa is very low. The yields are lower than those of the Pacific and Asian countries (FAO, 1987). Cultivars produced are also low yielding and produce many suckers leading to poor yields of ratoon crop. There is limited allocation of resources by farmers and policy makers to the taro industry. This in part has limited research effort on taro compared to other tuber crops in the Africa (Dapaah, 1994). Urbanization has also caused a shift in food habits to the exclusion of taro in some instances. This is aggravated by poor storability and lack of processing and stable taro products. There is unfavourable competition against taro among root and tuber crops for food uses. Drought and erratic rainfall distribution are major hindrances to upland taro production, since irrigation facilities are non-existent. In Egypt, where taro is grown commercially under flood irrigation, yield of 31, 00 kg ha^{-1} is common (Manrique, 1995; FAO, 2001). There is inefficient marketing strategies and limited and uncoordinated research. Leaf and corm rot diseases can cause 40-90% yield loss (Doku, 1984). Corm rot in storage can result in 75% corm loss during severe infection (Nwufu & Fajola, 1981).

Pests and Diseases

Pests of Taro

In many countries pests do not appear to present a serious problem on taro. However, in some places they are of major importance and over 180 insects have been listed as damaging to the leaves, and about 40 as causing damage to the corms; snails, slugs, birds, rodents and other mammals are pests on occasion (Sar

et al., 1998 & Carmichael *et al.*, 2008). Among the more important insects may be noted the taro leaf hopper, *Tarophagus proserpina*, which also transmits virus infections. The egg predator, *Cyrtorrhinus fulvus* has successfully controlled the leaf hopper in the Philippines and other Pacific areas (Jackson & Gollifer, 1975). Taro hornworm (*Hippotion celerio)*, the cluster caterpillar (*Spodoptera litura*), whiteflies (*Bemisia* spp.), spider mites (*Tetranychus* spp.) and aphids also attack the leaves. These insect pests are controlled by chemical means including the use of methomyl, carbaryl, diazinon, malathion and dimethoate (Carmichael *et al.*, 2008). However, avoidance of indiscriminate spraying is important as a measure of natural biological control frequently operates, and it is important not to eliminate the beneficial organisms: emphasis should be given to integrated control (Jackson & Gollifer, 1975).

The corms are sometimes affected by the taro beetle (*Papuana* spp.). A suggested control is by gamma-HCH applied to the planting holes and again at intervals after planting (Jackson & Gollifer, 1975). Root knot nematodes (*Meloidogyne* spp.) can cause severe damage, producing galls on the corms. Treatment of planting material by immersion in water at 50°C for 40 minutes is suggested (Jackson & Gollifer 1975).

Diseases of Taro

Diseases affecting taro include bacteria soft rot, leaf blight caused by *Phytophthora* spp, *Phyllosticta* spot by *Phyllosticta* spp.; Dasheen mosaic which is a viral condition transmitted by aphids or leaf hoppers, fungal root rots which

may be serious either on the field or in storage, soft rot caused by *Pythium* spp.; southern blight caused by *Corticium rolfsii* and others (Jackson & Gollifer, 1975).

Bacteria Soft Rot

Bacterial soft rot of corm is a strong smelling watery soft rot ranging in colour from white to dark blue and plants wilt suddenly. The disease is caused by the bacteria *Erwinia chrysanthemi* in the field and in storage (Figure 1). Wounds and bruises caused by the feeding of insects and other animals and those inflicted at harvest are the most common infection courts for this disease. Abundant moisture is required for the invasion of the bacteria (Ooka, 1994). Control measures therefore include careful handling of corms to minimize injury at harvest, air drying of corms, and storage at low temperatures of only the sound corms (Carmichael *et al.,* 2008).

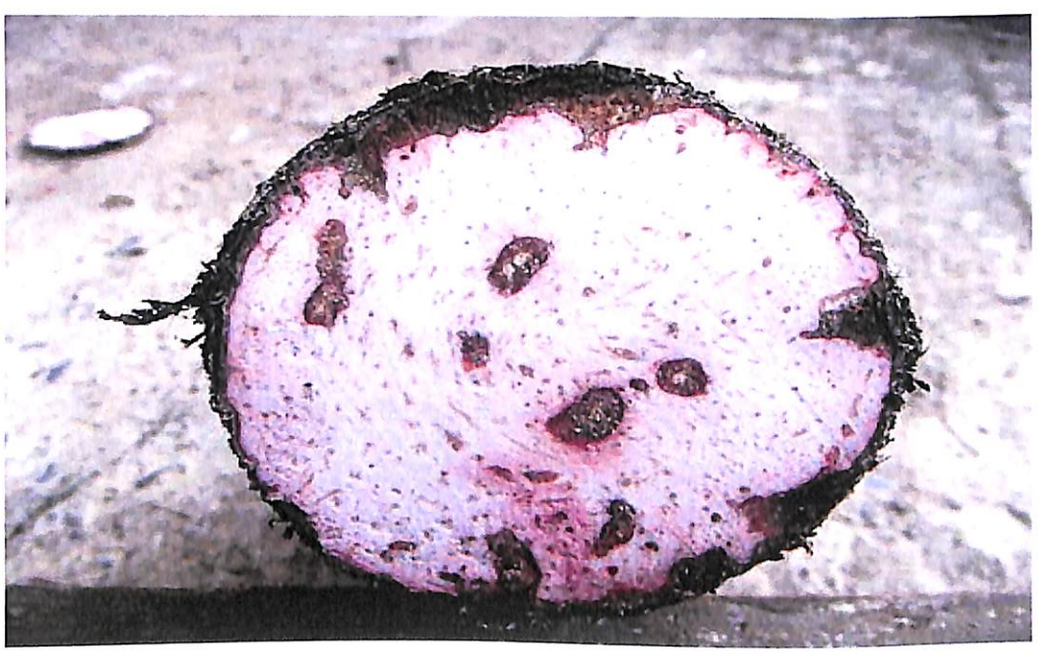


Figure 1. Taro corm affected by bacteria soft rot caused by *Erwinia chrysanthemi.* Source: Brooks (2005)

There are no specific measures to prevent field infections of *Erwinia chrysanthemi*, and the low incidence of the rot in taro planting precludes efforts to find any. However, the 'tops', the petiole base with corm piece from corm-rot affected plants should not be used as propagating material.

Fungal Diseases

Athelia rolfsii Corm Rot

The disease is caused by *Athelia rolfsii* (Curzi), which is a soil-borne fungus that infects taro at the soil level, causing corms and roots to rot and leaves to wilt. Infection starts at the soil level, at the base of the petioles. Fans of white mycelia grow over the infected area and leaves often wilt. The disease is characterized by the presence of more dead leaves than normal. The base of petiole of wilted leaves would usually be covered with white mycelia and a mass of sclerotia may be pale cream to reddish brown and 1–2 mm in diameter (plate 2). These are distinct from the basidiocarps produced by *Marasmiellus stenophyllus* which may also occur on wilted taro leaves (Carmichael *et al.*, 2008).

Athelia rolfsii is a major pathogen of several crops, hence a number of control measures have been developed, some of which may be applicable to taro. These include removing and destroying infected plants by burning, applying good cultural practices such as deep ploughing and encouraging the growth of micro-organisms (especially *Trichoderma* spp.) that inhibit fungal growth; using soil solarisation by covering the soil with plastic and allowing the sun to heat the trapped air; liming the soil; applying fungicides and using crop rotation

(McKenzie & Jackson, 1990). Crop rotation with non-hosts or tolerant hosts can greatly reduce numbers of infective propagules in a field, although the sclerotia can remain viable for many years. Cereal crops (Poaceae) are relatively resistant to the fungus and so can be integrated to help manage the disease (Carmichael *et al.,* 2008).

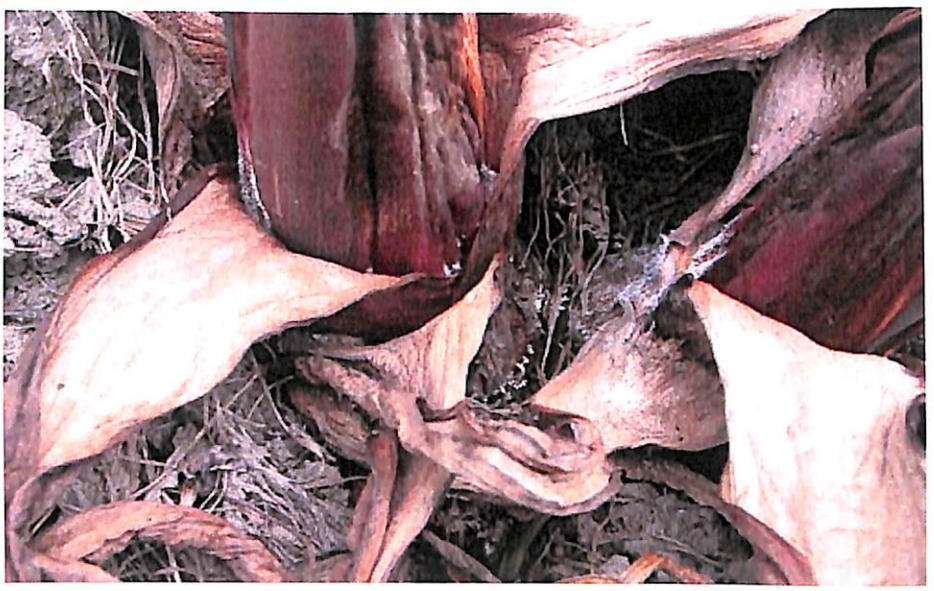


Figure 2. Base of taro plant infected by *Athelia rolfsii,* Note the fans of mycelium growing over the base of the petiole and a fringe of white sclerotia at soil level. Source: Brooks (2005)

Marasmiellus Corm and Leaf Rot

The fungal pathogen *Marasmiellus stenophyllus (Mont.)* infects taro at the base of the plant, destroying leaves, corms and roots, and commonly producing toadstools on the dying parts (Figure 3). Corm and leaf spot caused by *Marasmiellus stenophyllus* leads to leaf collapse due to the development of large brown rots at the base of the plant associated with white fungal growth (Kohler *et al.*, 1997). The leaves are often stuck together by the fungal threads (mycelia).

Toadstools form in large numbers on the withered leaves at soil level. The fungus grows over the roots and kills them, and soil particles become fastened to the roots in the process. Corms become inedible and, even at an early stage of decay, may be unsightly with mycelium growth causing small 'pocket' rots. However, the incidence of infection is low. *Marasmiellus stenophyllus* is quite distinct on taro, but could be confused with *Athelia rolfsii* on completely dead plants. The removal and destruction of infected plants by burning is helpful in controlling the fungus (Carmichael *et al.,* 2008).

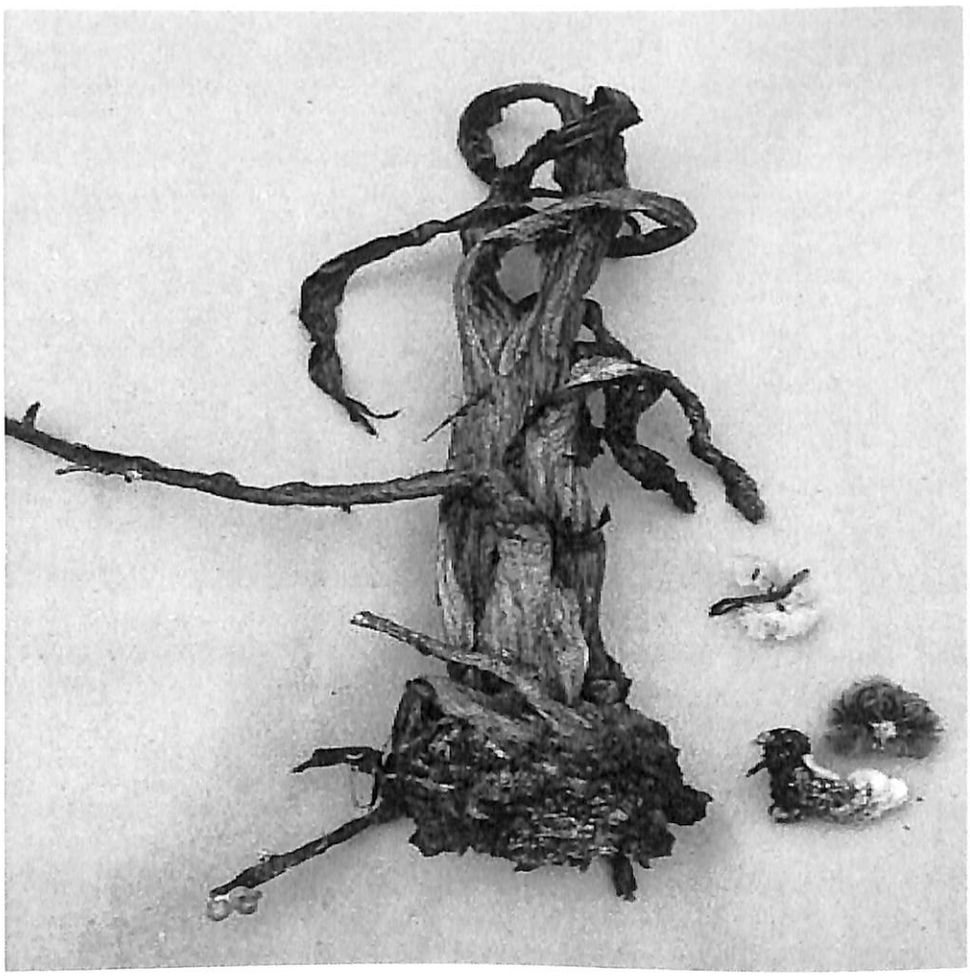


Figure 3. Late stage infection of taro by *M. Stenophyllus* showing matted leaves and mummified corm. Source: Brooks (2004).

Pythium Corm Soft Rot

A number of *Pythium* species have been isolated from the roots and corms of wilted plants in dry and wetland taro. These species cause corm soft rot in taro. When infected, the whole plant becomes stunted, the leaf stalks are shortened, the leaf blades become curled or crinkled and, instead of being a deep, healthy green, are yellowish and spotted (Brooks, 2004).

Figure 4. Taro plants showing signs of infection by *Pythium.* Source: Brooks, (2004)

The corms show rot of varying colour from whitish-yellow, through shades of grey and blue, to dark purple. Usually, rot starts at the base of the corm and progresses upward until the whole corm is affected (Brooks, 2004).

Occasionally, the disease starts at the side of the corm, 5–7 cm above the base. The skin of a diseased corm becomes softened, usually remaining intact until complete disintegration of the interior of the corm has taken place; then the

skin also disintegrates (Carmichael *et al.,* 2008). When the corm is cut open, a sharp line of demarcation can be seen between healthy and diseased tissue (Figure 5).

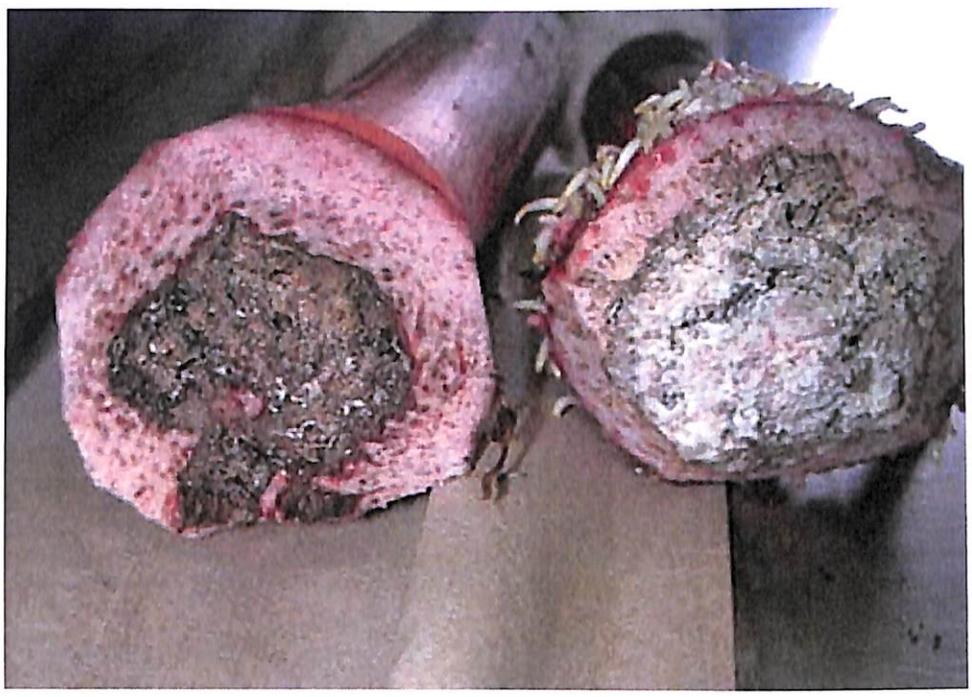


Figure 5. *Pythium* corm soft rot of young plants. Source: Brooks, (2004)

Generally, the rot is evident on the corms as it develops from the base. However, if it is an early infection, lesions on the surface of the corm may be observed. If these are found, the corm should be cut open to see what lies beneath. Although few other species of fungi cause rots in the field, there are others that cause postharvest rots (Carmichael *et al.,* 2008).

To manage this disease, only healthy material that is free from rot should be planted. Removal of diseased plant material from the field at harvest can reduce inoculum levels. Ploughing and drying of wetland taro fields are recommended (Brooks 2004). Crop rotation with non-host crop plants is also useful. Using 1% Sodium hypochlorite as corm dip has been found useful in

reducing post harvest rot in Solomon Islands. Storage in leaf-lined, shallow soil-pits have also been reported to reduce damage by rot in Solomon Island (Carmichael *et al.*, 2008).

Spongy Black Rot

This disease is caused by the fungus *Lasiodiplodia theobromae* (Pat.). This organism in taro corms causes postharvest rot that is initially whitish-cream, later becoming blue–black (Jackson & Gollifer, 1975). *Lasiodiplodia theobromae* is frequently isolated in decayed corm tissues behind advancing rots caused by *Phytophthora colocasiae* and *Pythium splendens*. Even in the absence of other fungi, it enters corms through wounds made during harvest and causes complete decay in 10–14 days. *Lasioplodia theobromae* causes a spongy rot, which occasionally becomes dry and powdery, with an indistinct margin between healthy and diseased tissue (Ooka, 1994).

Spongy black rot can be detected by cutting the corm to reveal the black interior; it has a strong, sour smell and black spore masses form on the corm surface (Carmichael *et al.*, 2008). Dipping corms in bleach (1% sodium hypochlorite) for 2 minutes before storing in polyethylene bags is effective in controlling this fungus. The traditional practice in the Pacific countries is to store taro for up to 4 weeks buried in pits situated in shaded, well-drained soil (Carmichael *et al.*, 2008).

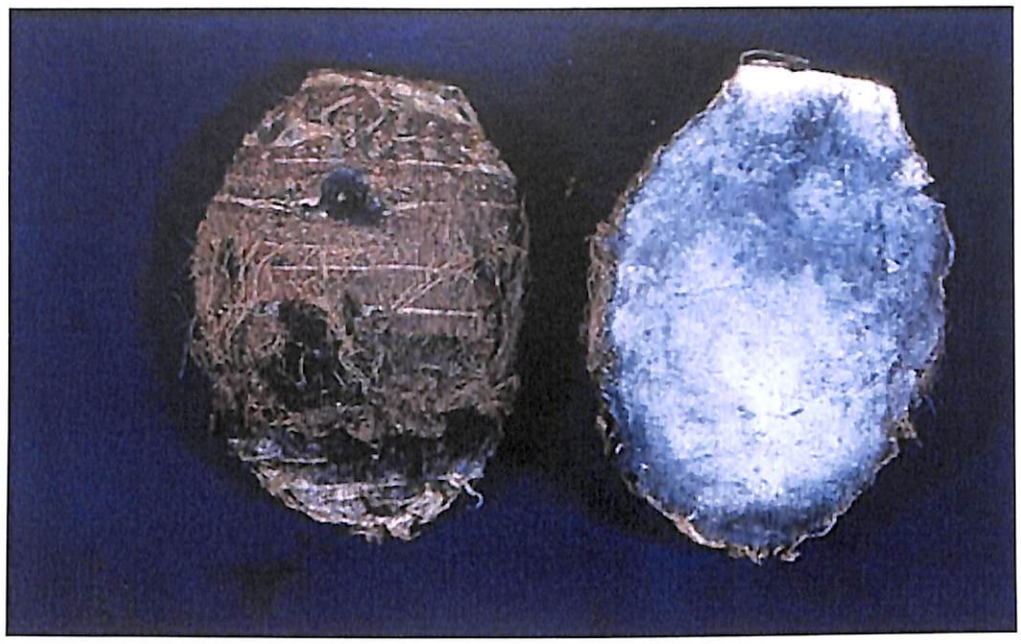


Figure 6. Spongy black rot, *Lasiodiplodia theobromae*, in taro corms, causing rots that are at first whitish cream and later blue black. Brooks, (2004).

Brown Leaf Spot (or Ghost Spot)

Brown leaf spot disease is caused by *Cladosporium colocasiae* (Sawada). It is a fungal disease of older leaves. It is also called ghost spot because the lesions are often less evident on the opposite surface of the leaf. This leaf spot causes symptoms very similar to those of *Neojohnstonia colocasiae* (orange leaf spot) (McKenzie & Jackson, 1990).

The symptoms include reddish brown, circular or irregular, diffuse spots or blotches on either leaf surface, sometimes with dark, diffuse centres.. Sometimes the spots are surrounded by a yellow halo or have a dark brown, diffuse border. Spots can be up to 15 mm in diameter, but are usually much smaller when there are many spots on a single leaf (Brooks, 2004).

Figure 7. Leaf showing symptoms of brown leaf spot. Source: Brooks, (2004)

The disease can be managed by applying Phytosanitary measures. Plant quarantine authorities might require certification that consignments of leaves are free from this pathogen when leaves are moved internationally. However, it is not considered to be a pest of potential economic importance. No control is required; however, removal and destruction by burning of infected leaves will reduce inoculum levels (McKenzie & Jackson, 1990).

Orange Leaf Spot

Orange leaf spot caused by *Neojohnstonia colocasiae* (M.B. Ellis) is a fungal disease of older leaves causing symptoms very similar to those of *Cladosporium colocasiae* (brown leaf spot). *Neojohnstonia colocasiae* causes yellowish-brown, circular or irregular blotches on either leaf surface. These become darker with the onset of sporulation. Spots are sometimes surrounded by

a yellow halo or have a brown border. They can be up to 15 mm in diameter, but tend to be smaller when there are many spots on a single leaf. On the leaves, the spots can be seen with the naked eye (McKenzie & Jackson, 1990; Brooks, 2004).

No control measures are recommended; however, removal and destruction by burning of infected leaves will reduce inoculums levels (Carmichael *et al.*, 2008).

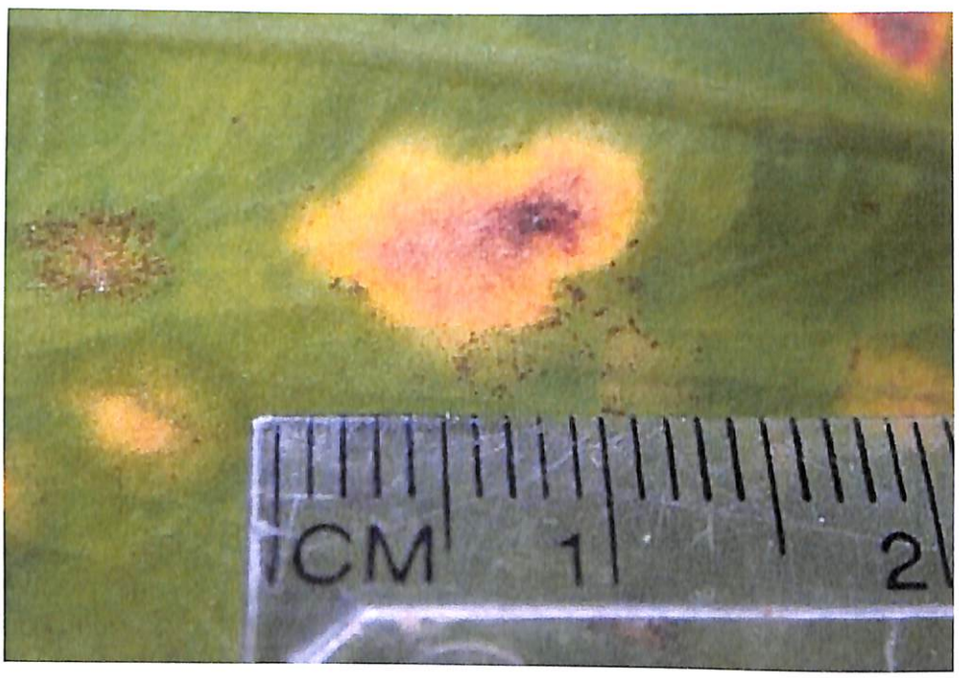


Figure 8. Orange leaf spot symptoms on taro leaf. Source: Brooks (2004)

Pseudocercospora Leaf Blotch

The disease is a fungal disease caused by *Pseudocercospora colocasiae* (Deighton), mostly affecting older leaves. The symptoms are similar to those caused by *Neojohnstonia colocasiae* (orange leaf spot) and *Cladosporium colocasiae* (brown leaf spot) (McKenzie &Jackson, 1990; Brooks, 2004).

The disease is characterised by blotches with indistinct, circular, yellow-reddish to whitish-green discolouration on the upper surface of the leaf, and black mould growth on the corresponding lower surface.

Figure 9. Taro leaf showing symptom of the leaf blotch disease Source: Brooks (2004).

The blotches can be up to 1.5 cm in diameter. This disease is not considered to be of economic importance; therefore, no control measures are necessary. It is a disease of older leaves (Brooks, 2004).

White Spot of Taro

The disease is caused by the fungus *Leptosphaerulina trifolii* (Rostrup) Petrak. This fungus produces yellow spots on taro leaves which later turn white. Spots sometimes merge and show 'shot hole' symptoms as the centres fall out

(Figure 10) (Kohler *et al.*, 1997). Infections are initially visible as small, yellow–green spots on the upper leaf. As spots mature, they become edged by a thin (1 mm), reddish-brown border and surrounded by an intense yellow halo, 1–2 mm wide. Mature lesions are 2–5 mm in diameter with paper-white centres. Small, black fruiting bodies (pseudothecia) can be seen on close observation against the white tissue of mature lesions (Carmichael et al., 2008). Centres often fall out, creating a 'shot hole' appearance. In severe infections, spots may coalesce, and the leaves look tattered (Kohler *et al.*, 1997).

Plate 10. Severe infection by *Leptosphaerulina trifolii* on taro. Source: Brooks, (2004).

The impact of this disease is very low and in Africa, only a few plants have been seen to be severely infected (25–50% leaf area). Control measures are usually not necessary (Carmichael *et al.,* 2008).

Phoma Shot Hole Disease

This type of disease is caused by *Phoma* spp. (*Phoma* sp. and *Phoma colocasiae*). The pathogen produces relatively large lesions on the leaf. As the spots age, their centres fall out, giving the 'shot hole' effect (Figure 11) (Carmichael *et al.,* 2008).

Figure 11. Shot Hole (*Phoma* sp.) damage to a taro leaf. Source: Carmichael *et al.,* (2008)

The first symptoms of a Phoma infestation are small, round, brown spots on the second or third leaves. As the spots enlarge to 2 cm in diameter, the brown centres fall out, resulting in the typical 'shot hole' symptom. The holes have a narrow, brown margin, which is surrounded by an intense yellow halo. The holes may merge, so that large areas of the leaf are destroyed. This leads to premature leaf death. *Phoma* spp. can be mistaken for taro leaf blight (*Phytophthora colocasiae*), particularly when infection levels are high. The difference is that *P. Colocasiae* lesions are often surrounded by a white zone of spores and exude droplets that dry as dark pellets (Jackson & Gollifer, 1975).

Taro Leaf Blight Disease

Taro leaf blight (TLBD) caused by *Phytophthora colocasiae* is a major disease of taro in the Pacific island countries and now some countries in Africa (Carmichael et al., 2008). A small, circular speck, brown on the upper surface of the leaf and water-soaked below, is the first sign of the disease. Infections often begin on the lobes and sides of the leaf where water collects. The spots enlarge, become irregular in shape, and are dark brown with yellow margins (Figure 12). Initial spots give rise to secondary infections and, soon afterwards, the leaf blade collapses and dies (Jackson & Gollifer, 1975). Spores are produced at night and can be seen around the spots in the morning.

Figure 12: Symptoms of taro leaf blight disease.Source: Brooks (2004).

Clear, yellow-to-red droplets ooze from the spots and develop into dark brown, hard pellets as they dry. This is a characteristic symptom of the disease. Spores may be trapped inside the pellets. Usually, petioles are not attacked, but instead collapse as the leaf blade is destroyed (Brooks, 2005). The fungus can also cause a postharvest corm rot that is difficult to detect unless corms are cut open. The rots are light brown and hard. Corms can carry spores on the surface (undetectable) and mycelium in postharvest rots. Corms need to be cut open to detect the rots (Carmichael *et al.,* 2008).

Origin and Distribution of Taro Leaf Blight

Raciborski (1900), in Java, was the first person to study taro leaf blight disease and to name the causal pathogen. There is limited information on the origin of *P. colocasiae* (Zhang *et al.*, 1994). Ko (1979) indicated that Asia may be

the centre of origin of *P. colocasiae* given that it is the centre of origin in the world for many wild and cultivated varieties of taro. Prior to this, Trujillo (1965) had also speculated on a Southeast Asian origin for the pathogen. Based on this, Trujillo (1965) further postulated that the disease dispersed into the Pacific region by three different routes: first to Hawai'i via the Philippines; secondly from Taiwan to Micronesia via the Philippines; and thirdly to Fiji via Papua New Guinea and Solomon Islands. The movement of taro leaf blight via Papua New Guinea and Solomon Islands would appear to be a separate route and is supported by anecdotal evidence from inhabitants of these countries expressing that the disease only appeared after the Western Pacific Campaign of World War II (Oliver, 1973). The disease is currently in Africa having been reported in Nigeria, Cameroon and Ghana (Bandyopadhyay *et al.*, 2011, Omane *et al.*, 2012).

Host Range of *P. colocasiae*

Phytophthora colocasiae has limited host range (Nelson *et al.*, 2011). The pathogen is known to infect primarily *Colocasia* spp. (*C. esculenta*, *C. esculenta* var. *globulifer*, *C. antiquorum*) and *Alocasia macrorhiza* (giant taro). Although Alocasia 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 (Brunt *et al.*, 2001). *Xanthosoma saggittifolia* is immune (Fullerton & Yyson, 2001). Other reported hosts include *Amorphophallus campanulatus* (elephant-foot yam), *Bougainvillea spectabilis* (bougainvillea), *Cantharanthus roseus* (periwinkle), *Hevea brasiliensis* (rubber), *Panax quinquefolius* (American ginseng), *Piper*

betle (betel), *Piper nigrum* (black pepper), *Ricinis communis* (castor bean) and *Vinca rosea* (periwinkle) (USDA, 2010).

Epidemiology of Taro Leaf Blight Disease

Inoculum in the form of spores is spread by wind-driven rain and dew to adjacent plants and nearby taro plantations (Jackson, 1999). The disease can also be spread through planting materials, and *Phytophthora colocasiae* has been reported as remaining active on planting material for about three weeks after harvest (Jackson, 1999). Mostly, taro planting material for the next crop comes from the crop being harvested (Ooka and Brennan, 2000), and the use of planting material from infected corms increases leaf blight disease incidence in subsequent taro crops. In addition, the disease is found to occur more and is severe in flood land taro than dry land taro (Ooka, 1994).

Plant density, temperature and humidity appear to be the most important factors influencing infection and spread of blight disease (Ivancic *et al.*, 1996). Ooka and Brennan (2000) have also reported that the number of plants grown in a given space affects taro leaf blight disease prevalence and yield. High plant density makes it easier for insect pests to move among plants and if sunlight and air circulation are too restricted, blight disease can occur more readily (Ooka and Brennan, 2000). Plants growing in extremely hot and humid environments show higher susceptibility to blight disease than those growing under normal conditions (Ivancic *et al.*, 1996). The absence of certain important soil nutrients such as calcium and phosphorus can also exacerbate the disease (Tilialo *et al.*, 1996).

Guanino and Scot (2010) have recently reported that under cloudy weather conditions with intermittent rains and temperature around 28 °C, the disease quickly spreads across entire fields giving them a blighted appearance. Epidemics are favoured by repeated night temperatures close to 20 to 22 °C and relative humidity of 90-100 % when zoospore release is greatest. Under such conditions colocasiae leaves could be damaged in 5-7 days.

Phytophthora produces thick-walled asexual chlamydospores and thick-walled sexual oospores for survival in unfavourable environmental conditions. In addition, *Phytophthora* produce asexual sporangia that can be dispersed by water and wind (Alexopoulos *et al.*, 1996). When the sporangia are exposed to high humidity or free water, they can germinate directly or indirectly. Direct germination is common under conditions of high humidity and occurs when the sporangium produces a germ tube that is able to cause infection (Alexopoulos et al., 1996) while indirect germination occurs in the presence of free water. Occasional sunlight with intermittent rains is more favourable for disease severity compared to prolonged cloudy weather with rainfall (Misra and Chowdhury, 1997).

Management of Taro Leaf Blight Disease

Taro leaf Blight disease if not managed early can lead to yield reduction of more than 50% (Jackson, 1999). Unmanaged blight disease also causes changes in cropping patterns of *Colocasiae esculenta* (Jackson, 1996) and consequently, the existence of taro can be jeopardized. The survival of the crop and genetic data has been threatened with extinction (Jackson, 1996). Various management strategies

have been used for taro leaf blight, including cultural, biological and chemical control, the use of resistant cultivars and integrated pest and disease management (IPM) (Jackson, 1996).

Cultural control

Cultural control is the use of farming practices to manage pest and diseases of crops in the field. Various cultural methods have been recommended for the control of taro leaf blight (Hunter *et al.*, 2001). The removal of infected leaves has been effective during the early stages of disease development in a number of countries (Hunter *et al.*, 2001). However, regular rogueing of diseased leaves in plots affected by severe blight did not eradicate the pathogen (Jackson *et al.* 1980). Although rogueing of infected leaves may not eradicate the pathogen, it could delay the start of epiphytotics (Ashok & Saikia, 1996). They observed a rapid increase in disease and a decline in corm yields after rogueing had ceased.

Wide spacing of plants has been reported to reduce disease severity but this appears to have a negligible effect when conditions favour disease development (Hunter *et al.*, 2001). Attempts to decrease the effect of *Phytophthora colocasiae* by wider spacing than the traditional spacing (76 ×76 cm) were unsuccessful (Jackson *et al.*, 1999).

Other cultural methods that have been recommended include delay planting on the same land for a minimum of three weeks, avoiding plantings close to older infected ones and preventing the carry-over of corms or suckers which can harbour the pathogen from one field to another (Jackson, 1999).

Intercropping has also been suggested as one of the cultural methods for controlling TLB disease. Amosa and Wati (1997) reported that disease incidence and severity of taro leaf blight was lower in taro and maize intercropping system than those grown in monoculture. The effect of planting density and relative time of planting on taro and rice intercropping system yielded similar results (Agyekum, 2004). A trial to investigate the effect of planting and harvesting time, intercropping, the role of fertilisation on the incidence and severity of the disease and the effect of leaf removal was inconclusive (Chan, 1997).

Chemical control

The use of fungicides such as Copper and Copper metalaxyl-based compounds have been reported to be the most reliable and popular method with farmers in Asia and the Pacific because of the quick and effective action (Adejumo, 1997). Jackson (1996) reported that blight disease can be controlled by spraying with Copper fungicides. Ashok and Saikia (1996) also observed in field trials that excellent control of taro leaf blight was obtained when plants were treated with Chloroneb and Captafol, good control with Metalaxyl; fair control with Copper oxychloride; and poor control with Thiophanate-methyl and Zineb. Field experiments conducted to study the effect of fungicides in controlling leaf blight caused by *P. colocasiae* in taro revealed that 0.2% Metalaxyl and Mancozeb as Ridomil MZ-72 was the most effective treatment, followed by 0.2% Captafol, Bordeaux mixture (1% Copper sulphate and lime) and 0.25% Mancozeb (Ashok and Saikia, 1996). An increase in yield was recorded for all treatments over the untreated control.

The frequency and time of spray application have been reported to affect the effectiveness of fungicides (Adegbola, 1993). Bergquist (1974) confirmed the effect of fungicide rate, spray interval, timing of spray application and precipitation in relation to control of leaf blight disease of taro with Mancozeb at various rates. it was observed that rate of fungicide had no effect in the drier sites, while at wetter sites, the highest rate of 4.48 kg/ha was the most effective. Spraying every 5 days was more effective than spraying every 14 days. Applications of fungicide at 7-day intervals gave substantial disease control.

Use of resistant varieties

The use of resistant varieties to manage pest and diseases of crops is the manipulation of the morphology or physiology of a crop plant by selective breeding and hybridization so that the pest, pathogens and diseases do not or cannot become established (Hunter *et al.*, 2001). Host resistance is probably the most valuable control in agriculture (Erwin and Ribiero, 1996), if available. Resistant varieties are not only environmentally friendly but also require little additional disease control inputs from farmers.

Relatively, there are very few varieties of taro and this is believed to be as a result of diseases (Wall and Wiecko, 1998). Most farmers who traditionally grow taro cannot afford the extra costs required for fungicides and labour involved in leaf removal and spraying (Hunter et al., 2001). In Samoa, four taro cultivars screened and evaluated for their resistance to taro leaf blight, for their yield and eating quality performed well and gave positive results whiles in Africa, especially in Ghana and other parts of West Africa, most farmers grow the white

and brown taro types which are found elsewhere to be susceptible to taro leaf blight disease (Hunter and Pouono, 1998).

Biological control

Biological control is the use of living organisms to suppress the population of a specific pest organism, making it less abundant or less damaging than it would otherwise (Englberger *et al.*, 2001). Several potential biocontrol agents have been reported on various plants. These include *Aspergillus niger* (Van Tieghan), *Penicillium* spp. and *Trichoderma viride* (Peri) (Odamtten, 1977), *Bacillus* spp. (Odigie and Ikotun, 1982) and *Anoplolepis longipes* (Jerdon) (McGregor and Moxon, 1985).

Soil application, seed treatment, and foliar spray of rhizobacterial cultures that were isolated from taro on *Phytophthora* blight reduced the disease incidence and severity and increased the yield, compared to untreated pathogen-inoculated control plants (Sriram et al., 2003). Biological control agents may be used judiciously as a complement to chemical application and cultural practices. In such a situation, compatibility with the synthetic fungicide would be desirable, as it is often possible to schedule both in control programmes (Coffey, 1991).

Integrated pest management

Taro leaf blight epidemics can progress quickly and with high severity. The highly infectious nature of the disease may exclude the use of a single cultural, physical management practice, biological control methods or use of resistant varieties and the use of pesticides on taro is costly and can pose

environmental hazards (Jackson, 1996). Therefore, taro growers may need several complementary methods may be needed to reduce the incidence and severity of taro leaf blight to acceptable levels.

A farmer friendly integrated disease management package of TLBD has been developed by Misra et al. (2004). The package includes growing short duration crop with early planting, for example, in March one protective spray with mancozeb (0.2%) at 45 days after planting followed by one spray with metalaxyl (0.05%) at 60 days after planting, intercropping with non-host crops like okra, use of disease free seed tubers and seed tuber treatment with *Trichoderma viride*.

CHAPTER THREE

ASSESSMENT OF TLBD PREVALENCE, TARO PRODUCTION ACTIVITIES, PERCEPTION AND MANAGEMENT OF THE DISEASE AMONG FARMERS IN THE EASTERN REGION

INTRODUCTION

Taro (*Colocasiae esculenta*) is a very important food crop for many small scale farmers in Ghana (Ackah *et al.*, 2014). The crop provides several opportunities for generation of income and the attainment of food security because of its multiple uses and the consumption of its various products (MOFA-SRID, 2013; Sagoe, 2006).

The major producing areas in Ghana are in the Eastern, Brong Ahafo, Ashanti and Western Regions of Ghana (Acheampong *et al.* 2014). Even though taro has numerous socioeconomic and nutritional importance, production levels continue to drop each year. Land areas under cultivation have consistently declined whereas current yield levels are below national achievable average of 8 mt ha^{-1} (MoFA, 2010), and this has been reported to be as a result of the taro leaf blight disease (van der Puije et al, 2015), which was first reported in the Eastern region of Ghana (Omane *et al.*, 2012). The little research attention received by the crop may also play a role in the yield decline.

Assessments of incidence and severity are the currency by which the TLBD epidemics from the various districts in the Eastern region of Ghana can be characterized and compared. Assessment of the disease also is vital to the interpretation as to whether disease management practices are successful.

Currently, there is no clear documentation of the cultural practices associated with taro production in Ghana and the reason for the lack of documented knowledge about taro production may be associated with its status as an underutilized crop in the country. For an effective management strategy to be developed for the taro leaf blight disease in a particular place, there is the need to assess its prevalence, current farming practices, farmers knowledge of the disease and the disease management practices they are adopting. That is the purpose for this aspect of the research.

MATERIALS AND METHODS

Study Area

The study was conducted in ten (10) districts (Asuogyaman, East Akim, Yilo Krobo, New Juabeng, Fanteakwa, Atiwa, Kwawu South, Kwawu West, Birim South and Suhum/Kraboa/Coaltar) of the Eastern region. The Eastern region covers an area of 19,323 square kilometres and occupies 8.1 per cent of the total land area of Ghana. It is the sixth largest region of the country and has a total population of 2.106,696, representing 11.1 per cent of Ghana's population. It is the third most populous region, after Ashanti and Greater Accra. The population is made up of 49.2 per cent males and 50.8 per cent females (Government of Ghana, 2018).

It lies between latitudes 6° and 7° North and between longitudes 1°30' West and 0°30' East. The region shares common boundaries with the Greater Accra, Central, Ashanti, Brong Ahafo and Volta Regions. The region has four main geographical features, namely, the Kwahu scarp with an elevation 788

metres above sea level, the Atiwa-Atwaredu Ranges near Kibi, reaching an elevation of 732 metres, the Akuapem highland attaining an elevation of 466 metres which is the southern extension of the Togo-Atakora mountain ranges and the isolated hills/mountains dotting the relatively low-lying plains to the south, notably the Krobo and the Yogaga mountains.The region is also characterized by long range forest highlands such as the Akim, Kwahu, Akwamu, Krobo and Shai Hills (GoG, 2018).

The region falls within two main vegetation zones. The Tropical Forest zone (60%) and Guinea Savanna zone (40%). The soils from these zones are suitable for the cultivation of a variety of crops including cocoa, cola-nuts, citrus, oil palm and staple food crops such as cassava, yam, cocoyam, maize, rice and vegetables. The region contributes significantly to the production of industrial crops such as cocoa, pineapple, pawpaw, cola nut and oil palm and also has a substantial share in the national production of maize, cassava, and citrus. Available also in the region are exotic crops such as black and sweet pepper, ginger, cashew nuts, Irish potatoes, rubber and mangoes, which are all gaining importance as export commodities (GoG, 2018).

The region lies within the wet semi-equatorial zone characterized by double maxima rainfall in June and October. The first rainy season is from May to June, with the heaviest rainfall occurring in June while the second season is from September to October, with little variations between the districts. Temperatures in the region are high and range between 26 °C in August and 30 °C in March. The relative humidity which is high throughout the year varies between 70 per cent - 80 per cent (GoG, 2018).

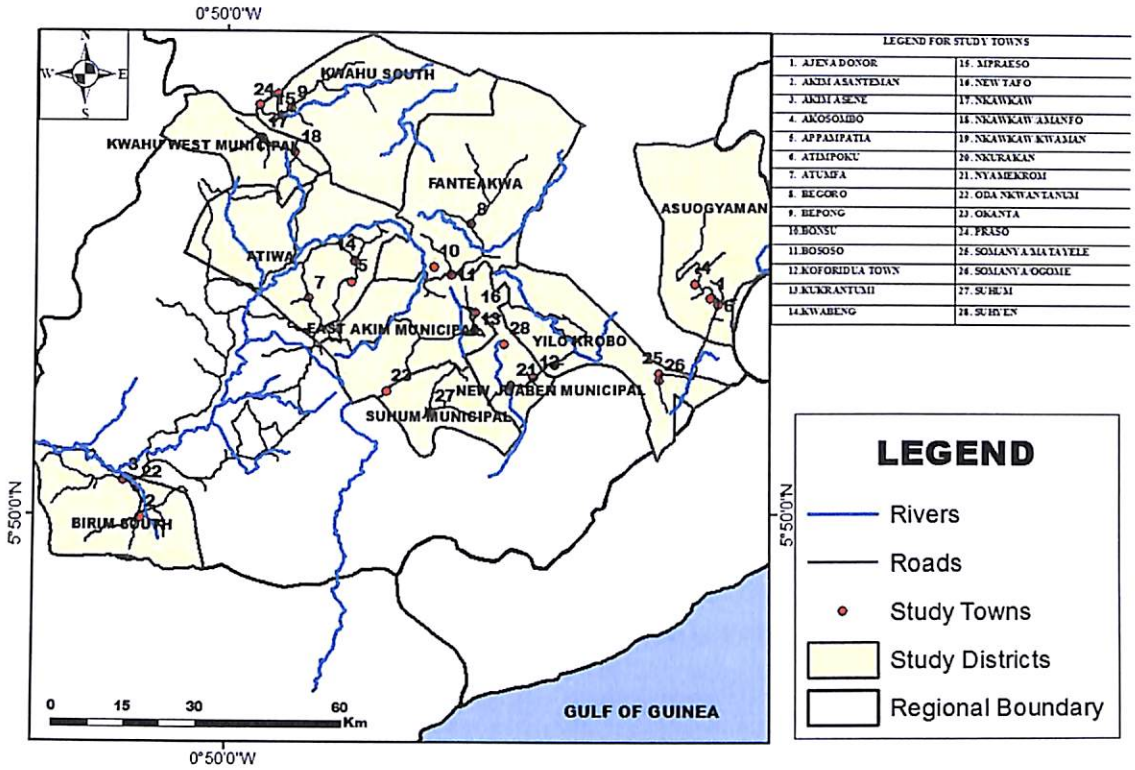


Figure 13. A map of the Eastern region with the surveyed districts and communities (marked red).

Assessing taro production activities, farmers perception and management (pesticide and rouging/pruning) of the TLBD in the Eastern Region

Questionnaires (Appendix 1) were administered to a total of 210 farmers from the ten selected districts (Figure 13). In each district, 21 taro growing farmers were selected with the help of the Agricultural extension officers (AEAs). Both open-ended questions that permitted the farmers to record their own opinions and closed-ended ones that offered a list of possible options from which the farmers could choose, were administered through interviews. The purposive sampling technique was used. The questionnaire sought information on taro production activities (land area (acres), topography, cropping systems, source of planting materials, and mode of planting), perception of farmers' on TLBD and

their management practices (whether the respondents use pesticides, whether they prune or rogue diseased leaves and their effectiveness).

Field Assessment of disease incidence and severity

Surveys to establish incidence and severity of the leaf blight disease in the region were conducted in two seasons (rainy and dry seasons) in the ten selected districts. The sampling procedure was done according to the method proposed by van der Puije *et al.* (2015). In every district, three taro farms were assessed with one from each selected community. The communities selected were between 5 to 10 km apart. A total of thirty (30) farms were assessed. The diagonal pattern was used during selection of plants for assessment on a farm. At every five paces, a plant was assessed for presence or absence of leaf blight symptom. Percentage incidence was then determined by the given formula;

$$\text{Disease incidence} = \frac{\text{Number of infected plants}}{\text{Total number of plants assessed}} \times 100$$ (Shakywar *et al.*, 2012)

Disease severity was scored using a scale of 0-6 as described by Gollifer and Brown (1974) and modified by Ackah *et al.* (2014), with 0= 0% of leaf area damaged to 6= 94-100% leaf area damaged by the leaf blight (Table 1) . Climatic data (temperature and relative humidity) during the period of survey were obtained from the Meteorological Agency, Accra.

Table 1. Assessment Key for Scoring Severity of Taro Leaf Blight (TLB) Disease on the Field

Disease Score	Nature of Infection (%)	Description
0	No visible symptoms	
1	1-7% of leaf area damaged	
2	8-25% of leaf area damaged	
3	26-50% of leaf area damaged	
4	51-75% of leaf area damaged	
5	75-93% of leaf area damaged	
6	94-100% of leaf area damaged	

Data Analyses

Data for the socioeconomic survey was analysed using descriptive statistics which was accomplished using Statistical Package for Social Science (SPSS), version 16. Results were illustrated as percentages and charts. Incidence and severity scores were analysed with generalized linear model (GLM) using GenStat 12th edition and the predicted means separated using Fisher's protected least significant difference (LSD) at 5% level of probability.

RESULTS

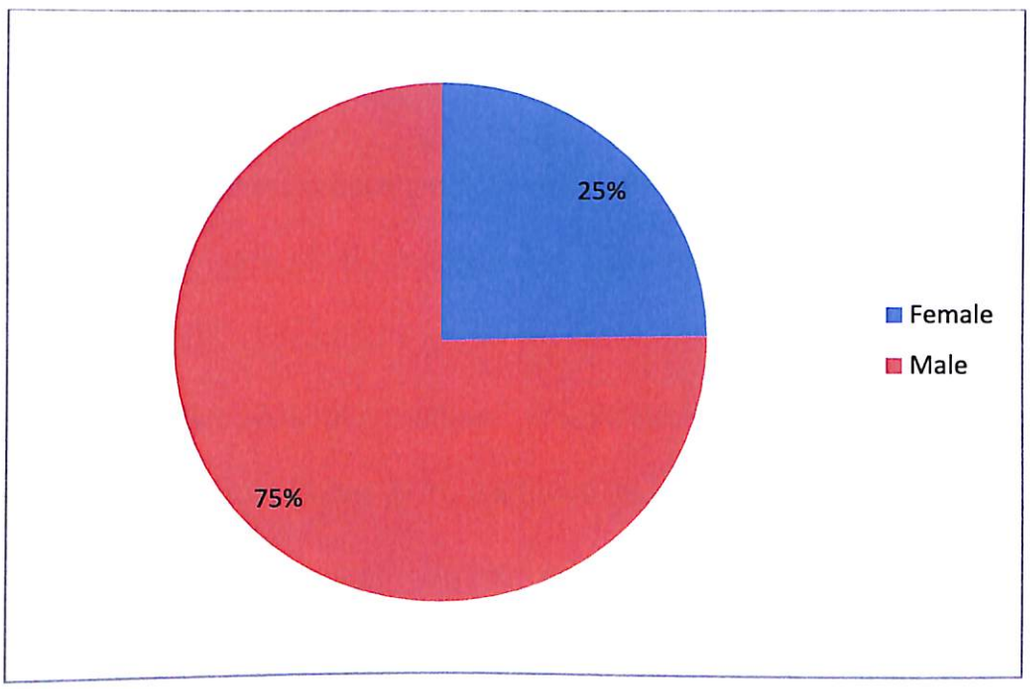
Background characteristics of Farmers (respondents)

Gender Distribution

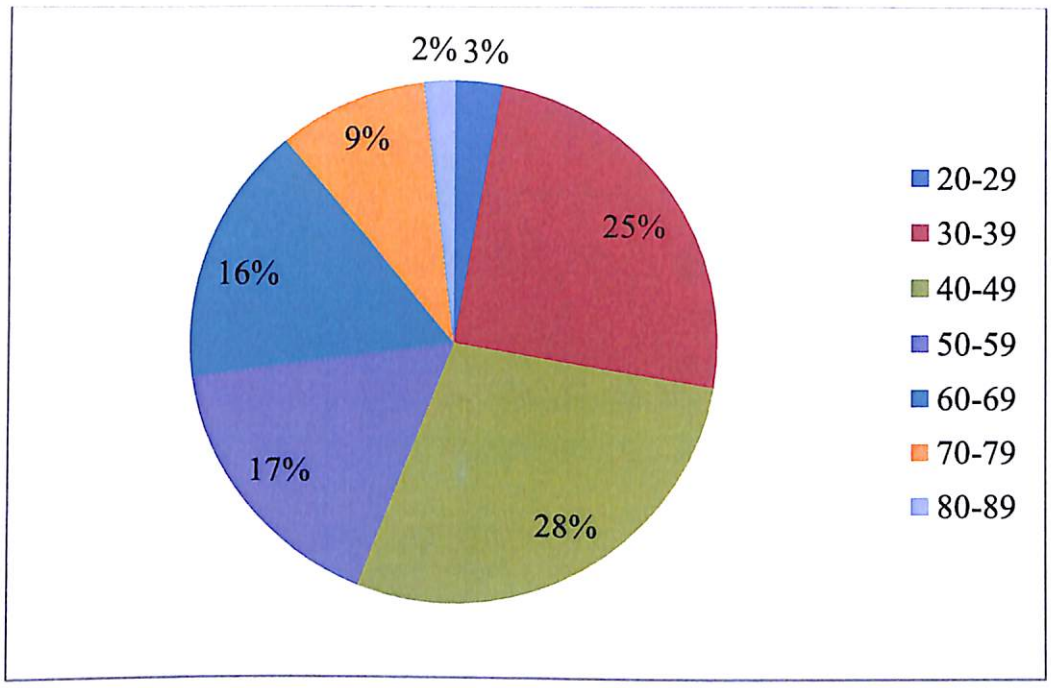
From Figure 14, seventy five percent (75%) of the respondents were male while 25% were female.

Age Distribution

Majority (28%) of the respondents were between the ages of 40 to 49 years while 25% were 30 to 39 years. More than 50% of the respondents were relatively young (Figure 15).



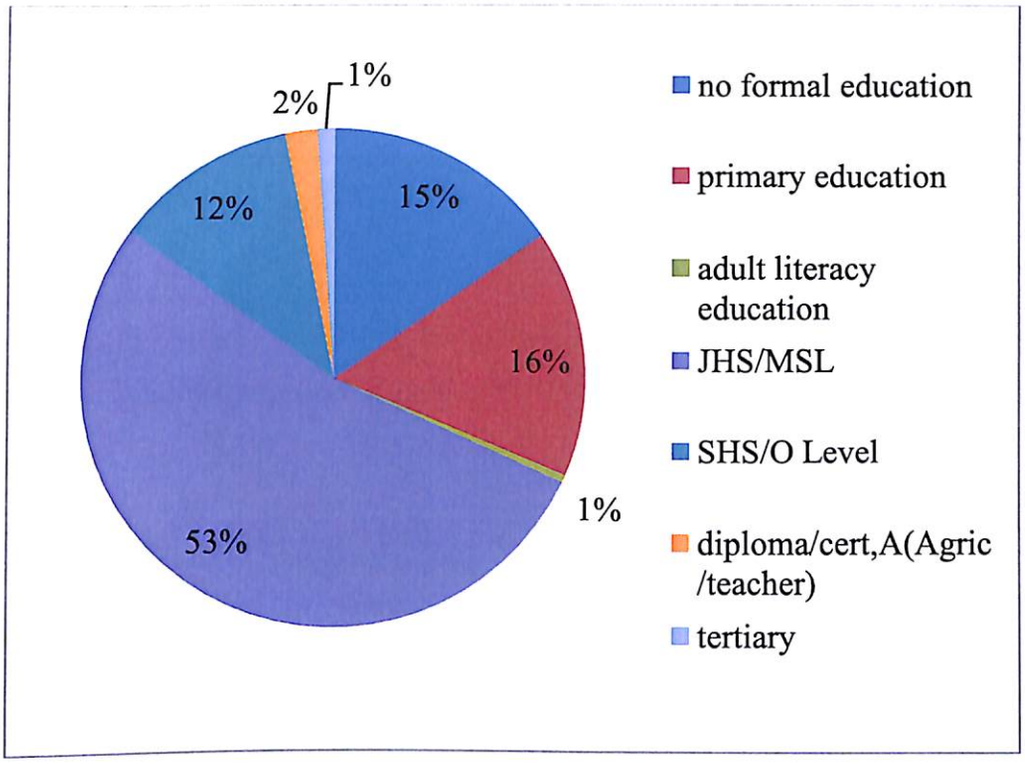
N=210
Figure 14. Gender distribution among respondents



N=210
Figure 15. Age distribution of the respondents.

Educational Level

The highest educational levels attained by farmers/respondents are presented in Figure 16. It is evident that majority of the farmers (53%) are Junior high school (JHS) or Middle school leavers (MSL). Sixteen percent (16 %) have obtained primary school education, 12%, senior high school (SHS) education, 2% with diploma or certificate A from agriculture or teacher training schools, and 1% each, had tertiary or adult literacy education. Fifteen percent (15%) of the respondents did not have any formal education.



N=210
Figure 16. Education Level of Taro Farmers in the Study Area

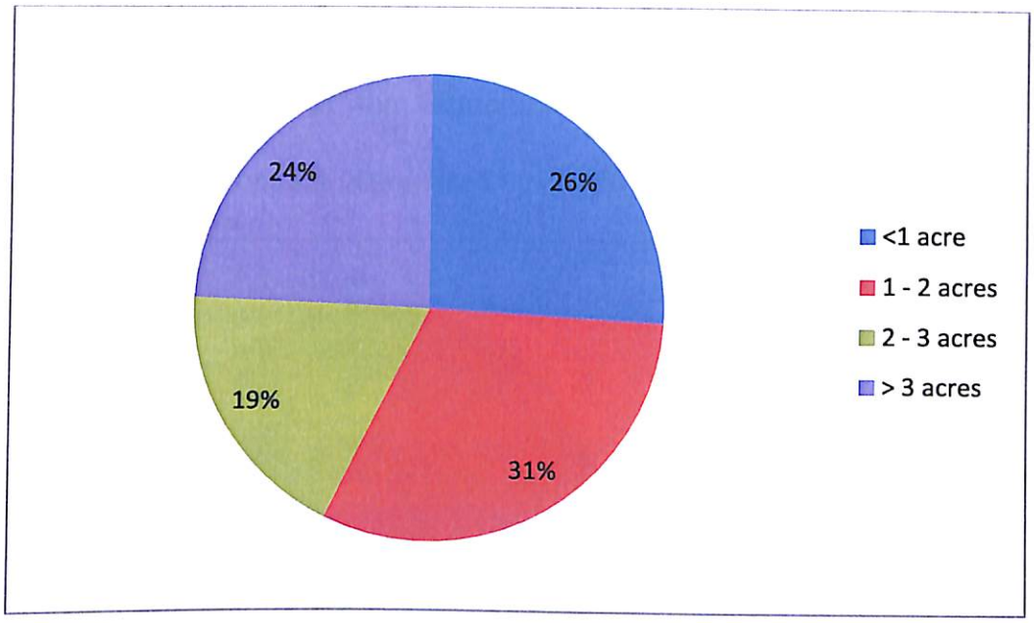
Taro Production Activities by farmers in the study area

Land Holdings

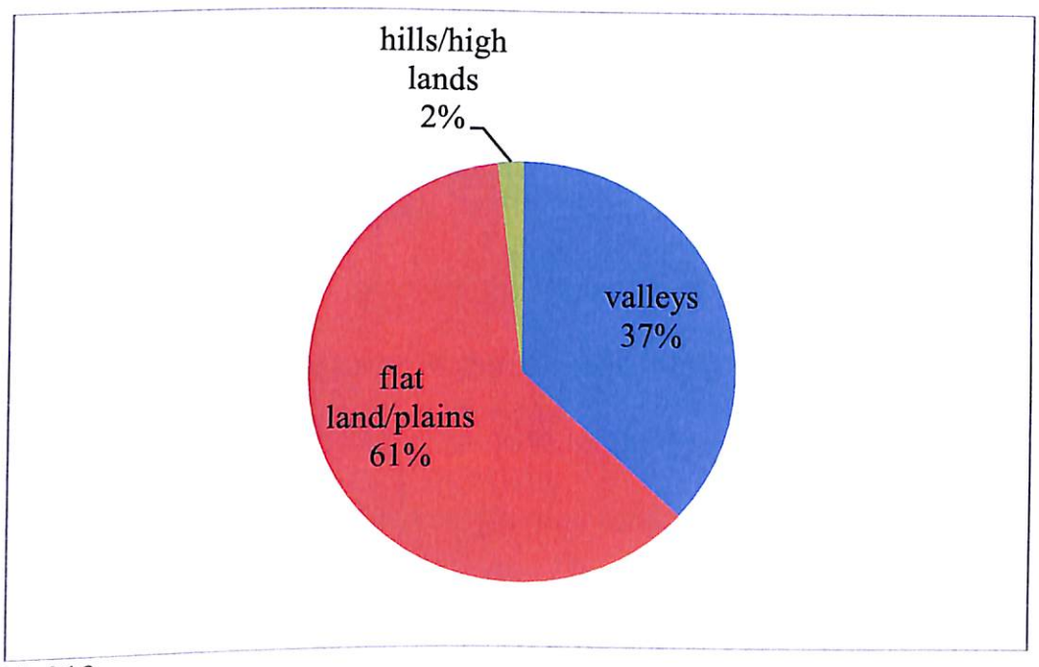
Figure 17 presents the land holdings of taro farmers in the ten districts. Majority (31%) of the farmers had land sizes between 1 to 2 acres and 26% with less than 1 acre. Twenty-four percent (24%) of the farmers had land sizes of greater than 3 acres and only 19% owned between 2 to 3 acres of land.

Topography of Farm Land

From Figure 18, which presents the responses of farmers about the topography of land used for taro cultivation, majority of the farmers (61%) cultivate on plains or flat lands of river banks, while 37% cultivate in valleys. Only 2% cultivate taro on hills or highlands.



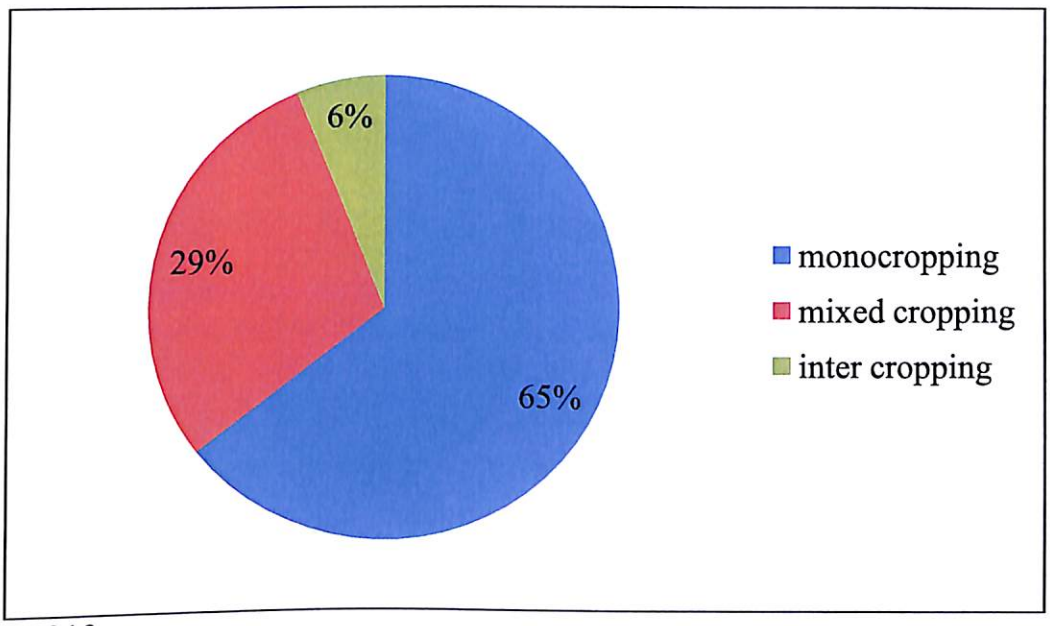
N=210
Figure 17. Land holdings for taro production in the study area



N=210
Figure 18. Topography of site used for taro production by farmers

Cropping Systems

Cropping systems practiced by farmers are presented in Figure 19. Sixty-five percent (65%) of the farmers practise monocropping and 29% mixed cropping. Intercropping is practised by only 6% of the farmers.



N=210

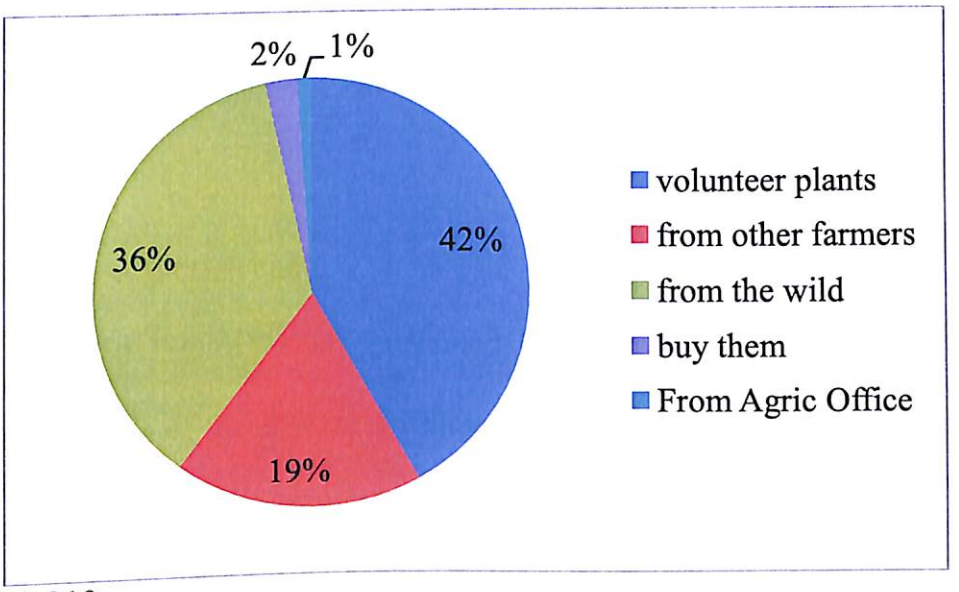
Figure 19. Cropping systems practised by taro farmers

Sources of Planting Materials

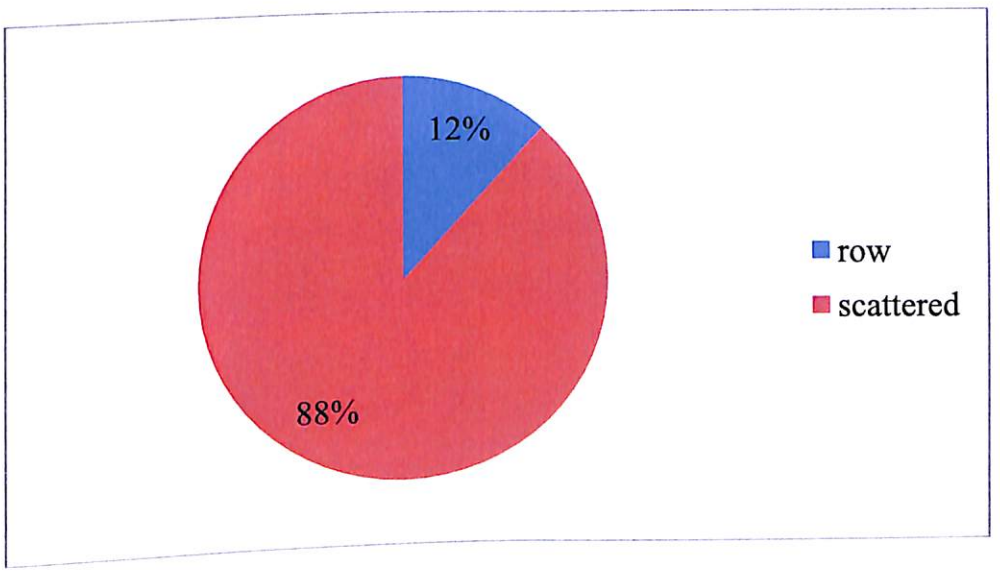
In Figure 20 are presented the responses of farmers about their sources of planting materials. Majority of the farmers (42%) used volunteer plants, 36% obtain them from the wild while 19% of the respondents obtained them from other farmers. Only 2% buy their planting materials from the market or get them from the Agric offices (1%).

Mode of Planting

Figure 21 represents the responses of farmers on the mode of planting. Eighty eight percent (88%) of the farmers planted in a scattered mode while 22% plant in rows.



N=210
Figure 20. Main source of planting materials of farmers



N=210
Figure 21. Mode of planting of taro suckers by farmers

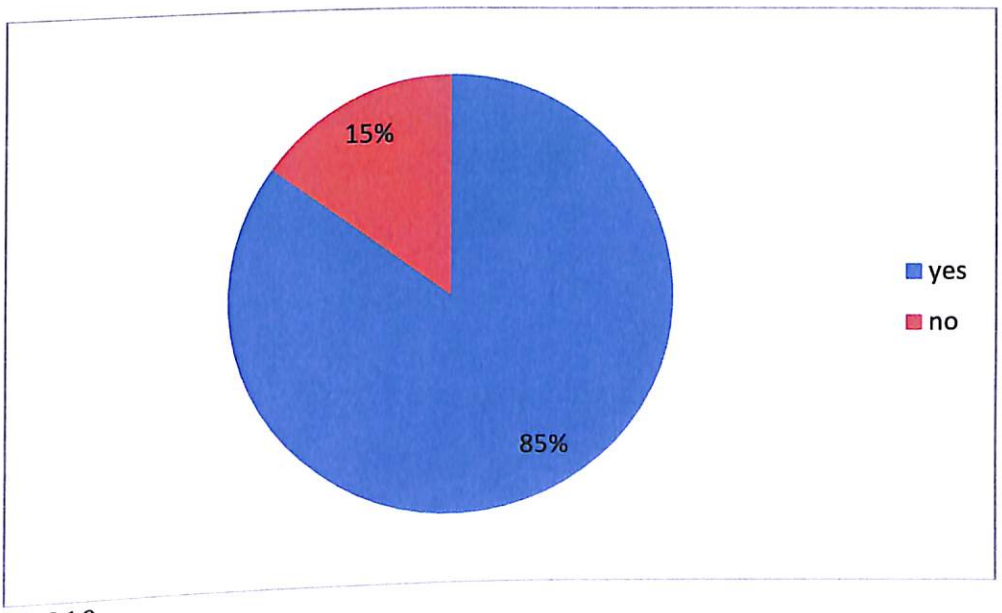
Farmers Perception of Taro Leaf Blight Disease (TLBD)

Observation of TLBD

Figure 22 presents the responses of farmers to their observations of the disease on their farms. It is evident from the figure that 85% of the farmers had observed the disease on their farm and only 15% responded they had not observed it on their farm.

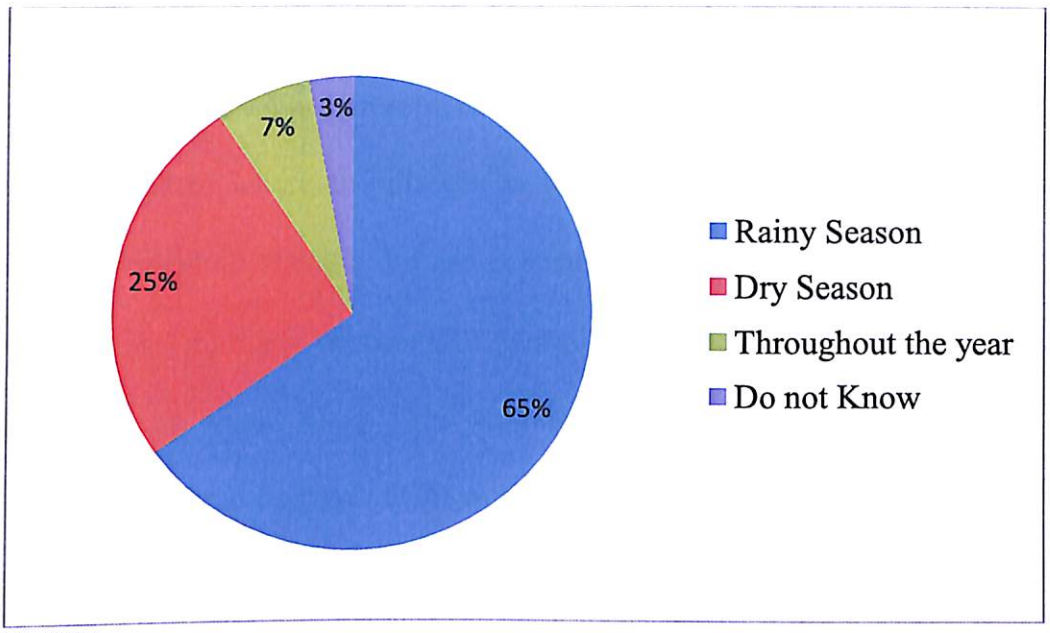
Period of Occurrence

In Figure 23 are presented the responses of farmers on the period of occurrence of the disease on their farms. While 65% responded that the disease occurs in the rainy season, 25% indicated that it occurs in the dry season; 7% reported that the disease occurs throughout the year, and 3% were not sure of the period of occurrence.



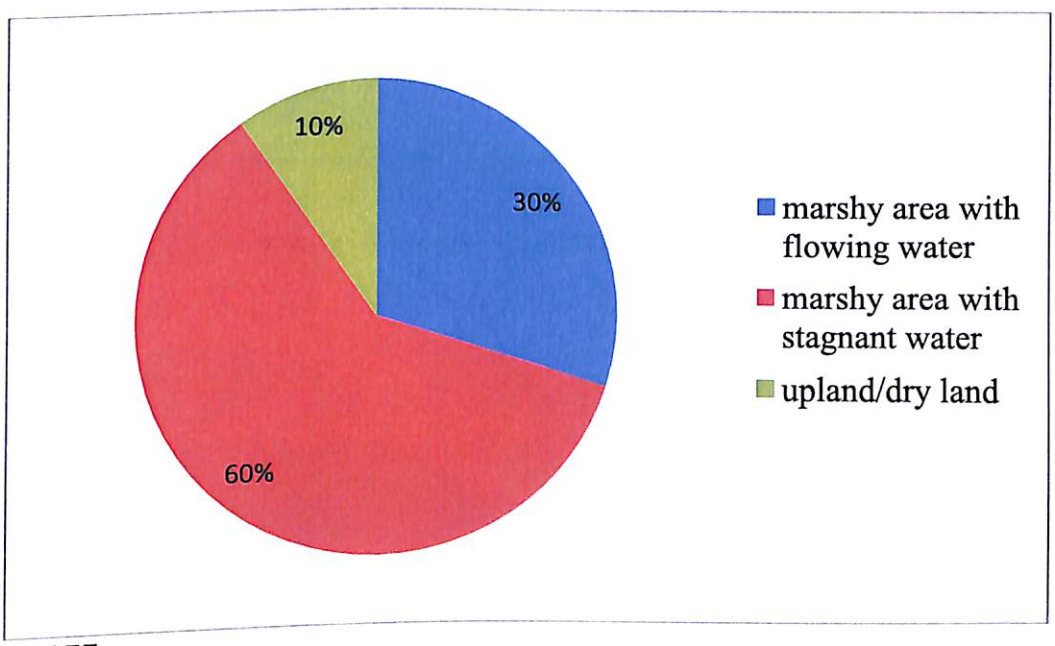
N=210

Figure 22. Response of farmers to the observation of TLBD on their farm



N=177

Figure 23. Period of year the disease occur on farmers' field.



N=177

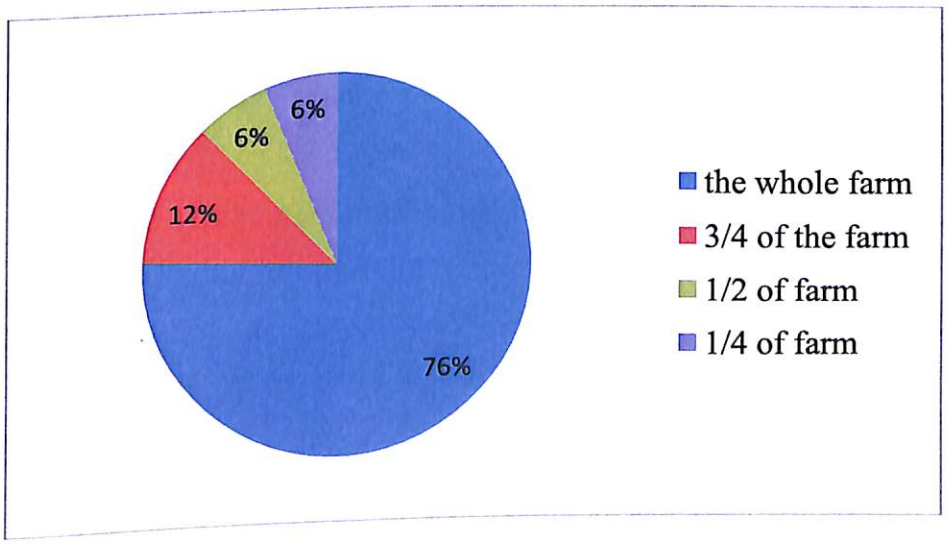
Figure 24. Responses of Farmers on the drainage of part of farm and where disease is severe

Distribution of TLBD on Farm

In Figure 24 are presented the responses of farmers concerning the part of their taro farm where the disease is severe. While 60% of the respondents or farmers indicated that the disease is severe on plants found in marshy area with stagnant water, thirty percent (30%) said the disease is severe in marshy areas with flowing water. Only 10% responded that the disease is severe on plants found on dry land on river plains or under upland conditions.

Extend of TLBD Attack on Farm

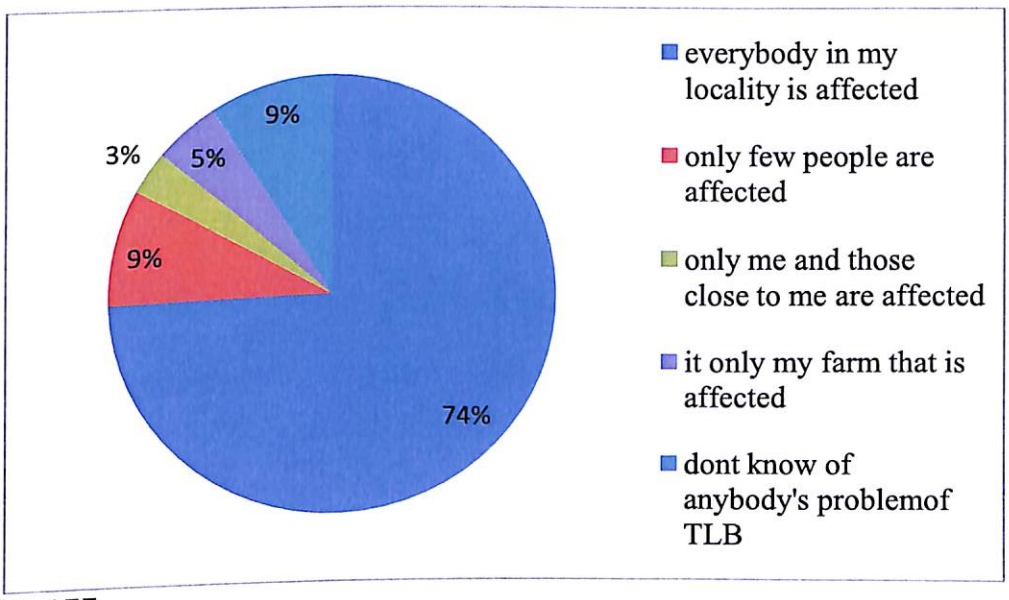
Figure 25 presents the farmers' responses of the land area attacked by the TLBD. Majority of the respondents (76%) indicated that the whole farm had been attacked, 12% indicated that three quarter (3/4) of their farm had been attacked and 6% each of the respondents reported that half (1/2) and a quarter (1/4) of their farms had been attacked by the disease, respectively.



N=177
Figure 25. Area of taro crop attacked by the disease on farmers field

Severity of TLBD in Surveyed Locality

Figure 26 presents the response of farmers on the widespread nature of the disease in their locality. Seventy four percent (74%) of the farmers responded that all taro farmers in their locality is affected by the disease, 9% each responded that only few people are affected or did not know the disease situation on other farmers field, 5% responded that it is only their farm that is affected. Three percent (3%) responded that their farms and those closer are the only affected farms.



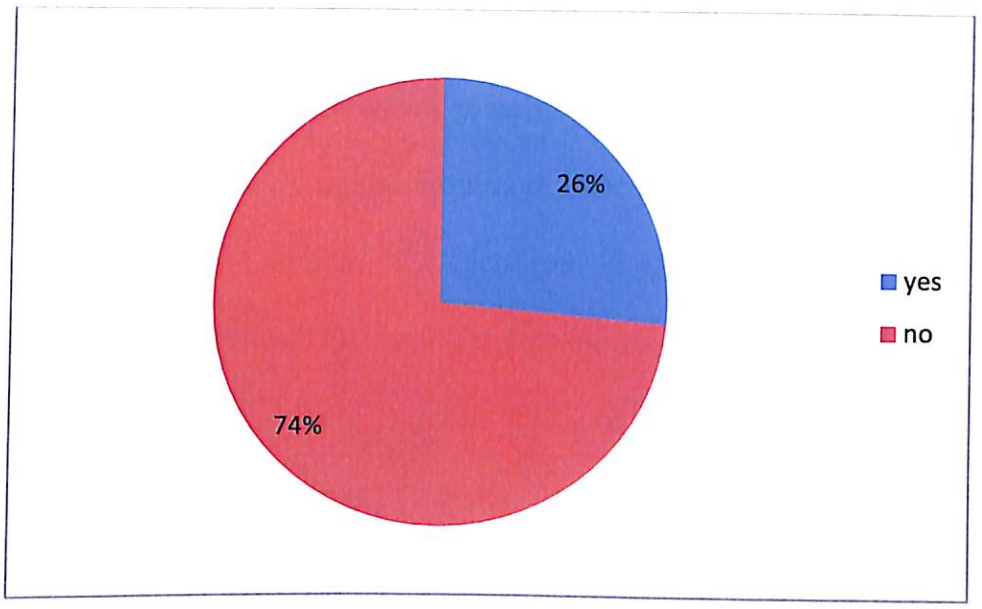
N=177

Figure 26. Farmer's responses of the prevalence of the disease in their locality

Responses of Farmers on Management of TLBD in the Region

Control of TLBD

In Figure 27 are presented the response of farmers on their attempt to control the disease. Twenty-six percent (26%) of the respondents or farmers had made effort to control the disease while Seventy-four percent (74%) had not.

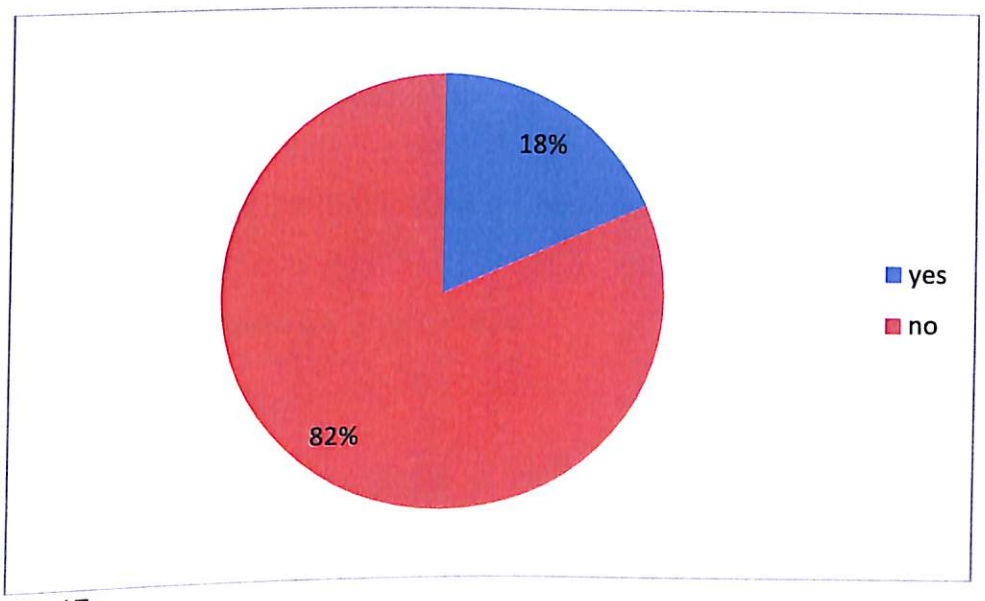


N=177

Figure 27. Response of Farmers on their attempt to control the TLB disease on their farms

Use of Pesticide

Figure 28 shows the response of farmers on the use of pesticides. Amongst the 26% who control the disease in Figure 15, 82% used pesticide and 18% did not use pesticide.

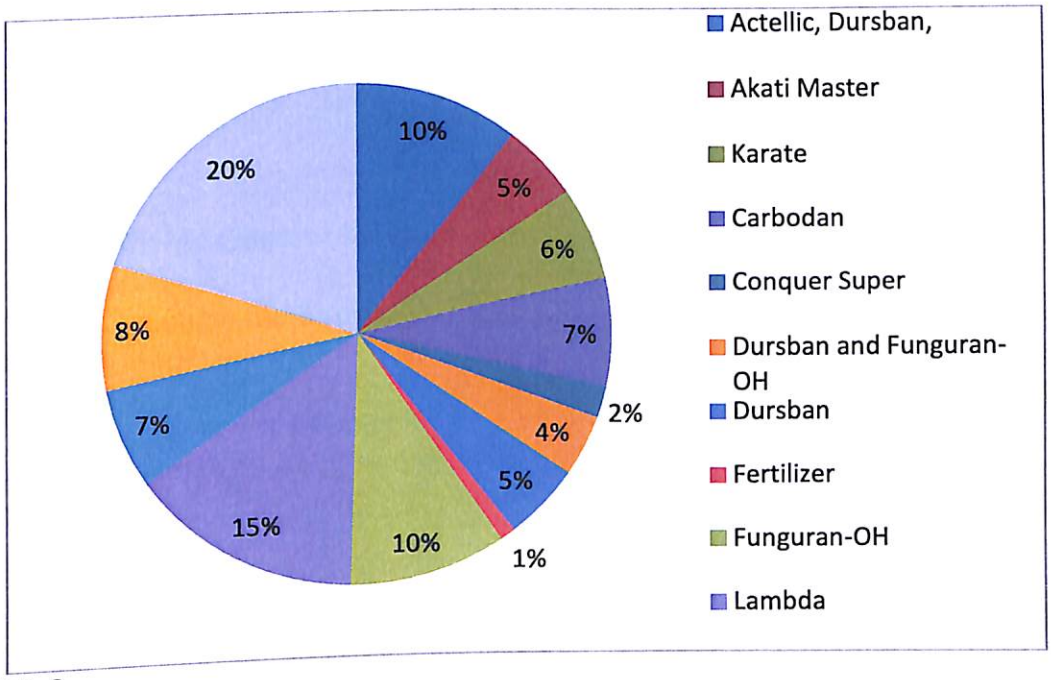


N= 47

Figure 28. Response of farmers' on the use of pesticide to control TLB

Types of Pesticide Used

From Figure 29 which presents the responses of farmers on the type of pesticides used, 20% of the farmers did not remember the kind of pesticide they used, 15% used Lambda, 10% each used Funguran-OH or Actellic and Dursban, 8% used sunpyrifos, 7% each used Carbodan or Poison, 6 % used Karate, 5% each used Akati master or Dursban, 4% used both Dursban and Funguran-OH, 2% used conquest and 1% used fertilizer.

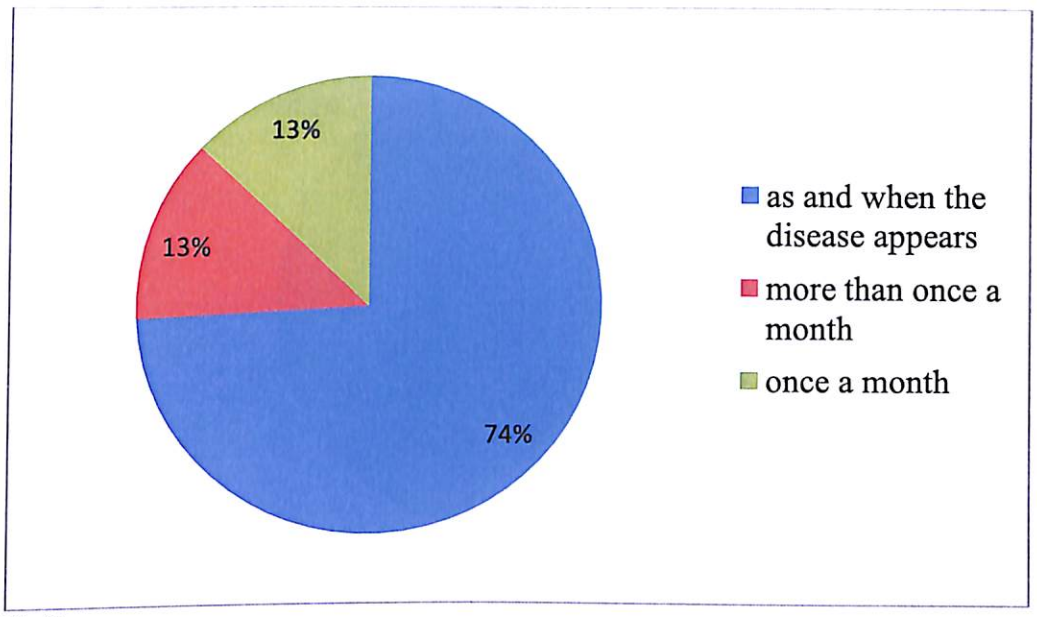


N=8

Figure 29. Type of pesticide used by the respondent to control the disease

Frequency of Pesticide Application

With respect to the frequency of application (Figure 30), 74% of the respondents apply the pesticide as and when the disease appears and 13% apply once or more than once a month.

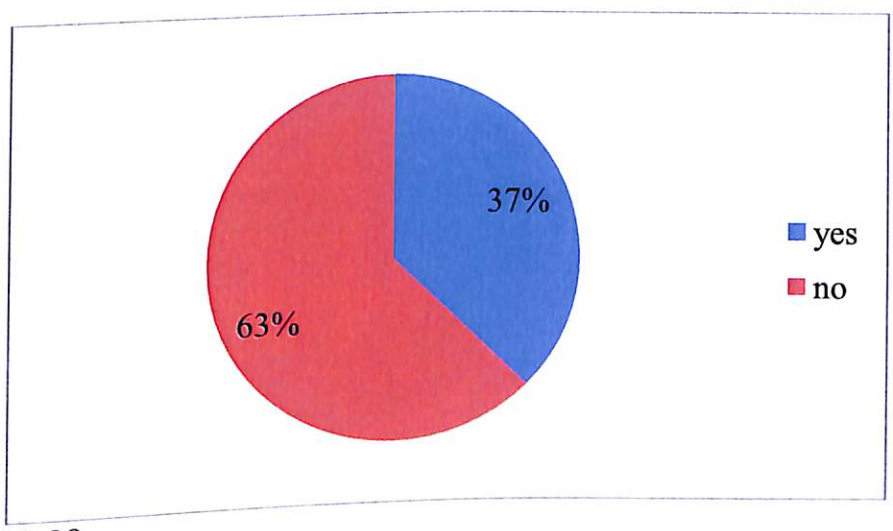


N=8

Figure 30. Response of farmers on the Frequency of application of pesticide

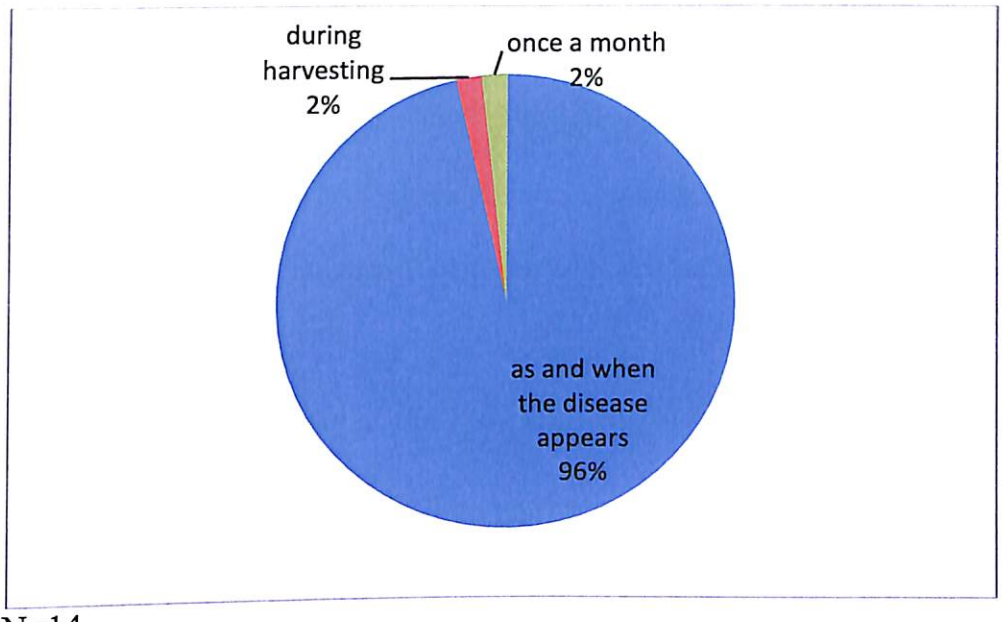
Non-Pesticide Control Method

Amongst the farmers in Figure 28 that did not use pesticides in controlling the disease, 37% prune or rogue infected plants in managing the disease while 63% did not (Figure 31).



N=38

Figure 31. Response of farmers on the use of pruning/rouging of infected plants to manage the disease.

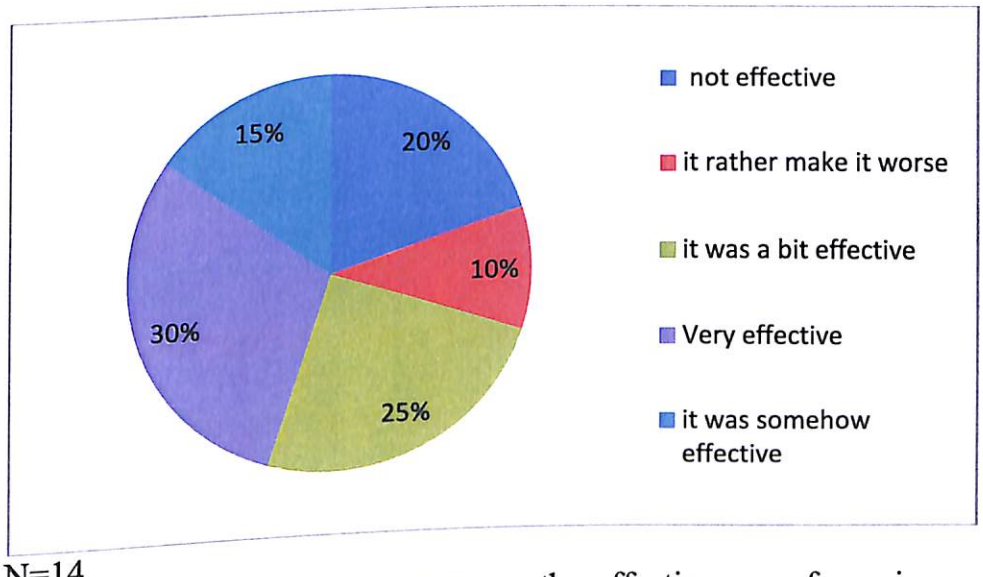


N=14

Figure 32. Responses of farmers on the period during which infected plants are pruned or rogued

Time of Pruning and Roguing

From Figure 32, 96% of the farmers responded that they prune or rogue as and when the disease appears, 2% each, said during harvesting and once every month respectively.



N=14

Figure 33. Responses of farmers on the effectiveness of roguing or pruning on their farm

Effectiveness of Pruning or Roguing

From Figure 33, 30% of the respondent found rouging to be very effective, 25% indicated it was somehow effective with 20% responding that it is not effective. Fifteen percent (15%) of the respondent indicated that pruning was somehow effective and also 10% revealed that it rather made it worse.

Incidence and Severity of the Taro Leaf Blight Disease in the Eastern Region of Ghana

The results in Figures 34 to 37 represent the incidences and severities of the TLBD in two different seasons in the ten selected districts (Asuogyaman, Atiwa, Birim South, East Akim, Fanteakwa, Kwawu South, Kwawu West, New Juabeng, Yilo Krobo and Suhum/Kraboa/Coaltar) in the Eastern Region of Ghana.

Incidence of Taro Leaf Blight Disease in Ten Taro Growing Districts in the Eastern Region

Wet Season Incidence

Figure 34 shows the mean incidence of TLBD in 10 districts of the Eastern region during wet season. From the figure it can be observed that the highest disease incidence of 92.2% was recorded at Fanteakwa and New Juabeng districts, followed by East Akim, Kwawu West and Kwawu South with incidences of 90% each. The Suhum/Kraboa/Coaltar and Asuogyaman districts recorded significantly lower incidences, of 62.2% each.

Dry Season Incidence

In the dry season (Figure 35), the highest TLBD incidence of 78.9% was recorded at Fanteakwa district, followed by Yilo Krobo district (77.8%) and East Akim district (76.7%). The lowest percentage incidence of 69.9% was recorded at Kwawu South district (69.9%).

Figure 34: Incidence of TLBD in Ten Districts of Eastern Region during the Wet Season

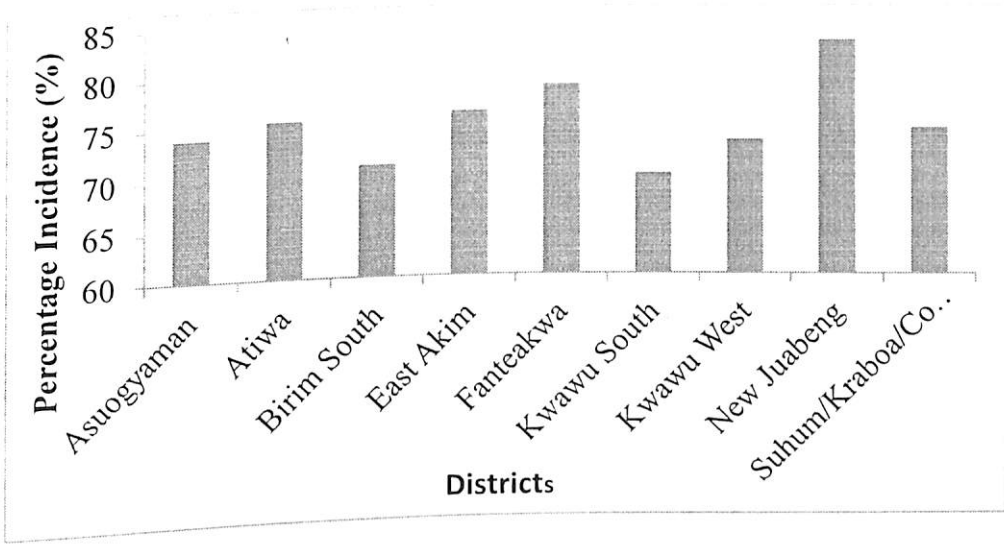


Figure 35: Incidence of TLBD in ten districts of eastern region during the dry season.

Severity of TLBD in Ten Taro growing Districts in the Eastern Region of Ghana

Figure 36 shows the mean severity and the GLM means prediction during the wet and dry seasons. In the wet season, it can be seen that the severity scores range from 1.075 to 2.332 with the highest mean severity of 2.332 recorded at New Juabeng District. It was however not significantly different ($p>0.05$) from that recorded at Kwawu West (2.103). The mean severity at Kwawu West was not also significantly different from East Akim district which recorded a mean severity of 1.966. Kwawu South, Atiwa, Yilo Krobo and Asuogyaman districts were not different from each other. Again, Kwawu South, Asuogyaman, Yilo Krobo and Birim South districts were not significantly different ($p>0.05$) from each other. The lowest mean severity of 1.075 was predicted at Suhum/Kraboa/Coaltar district but was also not significantly different from the means predicted at Fanteakwa (1.210) and Birim South Districts (1.353).

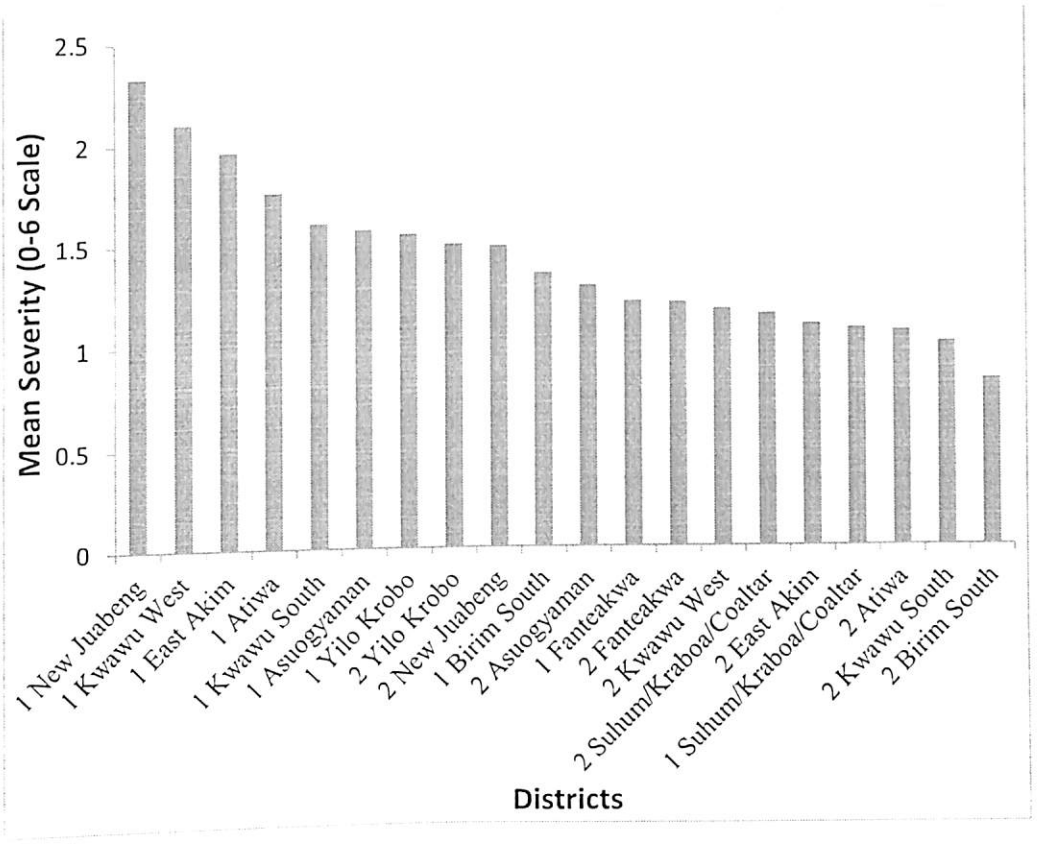


Figure 36. Mean severity of TLBD in ten taro growing districts in the eastern region of Ghana in two different seasons.
(Districts 1= means in wet season, District 2 =means in dry season

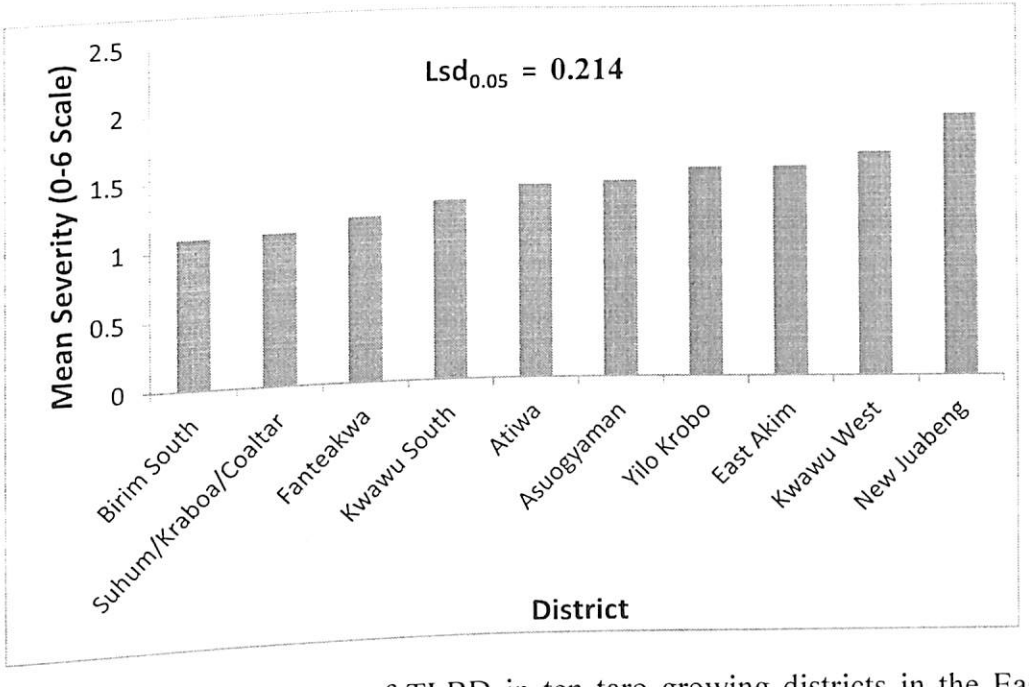


Figure 37. Mean severity of TLBD in ten taro growing districts in the Eastern region of Ghana

District Mean Severity of TLBD

From figure 37, it can be observed that the overall mean severity shows New Juabeng district having the highest severity of the disease (1.911) and the means was significantly higher than all the other districts. The mean severity predicted for Kwawu West district of 1.635 was not significantly higher than those predicted for East Akim (1.531), Yilo Krobo (1.528) and Asuogyaman Districts (1.434), but were however significantly different from the severity predicted for Birim South (1.090) Suhum/Kraboa/Coaltar (1.109) and Fanteakwa Districts (1.206). Suhum/Kraboa/Coaltar, Fanteakwa and Kwawu South Districts were not also significantly different from each other in their predictions. Again Fanteakwa district, Kwawu South and Atiwa districts were not significantly different from each other in the severity predicted. And the same applies to Kwawu South, Atiwa and Asuogyaman.

DISCUSSIONS

Agricultural production is affected directly and indirectly by many factors because farmers decide what to grow, where to grow as well as the methods of production to be used constantly. Production activities and perception of farmers can influence management strategies used in combating diseases (Boakye-Acheampong, 2016).

The background characteristics of the farmers in the study area revealed that most of the farmers who are into taro production in the Eastern Region are male. Men have been reported to be responsible for major work in taro production with the women responsible for processing, selection for culinary use and

maintenance of planting materials (Dagne & Mulualem, 2014). The farmers ages range between 20 to 89, with majority between the ages of 40 to 49. Based on age categorisation by Petry (2002) ages of between 36 to 55 years are referred to as young adults, 18 to 35 years are middle-aged adults and older than 55 years referred as older adults. Based on this categorisation, most of the taro farmers in the region were identified to be young and middle-aged adults. These groups of people are very active and full of energy and also have a lot of responsibilities which includes finding food to feed the family. Taro being a food security crop is an option for these age groups of farmers in the Eastern region in providing food for their homes, since taro thrives in areas where other crops will not survive. In addition, taro needs little attention, so the farmers can also be doing other activities growing taro. Though most of the farmers in the study area were identified to have formal education being junior high school or middle school leaver, only a few of them had diploma or certificate A from agriculture or teacher education colleges or tertiary institutions. With this level of education of the farmers in the region, it will be difficult for them to be able to make the right diagnosis of the disease and also apply the right management methods if not properly trained, since most Middle school leavers or JHS graduates cannot even read or write in the country (Davidson, 2014). In South Africa, eighty percent (80%) of taro farmers were observed to have grade seven or less formal education, consequently affecting taro production in the country (Shange 2004).

The results on the production practices employed by farmers in the study area revealed that majority of the farmers in the districts cultivated taro on smaller pieces of land (0.45 to 1.44 acres) though some also produced on land sizes

greater than 4 acres. This confirms the report of Quaye et al. (2010) who revealed that taro is cultivated predominantly on small holdings with an average farm size of 0.8 hectares. Acheampong et al. (2014) made similar observation and reported that cultivation of taro and cocoyam are done on plots of sizes between 0.2 and 0.5 acres in Ghana.

The farmers cultivated taro on plains or flat lands along river banks where there is normally flooding in some period within the year and in valleys. Planting in plains or flat lands is easier than in valleys and also water drains easily from flat lands or plains, whereas in valleys there is always a lot of water which sometimes becomes stagnant (De la Pena, 1998). Taro has been reported to mature early when grown on flood plains with good drainage than in valleys with stagnant water, since water accumulation on taro field encourages vegetative growth, delays bulking (De la Pena, 1998) and also affects disease occurrence and severity, consequently, the high incidence of the disease in the region. Some farmers also plant taro with other crops and this may account for the reason why most farmers in the study area cultivate taro in flood plains or on flat land. Flood waters recede faster on river plains than in valley bottoms where soils maybe heavy.

With respect to cropping systems, it was observed that most of the farmers practiced monocropping, with some practicing mixed cropping and intercropping. Taro does well in areas where other crops may not survive and that may be one of the major reasons for it being grown as a sole crop by most of the farmers in the study area (Robin, 2008). Boakye-Acheampong, (2016) made similar observation on the cropping system of taro and cocoyam in the Fanteakwa and Asunafo South

district in the Eastern region. He also observed that mixed cropping was the most common cropping system where farmers intercropped taro with tomatoes, okra and garden eggs. This is because cultivating taro in river plains provide space for intercropping, since flood water that drains from the river plains within the growing season makes the field suitable for other crops to be intercropped with taro. Dagne & Mulualem (2014) in their research to explore indigenous knowledge and production constraints of taro cultivars in Ethiopia reported that most taro farmers in Ethiopia did not practice intercropping but rather monocropping, and this is because taro is mostly cultivated in valleys or in areas where water accumulates all year round, and this do not make the soil suitable for growing other crops, but only support taro production.

The survey also revealed that most farmers in the study area get their planting materials as volunteer plants on their farm lands while others got them from the wild and from other farmers. Such planting materials could be infected with TLBD can lead to the build up of causal agent hence, the high incidence of disease in the area. Taro has received little research attention until recently, so getting good quality planting materials which are disease free would be very difficult by the farmers and therefore the choice to rely on volunteer plants and also planting materials from the wild. Boakye-Acheampong, (2014) confirmed in his research on taro and cocoyam that taro farmers mostly benefit from volunteer sprouting in Ghana. This is because the cormels are able to stay in the soil for some period until a good condition is created for it to sprout. Therefore it is common in the region that whenever a new field is cleared, taro or cocoyam easily sprouts by themselves. However, using such planting materials which could

be infected with TLBD can lead to the build up of inoculums and spread of disease, hence high incidence observed in the area.

Taro Farmers in the study area planted their suckers in scatter rather than in rows and that is because of the little research attention received. They may also have not received any special training on taro cultivation practices.

In assessing the perception of the farmers on the taro leaf blight disease and the method of managing the disease, it was identified that most of the farmers had observed the disease on their farms and they also responded that the disease occurs mostly in the rainy season than the dry season. This is not surprising because after the first report by Omane *et al.* (2012), the disease has been reported in Aowin Suaman district (van der Puije et al. 2015) and also in the Sefwi-Ahwiaso-Bekwai district (Essane, 2014). The widespread nature of the disease could be attributed to the use of infected planting materials obtained from other farmers, and in the wild as observed in Figure 4. Van der Puije *et al.* (2015) observed tha the incidence and severity of the disease in the Aowin Suaman district was high in the rainy season than the dry season and this confirms the responses made by the farmers on the period the disease occurs in their field.

Poor drainage that leads to stagnant water has been reported to be one of the agronomic practices that make *Phytophthora* species successful as pathogens (Drenth & Sendall, 2004). *Phytophthora colocasiae* produces motile zoospores that are able to swim and infect nearby plants when released into stagnant water, but in flowing water, the released zoospores or sporangia are easily washed away before they could swim and get attached to a nearby plant (Brooks, 2005). That

may account for the high incidence of the disease in marshy areas with stagnant water than with flowing water as responded by the farmers.

Most of the farmers had their whole farm being attacked by the disease, indicating the widespread nature of the disease. According to Brooks (2005), the sporangia and zoospores of *P. colocasiae* is spread by rain splash and windblown spray and that influences the spread of the disease among plants in a farm, but long distance dispersal occurs by movement of planting materials as practiced by some of the farmers in the study area. This may account for the spread of the disease on the whole farm and on every farmer's field. Van der Puije *et al.* (2015) reported that the spread of the disease on farms in Ghana is aided by air sprays and that account for the high incidence of the disease on farms.

The use of appropriate fungicides (metalaxyl, mancozeb and copper oxychloride) has been reported to be effective in managing the disease (Adejumo, 1997). Though most of the farmers in the area did not attempt to control the disease, few of them used chemicals and other cultural practices including pruning. Among the chemicals used, majority were insecticides (Actellic (Pirimiphos-methyl), Durban (Chlorpyrifos-ethyl), Akati master (Bifenthrin), Karate (Lambda-cyhalothrin), Carbodan, Conquer Super (Lambda-cyhalothrin), Lambad (Lambda-cyhalothrin) , Poison and Sunpyrifos (Chlorpyrifos-ethyl)) rather than fungicides (Funguran-OH). This indicates that the wrong pesticide were being used, making control ineffective, and contributing to the widespread and persistent nature of the disease. Again, since these chemicals are ineffective, the farmers are tempted to apply higher rates believing that higher dosages may be effective but this rather leads to contamination of the environment and

development of resistance. The level of education of the farmers may account for the wrong usage of these chemicals since most are middle school or JHS leavers and have not received any special training on pesticides use.

Pruning or rouging is one of the cultural practices employed by farmers in the area though majority did not apply it. According to Singh *et al.* (2012), pruning is highly effective in controlling the disease. The very few farmers who practiced pruning do so as and when the disease appears, and this helps in reducing the amount of inoculums on the field by improving air circulation that reduces relative humidity on the field (Esiyok *et al.*, 1994), and consequently, the disease. This could be the reason why majority of the farmers responded that pruning was very effective.

Results of the field survey conducted in the Eastern region indicate a high incidence of taro leaf blight disease in the 10 taro growing districts in both seasons, though it was very high in the wet season than the dry season (Figures 14 and 15. Higher percentage and mean incidence represents a high presence of the disease in the districts.

Differences in incidence exhibited between districts suggest that the various locations influenced the disease in a unique manner which can be attributed to micro-climatic factors such as vegetation, soil type and fertility peculiar to each environment.

Environment has been recognized as one of the major factors that can influence the process of an epidemic, having the capacity to induce or retard it (Brooks, 2000; Chiejina and Ugwuja 2013; Van der Puije *et al*, 2015). All the surveyed districts fall within the same climatic zone and had similar weather

parameters and therefore other factors which may include varietal differences, could have also played a role in the differences in the incidence recorded in the those districts. Chiejina and Ugwuja (2013) reported of the interactive effect of the different environments and varieties on the blight disease in Nigeria and their findings revealed that the disease is more variety dependent.

Mehrotra and Aggarwal (2003) have attributed variations in disease incidence from one location to another to differences in inoculums potentials across these locations and also subject to the time of commencement of the epidemic in each site. They also reported that places where the disease starts first under favourable conditions produce higher inoculums and higher disease and vice versa. The first record of the TLBD in Ghana was reported by Omane *et al.* (2012) in the Eastern Region and the surveyed districts being Fanteakwa, New Juabeng, and West Akim. Atiwa and East Akim districts. The disease inoculums in these districts could have built up over the years and explain why these districts had high incidence of the disease.

Similar results were reported in the Aowin Suaman district in the Western region of Ghana by van der Puije *et al.* (2015) when ten communities were surveyed in the district to assess the incidence of the disease. Chiejina and Ugwuja (2013) too reported same in Nigeria, when they assessed the incidence of Phytophthora leaf blight disease on two local varieties in Nsukka area (Ede-Oballa, Nsukka-Urban and Obukpa) in Nigeria. High incidences of 74.2, 86.0 and 77.2% were recorded in the three surveyed communities. Again, Misra (1993) reported of a high incidence of the disease in Southern India and reported of 94% infection from the 128 taro fields sampled for the disease in India in 1988. The

high incidence of TLBD in the Eastern region in both seasons is indicative of how widespread the disease is in the region.

The assessment of severity of the disease in the surveyed districts revealed differences in severity in both seasons (Table 16). Most of the districts recorded mean severity approximation of 2 in the wet season, indicating that 8-25% of their leaf area was damaged. Only one district (Yilo Krobo) recorded that level of severity in the dry season, whilst the others recorded lower mean severity of 1 representing, 1-7% of leaf area damaged. The severity of the disease has been reported to be influenced by temperature and relative humidity (Brooks, 2000). The TLB disease is observed to be severe in areas having high relative humidity and frequent rainfall, whereas warmer areas having little rainfall and relative humidity are comparatively free from the disease. Disease development has been identified to be favoured by a high relative humidity (90%-100%) and a high temperature ($15^{O}C$-$35^{O}C$) with $28^{O}C$ as optimum (Brooks, 2005). Misra *et al.* (2008) reported that, the disease becomes severe when night and day temperatures ranged between 20 ^{O}C -22 ^{O}C and $25^{O}C$ -$28^{O}C$, respectively, with a relative humidity of 65% during the day and 100% at night and accompanied by overcast rainy weather. During the survey in the wet season, the average temperature recorded in the ten districts was 22 ^{O}C with a relative humidity of 85%. However in the dry season, the average temperature recorded was 25 ^{O}C with a relative humidity of 55%. This could explain why the severity was higher in most of the surveyed districts in the wet season than in the dry season. It is evident from the research that TLBD is a major problem in the study area and farmers have little knowledge of the disease and its management.

CHAPTER FOUR

CHARACTERIZATION OF PHYTOPHTHORA SPP ISOLATED FROM DISEASED TARO PLANTS FROM EASTERN REGION

INTRODUCTION

Phytophthora species infect different types of economically important crops including vegetables, fruits, ornamental crops, and forest trees. (Erwin and Ribeiro, 1996). They cause a lot of damage to these crops which leads to yield loss worth millions of dollars (Wawra et al., 2012; Misra, 1996). Over 100 species have been isolated and identified from these plants (Kroon *et al.*, 2012). Most *Phytophthora* species are hosts specific but some cause diseases on a wider variety of plants (Cline *et al.*, 2008). *P. colocasiae* has been reported to infect only *colocasiae* species whereas *P. nicotianae* infects close to 255 genera in 90 families (Brooks, 2005; Cline *et al.* 2008).

P. colocasiae causes leaf blight disease in taro and has been reported to limit taro production throughout Africa including Ghana (Jackson, 1999; Omane *et al.*, 2012; Ackah *et al.*, 2014 & van der Puije *et al.*, 2015). Yield losses may reach 50 to 60% under severe blight conditions and susceptible taro cultivars can be destroyed completely (Brooks, 2005).

Besides *P. colocasiae*, other species of *Phytophthora*, viz., *P. araceae*, *P. palmivora*, *P. parasitica,* and *P. nicotiana* have been reported to infect taro (Ackah, 2013). There have also been reports of different strains of *P. colocasiae* responsible for the disease in different localities (Adomako *et al.*, 2016). The correct identification of the causal organism is an important step towards

successful management of the disease. The objective of this chapter is to characterize the isolates of TLBD from ten districts of the Eastern region using morphological methods.

MATERIALS AND METHODS

Location and Experimental Site

During the field survey to assess the incidence and severity, infected leaves were taken from each of the three farms surveyed in each district for isolation of the microorganism associated with it. The pathogen was isolated according to the protocol used by Ackah (2013), using carrot agar (CA) media and sub-cultured onto potato dextrose agar (PDA) which was prepared as described in next section. The experiment was conducted at the Plant Pathology Laboratory of the Department of Crop Science, University of Cape Coast, Ghana.

Preparation of Carrot Agar medium

Fresh carrot was obtained from the science market of the University of Cape Coast and two hundred and fifty grams (250 g) of the fresh carrot was weighed using an OHAUS Precision plus electronic weighing balance. They were then cut into pieces and boiled with 500 ml of distilled water for 20 minutes. They were blended with a Mitsui electronic blender for two minutes after which it was mixed with 500 ml of distilled water and strained with a sieve into a 1 litre measuring cylinder. Two grams (2 g) of streptomycin and 15 g of agar powder were added to the extract in the measuring cylinder and topped with distilled water to the 1 litre mark and the content was stirred thoroughly for 10 minutes

using a magnetic stirrer. The flask and its content were then autoclaved at 120 °C for 20 min and at 20 p.s.i (1.4kgcm^{-2}). The carrot agar medium was allowed to cool to 50 °C and then poured into 9 cm Petri dishes in a laminar flow unit for the isolation process.

Preparation of Potato Dextrose Agar (PDA) Media

The PDA was prepared according to the method proposed by Mishra *et al.*, (1996). Two hundred and fifty grams (250 g) of pealed Irish potatoes was cut into pieces and boiled with 500 ml of water for 20 minutes. The water that was used to boil the potatoes was then strained using a strainer and then poured into a 1 litre Erlenmeyer flask. Twenty (20 g) of agar powder and 20 g of dextrose were weighed using an electronic balance and then added to the potato extract in the flask. It was then topped with distilled water to the 1 litre (1000 ml) mark of the flask and mixed thoroughly with a magnetic stirrer for 10 minutes. The flask and its content were autoclaved at 120 °C and 20 psi for 20 min.

Isolation of Microorganism Associated with Infected Leaves

A leaf segment of 1 cm × 1 cm was cut from the lesion margin on infected leaves. The leaf segments were surface sterilized in 5% bleach for 5 min, washed three times with sterile distilled water, dried and then plated on carrot agar amended with streptomycin in nine (9) centimetres Petri dishes. Two Petri dishes were used for each leaf sample with four (4) leaf segments placed in each plate. The plates with the diseased tissue were incubated at 28°C in an incubator. Fungal growth from the plated disease tissues were sub-cultured onto freshly prepared PDA in a nine centimetres Petri dish using mycelial plugs. Sub-culturing was

continued until pure cultures of isolates were obtained. All these were done in a laminar flow unit.

Preparation of Inoculums

Spore suspension was prepared from 14 days old culture of a *P. colocasiae* isolate, by flooding the surface of the growing colonies in a Petri dish with 5 ml sterile distilled water and dislodging the zoospores with a small sterilised brush. The supernatant was filtered through a 2 layered sterile muslin cheesed cloth. A drop of spore suspension was placed on the haemocytometer chamber, covered with a slide and the number of spores per ml estimated as an average of the spores counted in 10 standard heamocytometer fields (Charles *et al.*, 2016). The number of spores per ml was calculated using the formula adopted from Duncan and Torrance (1992).

$S = NV/v$

Where

S = Number of spores per millilitre

N = Mean number of spores in 10 large squares counted

V = 1 ml =1000 mm^3

v = volume of spore suspension under glass cover.

A spore suspension (inoculum) was adjusted with the aid of haemocytometer to 3×104 spores ml^{-1} of distilled water. The inocula were put in a refrigerator at a temperature of 4°C for 30 minutes to stimulate liberation of zoospores. The control was made up of 20 ml of sterilized distilled water.

Characterization of Isolates of *P. colocasiae*

Freshly prepared PDA was poured into a 9 cm Petri dish and allowed to solidify. A 1 cm-disc of each pure culture of an isolate was transferred onto the medium, incubated at 28°C and then observed for growth. The isolates from the different districts were characterized based on their morphology (culture and sporangia characteristics) using methods described by Gallegly & Hong (2008). The mycelial growths of all the isolates from the various districts were compared as well as the sporangia. Data were collected on culture characteristics (colony colour from surface and reverse colour, texture, shape, growth rate, and size) and microscopic characteristic (shape of sporangia, size (length and width), papillate, colour, and pedicel length) using a compound microscope with eye piece ocular and stage micrometer. Radial growth was measured each day with a ruler for each isolate until the plate was completely covered.

Pathogenicity Testing of P. colocasiae Isolate

The detached leaf method was used to perform this experiment. The second youngest leaves of a local susceptible taro variety established at the MoFA farms at Asuansi were detached and taken to the Plant pathology laboratory of the Department of Crop Science for this experiment (Figure 38 A). Leaf segments of 5 x 5 cm were cut from the leaf (Figure 38 B). Three segments were cut for each isolate. Each segment was inoculated with a drop of an isolate from a two weeks old *P. colocasiae* culture with a suspension of 50-70 sporangia in the middle. The suspension was prepared by flooding the Petri dish containing the two week old *P. colocasiae* culture of each isolate with 10 ml of distilled water for 12 hrs. The

inoculated leaf segments were arranged in a transparent 40 x 25 cm plastic container with a glass of water kept in it to increase the relative humidity (Figure 38 C and D). The containers were then covered (Figure 38 E) and kept under room temperature. The setup was monitored daily for symptoms development. Reisolation was also done from the symptoms developed on the leaf segments to confirm the pathogenicity of the organism.

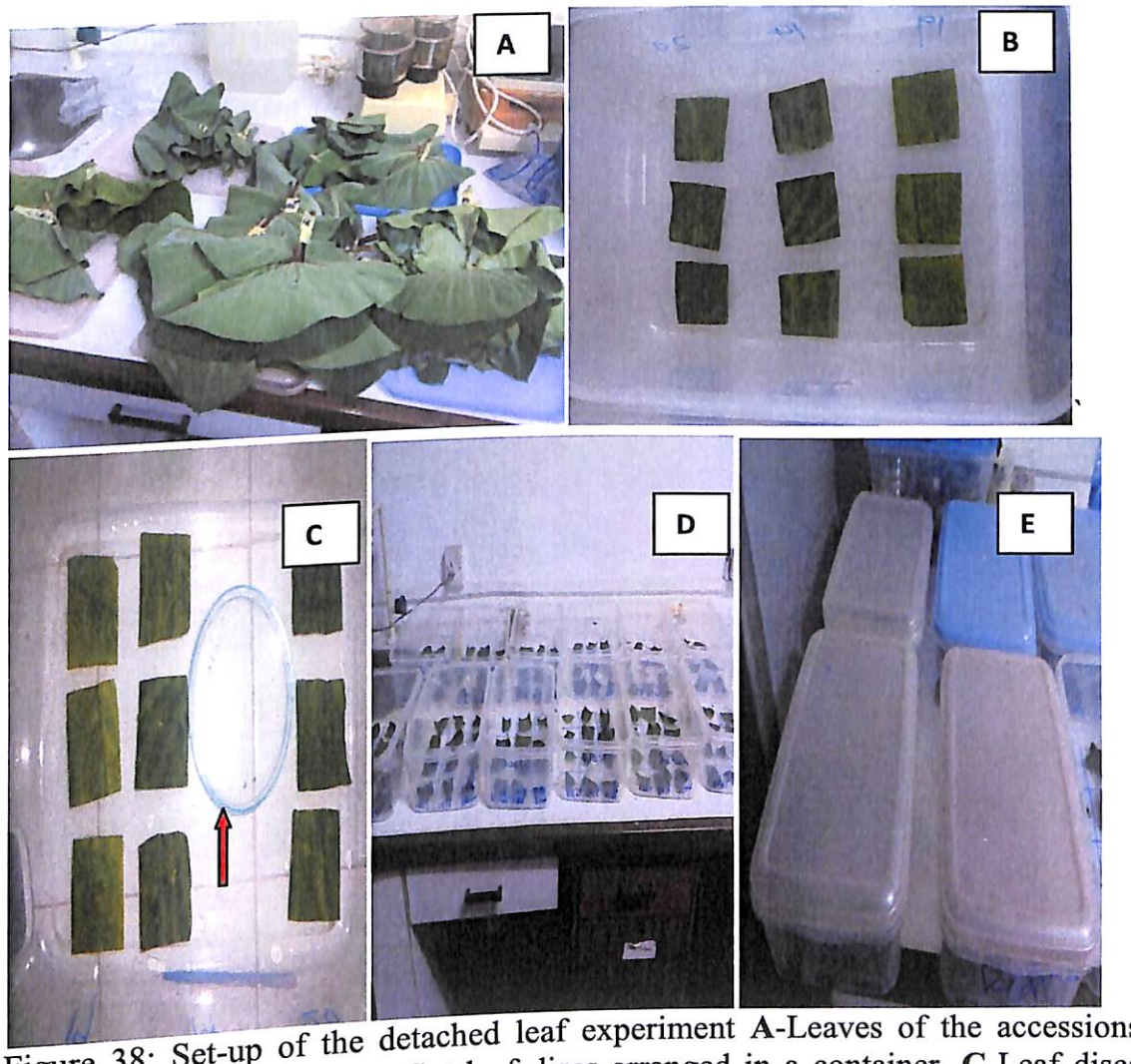


Figure 38: Set-up of the detached leaf experiment **A**-Leaves of the accessions collected from the field, **B**-Cut leaf discs arranged in a container, **C**-Leaf discs inoculated in the middle with a drop of water containing a suspension of *Phytophthora colocasiae* **(arrowed)**. **D**-The setup of the leaf disc experiment arranged on a benched, **D**-The setup covered

Determination of the Effects of Temperature on the Growth of *Phytophthora colocasiae*

This experiment was performed using methods described by Tyson and Fullerton (2015). Petri dishes of potato dextrose agar (PDA) were inoculated with 3 mm mycelial plugs taken from 2-day-old actively growing cultures of *P. colocasiae* (five plates per temperature). The PDA plates were incubated at 15, 20, 25, 30 and 35°C in incubators and mycelial growth assessed after 3, 4 and 5 days. Colony diameters were measured in two directions (random and at right angles) and adjusted for the diameter of the plug. Measurements were taken each day for a 5 day period. Completely randomised design was used for this experiment.

Data analyses

Results were analyzed using Analysis of Variance (ANOVA) with GenStat Discovery 12. Where there were significant differences, differences between means of individual treatments were determined using Fisher's protected Least Significant Difference test (LSD, P=0.05).

RESULTS

Morphological Characteristics of *P. colocasiae* Isolates from Ten Districts in the Eastern Region of Ghana

All the *P. colocasiae* isolates had a whitish colony as observed from the surface (Figure 39 B) and from reverse with floccose or cottony texture and a regular margin (Table 2).

Table 2. Colony characteristics of isolates of *Phythophthora colocasiae* on PDA at 25°C for 7 days

Isolate	Colour	Reverse colour	Texture	Margin
Akim Central	white	white	cottony	regular
Asuogyaman	white	white	cottony	regular
Fanteakwa	white	white	cottony	regular
Kwahu South	white	white	cottony	regular
Kwahu West	white	white	cottony	regular
New Juabeng	white	white	cottony	regular
Suhum/Kraboa/Coaltar	white	white	cottony	regular
Yilo Krobo	white	white	cottony	regular
East Akim	white	white	cottony	regular
Atiwa	white	white	cottony	regular

It was observed that the colony colour of all the isolates (Akim Central, Asuogyaman, Fanteakwa, Kwawu South, Kwawu West, New Juabeng, Suhum/Kraboa/Coaltar, Yilo Krobo, East Akim and Atiwa) was white both on the surface and reverse with fluffy or cottony texture and a regular margin (Table 2).

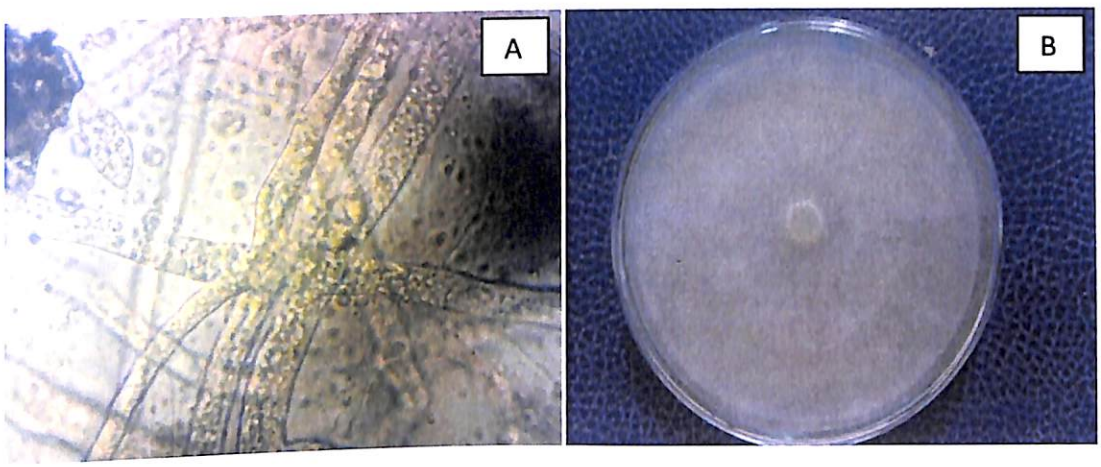


Figure 39. A- Micrograph of a uniform mycelium of an isolate, B-A 7 day old culture of *P. colocasiae* on a growing media (PDA) at 25° C.

In Table 3 are presented the microscopic characteristics of the ten isolates. It was observed that all the isolates had mycelia that were uniform, smooth walled, hyaline and aseptate (Figure 39 A). Seven isolates (from Akim Central, Fanteakwa, New Juabeng, Suhum/Kraboa/Coaltar, Atiwa and Kwahu South) had sporangia shapes that were ellipsoid and three (from East Akim, Kwahu West, and Asuogyaman) were ovoid in shape as shown in Figure 43. Also five isolates (from Akim Central, Kwahu South, Suhum/Kraboa/Coaltar, East Akim and Atiwa) had an apical plug observed as semi papillate and five isolates were non papillate (Asuogyaman, Fanteakwa, Kwahu West, New Juabeng and Yilo Krobo).

Table 3. Morphological characteristics of isolates of *Phythophthora colocasiae* from 10 districts in the Eastern Region of Ghana

Isolates	**Mycelium Morphology**	**Sporangial Morphology**	
		Shape	Apical plug (Papillate)
Akim Central	Uniform	Elipsoid	semi papillate
Asuogyaman	Uniform	Ovoid	non papillate
Fanteakwa	Uniform	Elipsoid	non papillate
Kwahu South	Uniform	Elipsoid	Semi papillate
Kwahu West	Uniform	Ovoid	non papillate
New Juabeng	Uniform	Elipsoid	non papillate
Suhum/Kraboa/Coaltar	Uniform	Elipsoid	semi papillate
Yilo Krobo	Uniform	Ellipsoid	non papillate
East Akim	Uniform	Ovoid	semi papillate
Atiwa	Uniform	Elipsoid	semi papillate

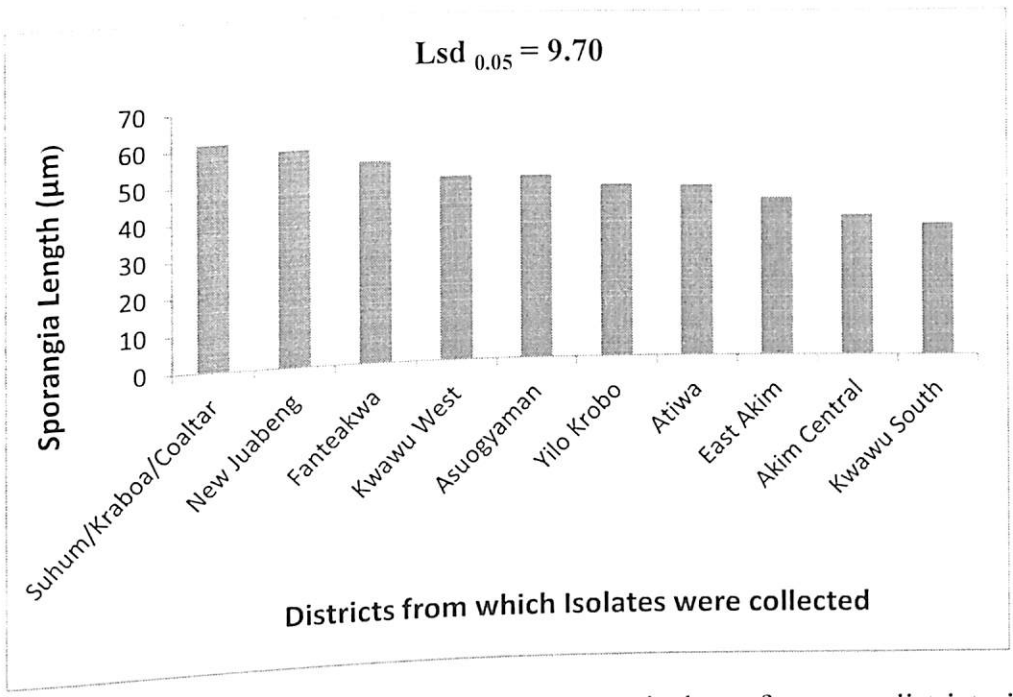


Figure 40. Sporangia length of *P. colocasiae* isolates from ten districts in the Eastern region.

In Figure 40 are presented the average length of the sporangia of the isolates from the ten destricts. The average length ranges from 36 µm to 61.67 µm. The isolate from the Suhum/Kraboa/Coaltar district had the highest average sporangia length of 61.67 µm and was not significantly different ($P<0.05$) from the isolates from New Juabeng (59 µm) and Fanteakwa (55 µm) districts, but was however significantly longer than all the other isolates. The Kwahu West isolate with a length of 50.33 µm was also not significantly different from that of Asuogyaman (50 µm) which was also not significantly different from the isolate from Yilo Krobo (47.33 µm), Atiwa (47 µm) and East Akim (43.33 µm). The isolate from Kwahu South had the lowest sporangia length of 36 µm and was not significantly longer than the isolate from Akim Central (38.33 µm) and East Akim, though was significantly shorter than the other isolates.

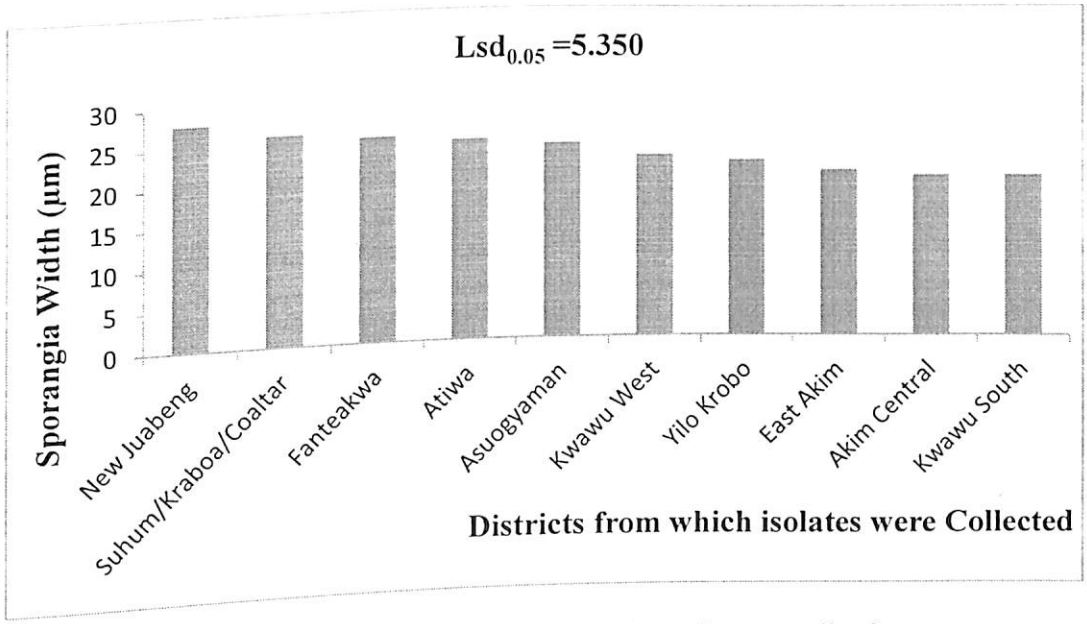


Figure 41. Sporangia width of *P.colocasiae* isolates from ten districts

The average width of the sporangia of the various *P. colocasiae* isolates from the ten districts ranges between 20 µm to 28 µm (Figure 41). There was no significant (P< 0.05) difference between isolates from New Juabeng (28 µm), Suhum/Kraboa/Coaltar (26.33 µm), Fanteakwa (25.67 µm), Atiwa (25 µm), Asuogyaman (24.33 µm) and Kwawu West (22.67 µm). The isolate from New Juabeng however had a wider sporangia than the isolates from Yilo Krobo (22 µm) , East Akim (20.67 µm), Akim Central (20 µm) and Kwahu South (20 µm). Again the isolate from Kwawu South and Akim Central were also not significantly different from the isolates from East Akim, Yilo Krobo, Kwawu West, Asuogyaman and Atiwa.

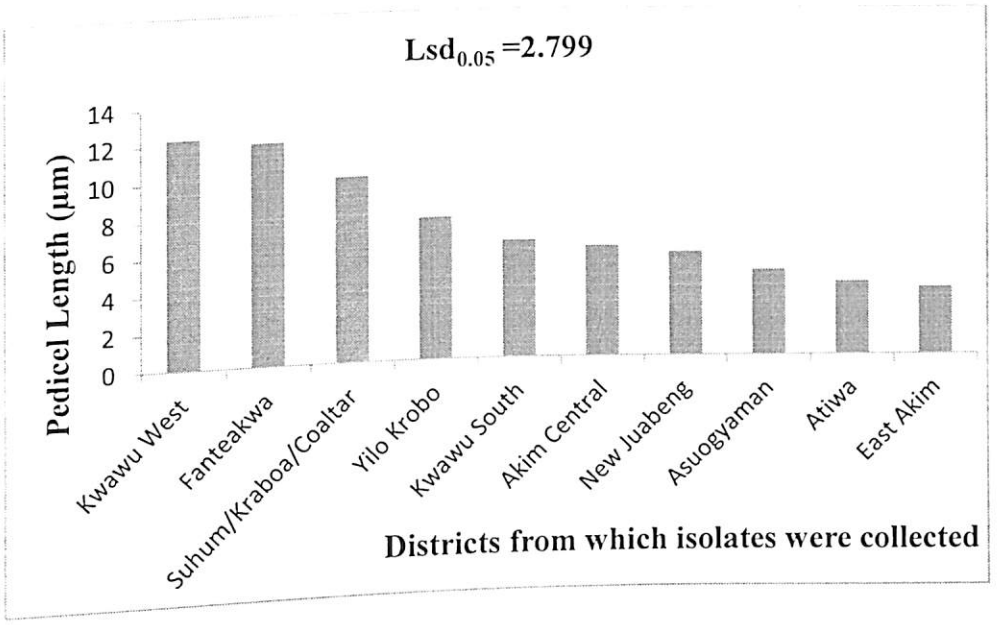
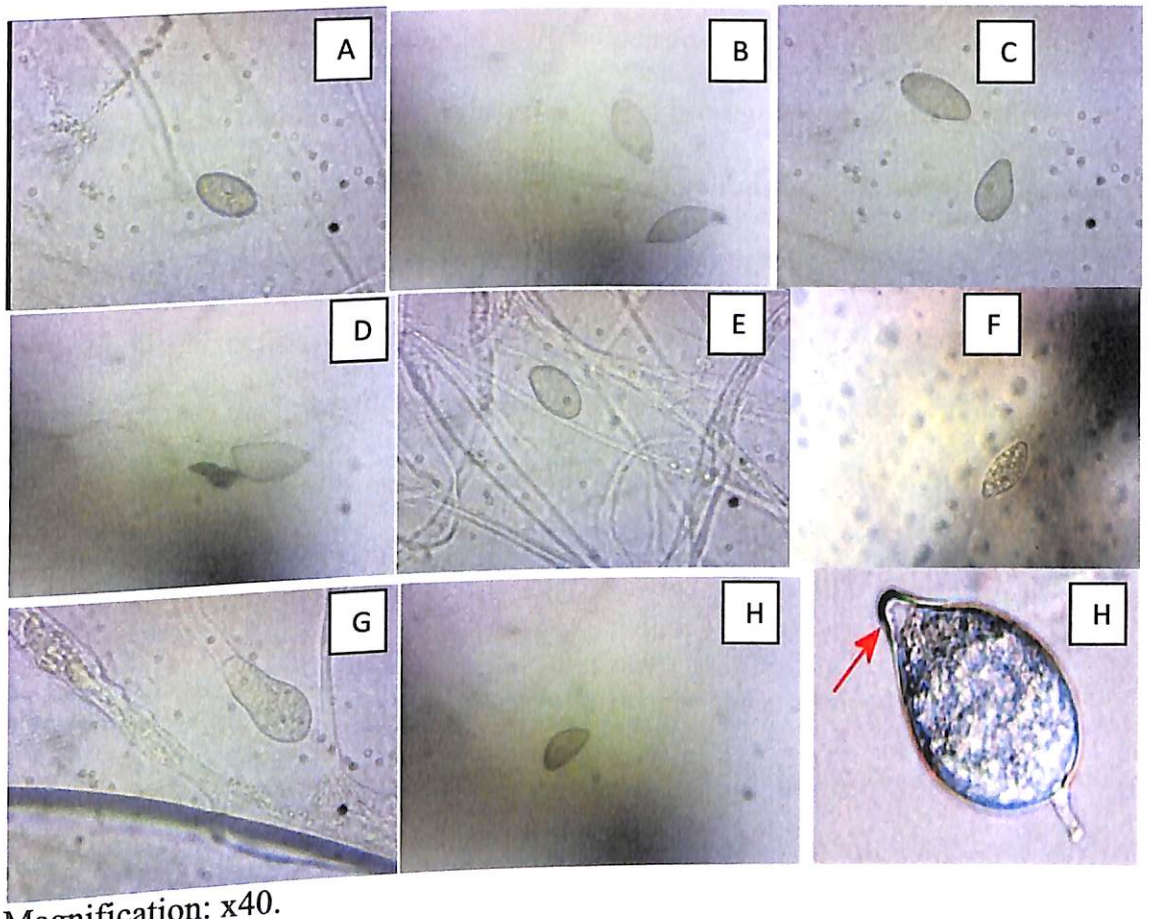


Figure 42. Pedicel length of sporangia of *P.colocasiae* isolates from ten districts

Figure 42 shows the average length of the pedicels of sporangia of the isolates from the districts. From the figure the pedicel length ranges from 3.667 µm to 12.333 µm. Isolates from Fanteakwa (12 µm), Kwawu West (12.33 µm) and Suhum/Kraboa/Coaltar (10 µm) were not significantly different in length from each other (P<0.05) but were significantly longer than all the other isolates

except the isolate from Suhum/Kraboa/Coaltar which was also not significantly different from isolates from Kwahu South (6.333 µm), Akim Central (6 µm), and New Juabeng (5.667 µm). The shortest average lenght of 3.667 µm which was measured for the isolate from East Akim was not significantly different from that measured for the isolate from Atiwa (4.667 µm), New Juabeng (5.667 µm), Akim Central (6 µm) and Kwahu South (6.33 µm. The pedicel length of the isolate from Yilo Krobo (7.667 µm) was also not significantly different from that for Suhum/Kraboa/Coaltar (10 µm) but different from the isolates from Kwahu West and Fanteakwa districts.



Magnification: x40.

Figure 43. Sporangia of different isolates of *P. colocasiae* (A-Akim Central, B-Asuogyaman, C-Fanteakwa, D-Kwawu West, E-New Juabeng, F-Suhum/Kraboa/Coaltar, G-Yilo Krobo,H- East Akim), H= Sporangia of *Phythophthora colocasiae* from literature (Brooks, 2005).

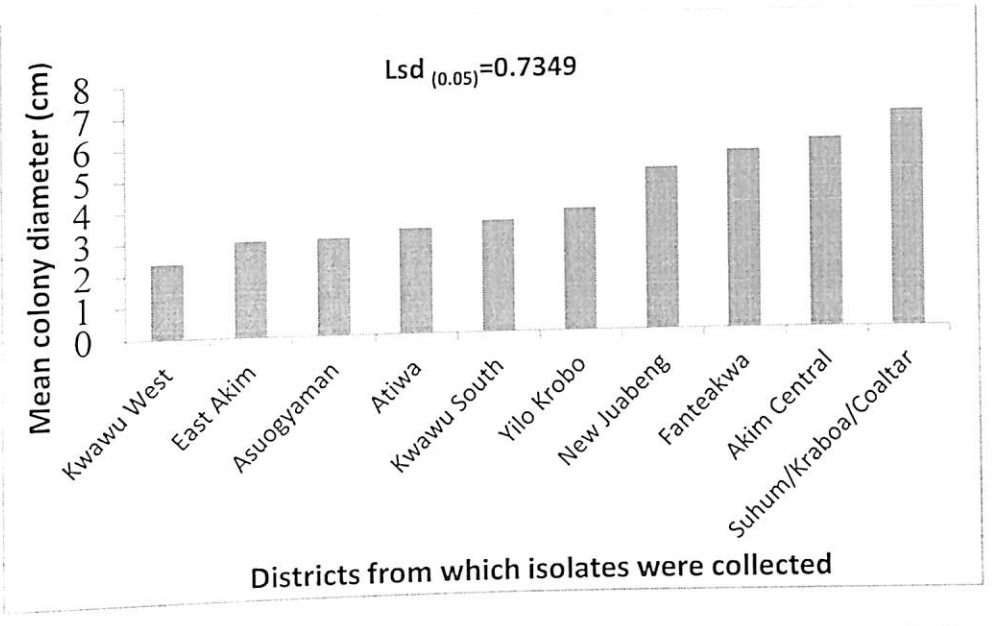


Figure 44. Mean colony diameter (cm) of *Phytophthora colocasiae* isolates from the 10 districts incubated for two days on potato dextrose agar at 28°C.

The mean colony diameter of *P. colocasiae* isolates from the ten districts in the Eastern region grown on a potato dextrose agar for 2 days at 28°C are shown in Figure 44. The isolate from the Suhum/Kraboa/Coaltar district had the largest mean colony diameter (6.925 cm) and was significantly longer ($P<0.05$) than the isolates from the other districts. The mean diameter of the colony from isolate from Akim Central (6.050 cm) was not significantly different from that from Fanteakwa (5.700 cm), which was also not different from that of New Juabeng (5.175 cm). The isolate from Yilo Krobo (3.900 cm) was however not significantly different from that of Kwahu South (3.550 cm) and Atiwa (3.350 cm), but was different from the other isolates. The lowest mean colony diameter was recorded for the isolate from Kwahu West (2.375 cm). This was not significantly different from the isolates from East Akim (3.050 cm) and Asuogyaman (3.075 cm) districts.

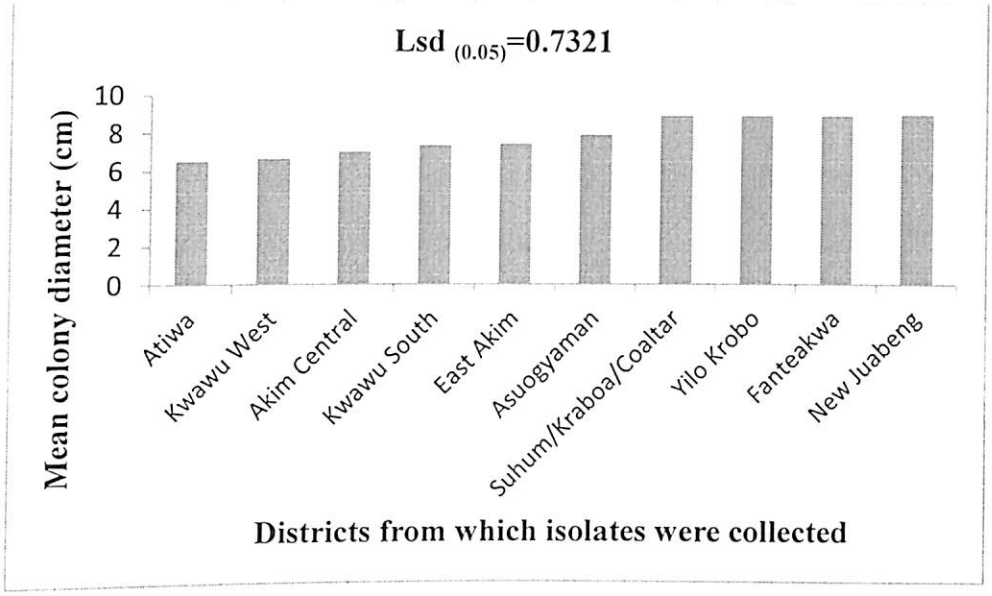


Figure 45. Mean colony diameters (cm) of *Phytophthora colocasiae* isolates 3 days after inoculations on potato dextrose agar at 28°C.

On Day 3 as shown in Figure 45, the mean colony diameter recorded for the isolates from New Juabeng (9.000 cm), Fanteakwa (8.950 cm), Suhum/Kraboa/Coaltar (8.925 cm), Yilo Krobo (8.925 cm) and Asuogyaman (8.463 cm) were not significantly different from each other. These isolates were however significantly different from those collected from Kwahu South (8.175 cm), Akim Central (8.000 cm), East Akim (7.850 cm) and Kwahu West (7.812 cm), except that from Asuogyaman. The isolate from the Atiwa district recorded the shortest mean colony diameter (7.075 cm) and was also significantly different from all the other isolates.

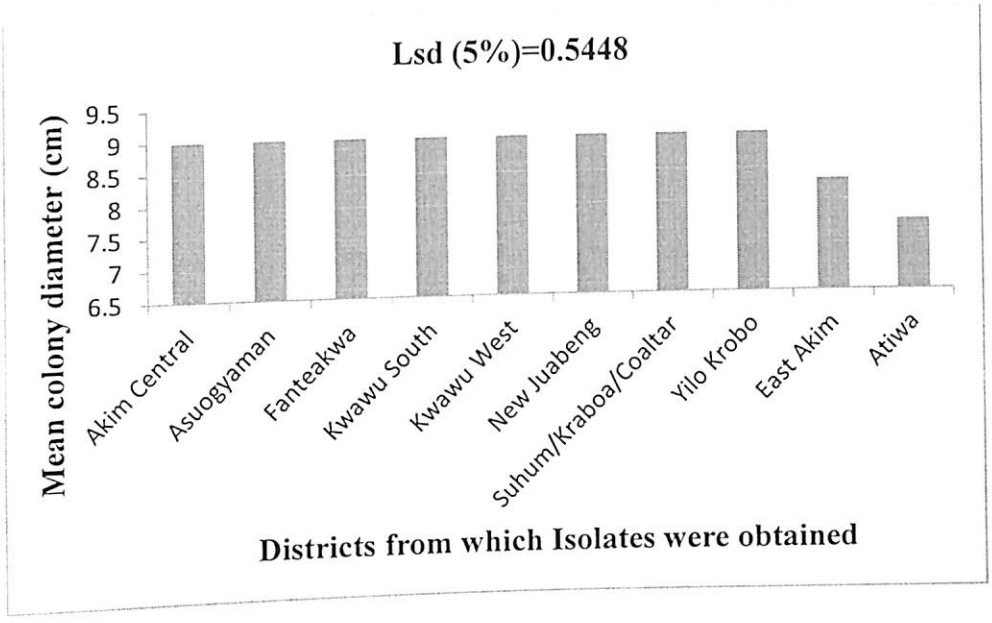


Figure 46. Mean colony diameters (cm) of *Phytophthora colocasiae* isolates 4 days after inoculations on potato dextrose agar at 28°C.

From Figure 46, there was no significant difference in the mean colony diameter for eight of the isolates (Akim Central, Asuogyaman, Fanteakwa, Kwawu South, Kwawu West, New Juabeng, Suhum/Kraboa/Coaltar and Yilo Krobo) which all had a mean colony diameter of 9.000 cm. But they were however significantly different from the isolates from East Akim (8.250 cm) and Atiwa (7.600 cm), which were also significantly different from each other.

Pathogenicity Test of *P. colocasiae* Isolates

Figure 48 shows the results of the Pathogenicity test three days after inoculation at 25 °C. Water droplets could be observed in the container as well as brown lesions which had developed at the point of inoculation on the leaf disc and had grown rapidly with a red-brown water droplet oozing it. The organism re-isolated was also similar morphologically to the one used for the inoculation.

Figure 47. Radial mycelial growth of three isolates *of P. colocasae* on PDA incubated at room temperature (27-30^{O}C) for three days.

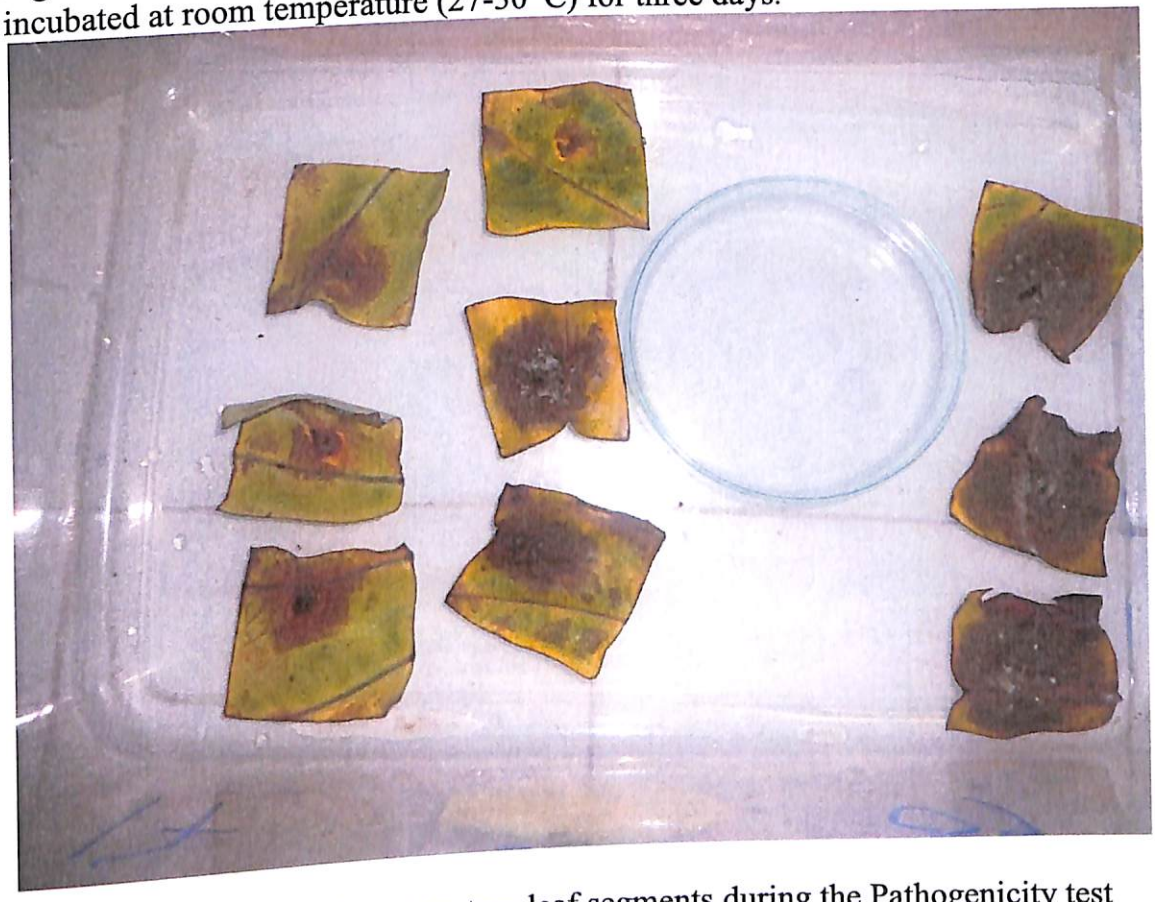


Figure 48. Lesion developed on taro leaf segments during the Pathogenicity test

Effect of Different Temperatures on the Growth of *P. colocasiae*

The mean colony diameters of *P. colocasiae* isolates at different temperatures on PDA are shown in Table 4. After three days of inoculation, there was no growth at 35°C. The highest growth (3.68 cm) was recorded at 25°C but was not significantly different ($P<0.05$) from the growth at 30°C (3.640 cm). The growths under these two temperatures were significantly different from all the others. Day four and five also recorded similar results with no growth at 35°C. The temperature at 25°C and 30°C resulted in the fastest colony growth which was significantly different from the other temperatures.

Table 4. Mean colony diameters (cm) of *Phytophthora colocasiae* grown on potato dextrose agar for 3, 4 or 5 days at different temperatures.

	Mean Colony Diameter (cm)				
Days	15°C	20°C	25°C	30°C	35°C
3	1.520 c	2.680 b	3.680 a	3.640 a	0.000 d
4	1.960 c	3.420 b	4.640 a	4.500 a	0.000 d
5	2.380 c	4.040 b	5.400a	5.320 a	0.000 d

*Means with the same letter in each column are not significantly different (LSD, $P<0.05$)

Colony diameter increases with time (days) and also at different temperatures from 15°C to 30°C. Growth was highest 25°C in all the days followed by 30°C. At 35°C there was no growth at all.

DISCUSSIONS

The pathogen isolated from the leaf tissues of taro from all the ten districts in the Eastern region, when cultured on PDA at 25°C appeared whitish on both the surface and reverse. The mycelia of all were hyaline and uniform when observed under a compound microscope. The sporangia shape varied from ellipsoid to ovoid with some being semi-papillate and others not having papillae (non papillate). All the isolates easily shed their sporangia from the sporangiophores (caduceus).Typically, *P. colocasiae* is characterized by the production of ovoid, ellipsoid, or fusiform, semi-papillate sporangia that are caduceus and ranges in length from 45 to 75 µm x 25 to 37 µm, with a medium pedicel length of about 12 µm long, where less than 5 µm is considered short, 5-20 µm is medium and greatter than 20 µm is considered long (Gallegly, & Hong, 2008 and Brooks 2005). This indicates that, though the isolates from the various districts are identified as *P. colocasiae,* they exhibit differences in length and width of their sporangia and the pedicel length and therefore of different strains.

The results from the mean colony diameter of the isolates from the ten districts reveal differences in growth by the various isolates when incubated under the same temperature (28°C) for four days. The difference in growth indicates the differences in strains of the isolates and how virulent some of the strains could be when provided with the right condition. Almost all the isolates had completely covered the 9 cm Petri dish on the fourth day of culture, suggesting that they could be virulent and cause disease quickly. Virulent strains have been reported to cause more disease than avirulent ones (Brooks, 2005).

The fact that all the leaf discs showed symptoms of TLBD three days after inoculation during the Pathogenicity test suggests that *P. colocasiae* isolates from the districts are the causal agents for the disease in these districts. The symptoms were similar to those found on the leaves in the field. This description is the same as observed by others (Ackah *et al.*, 2015 & Brooks, 2005). The morphological description reveals that the pathogen causing the leaf blight disease in all the ten districts was *P. colocasiae.*

The study has shown that temperature has a strong influence on the growth of *P. colocasiae*. The pathogen grew on the PDA media over the temperature range 15–30°C. Optimum growth was recorded within the range 25–30°C. The highest growth was observed at 25°C. Growth however was not recorded at 35°C. This confirms findings by Tyson and Fullerton (2015) when they studied the effect of different temperatures on the growth of *P. colocasiae* on agar media and leaf disc. They found out that *P colocasiae* grew on agar media and leaf discs over a temperature range of 15–30°C with 25°C being the optimum.

Based on the findings, it is evident that though *P. colocasiae* is the cause of the leaf blight disease of taro in the Eastern Region, the differences is strains from the different districts needs to be considered when management strategies are being developed.

CHAPTER FIVE

COLLECTION AND EVALUATION OF TARO GERMPLASM FOR RESISTANCE OR TOLERANCE TO TARO LEAF BLIGHT DISEASE

INTRODUCTION

Several control measures including exclusion, sanitation, the use of resistant varieties, fungicides and cultural practices (rouging and spacing) have been suggested for the management of TLBD (Misra *et al*, 2008; Ackah *et al.*, 2014). The use of ecological approaches such as the removal of infected leaves (rouging) could lead to complete defoliation of the crop with consequent effects on yield (Adams, 1999). All these management practices including the use of fungicides have been reported to be ineffective because of financial considerations and labour demands.

The use of resistant cultivars represents the only sustainable solution to taro leaf blight in most production systems (Omane *et al.*, 2009; Anon., 1998). In Ghana there is the need to evaluate the existing taro germplasm for resistance to TLB. Breeding programs in India, Papua New Guinea, Vanuatu and American Samoa have crossed TLBD resistant cultivars from other areas of the world with commercial cultivars in those countries after a nationwide germplasm collection (Okpul *et al.*, 2002; Seetohul *et al.*, 2007). It is now established that these countries have varieties that are resistant to the TLBD. However, there is inadequate knowledge about TLBD resistance of Ghanaian cultivars and other cultivars maintained in the Plant Genetic Resource Institute's plant museum.

The objective of this phase of the project was to collect and evaluate taro germplasm in Ghana together with some imported varieties against the taro leaf blight disease for effective management of TLBD.

MATERIAL AND METHODS

In the quest to obtain a resistant cultivar, germplasm collections were done in five taro growing regions in the country and then established. These accessions were screened to determine their level of resistance or susceptibility using the detached-leaf disc bioassay at the Plant Pathology Laboratory of the University of Cape Coast as explained in Chapter 4.

Germplasm Collection and Establishment

The germplasm collection was done from 2014 to 2015 in all five taro growing regions in Ghana (Figure 49). The entire taro growing districts in each region was visited. One hundred and thirty five (135) accessions were collected from the Central region, 163 from the Western region, 96 from Ashanti region, 119 from Eastern region and 26 from Brong Ahafo region.

Location of Site for Gemplasm Establishment

All the 135 taro accessions were established on a field at the Asuansi Farm Institute of the Ministry of Food and Agriculture (MoFA), which is located in the Central region (Figure 50). The area is a forest transition zone with swampy land condition suitable for taro production. Five of each accession was established in a row with a distance of 1 m × 1 m between and within rows. This was to multiply

the accessions for the next phase of the project (evaluation for resistance). A passport form (Appendix 2) was used for the collection.

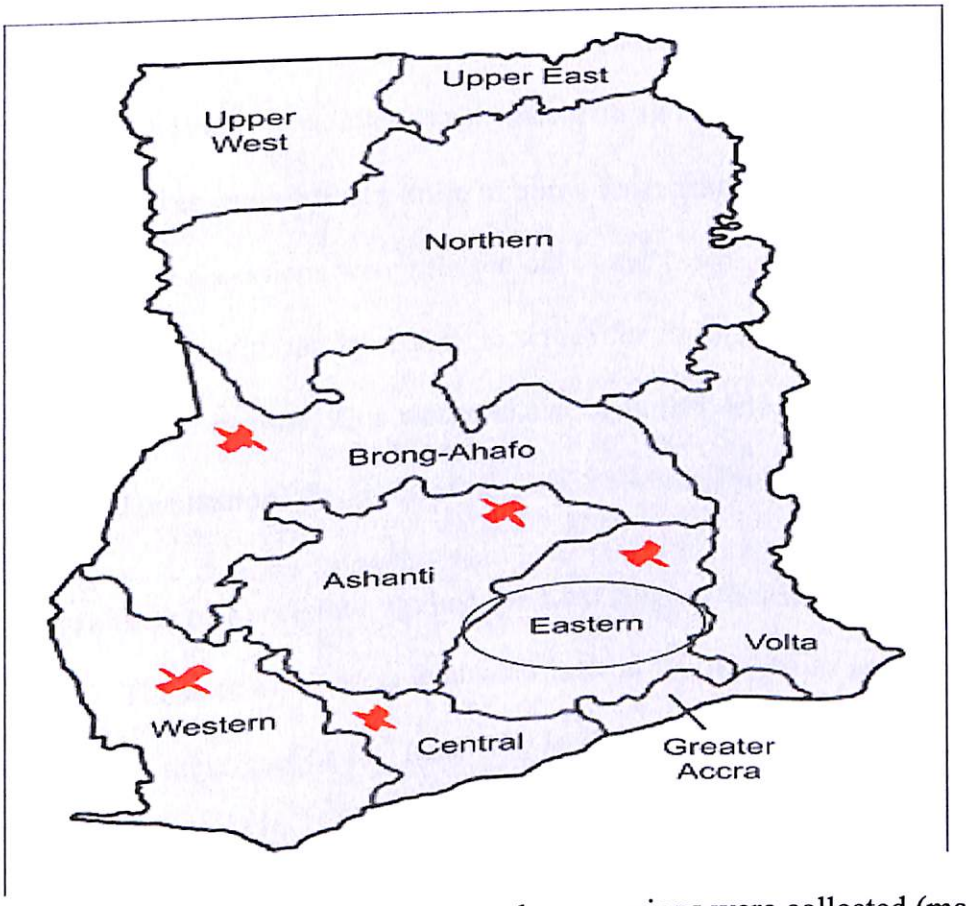


Figure 49: Regions of Ghana where the accessions were collected (marked).

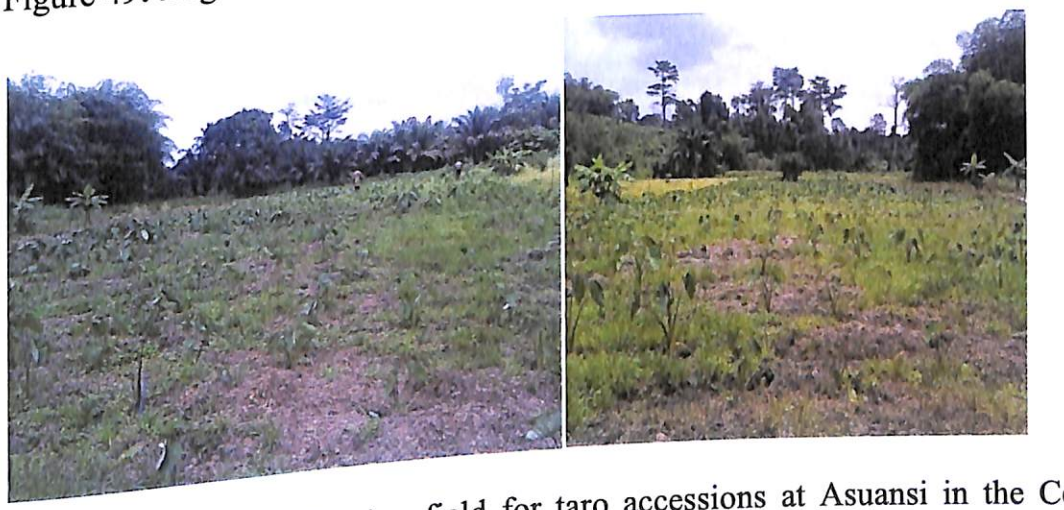


Figure 50: A multiplication field for taro accessions at Asuansi in the Central Region

Pruning of Infected Leaves on the Field

Six weeks after the establishment of all the accessions on the field, there were visible signs of the taro leaf blight disease on some of the accessions. To select some of the accessions for the next phase of the experiment, pruning was done on the eight week after establishment on all the accessions by the removal of all the leaves using a sharp knife to allow for regeneration. Four weeks after the pruning, 20 accessions were selected out of the 135 based on their reaction to the disease and sent to the laboratory to screen for *P. colocasiae* resistance using the detached leaf method. This was to allow for further selection of some accessions for field evaluation.

Evaluation of Accessions against the Leaf Blight Disease of Taro

The accessions were evaluated both in the laboratory and on the field to determine their reaction to TLBD. The leaf disc assay method described by Tyson and Fullerton (2015) was used to screen the accessions in the laboratory while the field screening was done using guidelines proposed by Singh et al. (2001).

Detached-leaf assay for determining resistance of taro to *Phytophthora colocasiae*

The detached leaf assay was used to screen accessions from the multiplication site at Asuansi in the Central region as explained in the previous section and the accessions that was later established on the field at Bososo in the Eastern region of Ghana.

Evaluation of Local Accessions from the Multiplication Field (Asuansi)

The fifteen taro accessions (WR0005, CR0036, ER0063, AS0062, CSRI0004, CR0091, ER0045, AS0020, AS0060, CR0015, CR0001, WR0096, CSIR0003, WR0025, CR0036) selected after pruning were screened against *P. colocasiae* infection, using detached-leaf method .The second youngest leaf of each of the taro accessions were selected for this *in vitro* experiment. The selected leaves were clean from any infections. Four leaf segments of 5 x 5 cm were cut from each leaf. Each leaf segment was inoculated in the middle, with a drop of a *P. colocasiae* isolate (Fanteakwa) suspension containing 50-70 sporangia as described earlier for the Pathogenicity test. The isolate (Fanteakwa) was selected from among the ten described in the earlier chapter (Chapter 4), after it was identified to be more virulent. The suspension was prepared by flooding the Petri dish containing the two week old *P. colocasiae* culture of each isolate, with 10 ml of distilled water for 12 hrs. Control leaf segments were inoculated with a drop of distilled water. The inoculated leaf segments were arranged in a transparent 40 x 25 cm plastic container with a glass of water kept in each to increase the relative humidity as shown in Figure 18. The containers were then covered and kept under room temperature.

Data was collected daily on lesion development and the mean lesion diameter for seven days, starting a day after inoculation. Lesion diameter was measured using a 30 cm length rule.

Evaluation of Accessions on the Field for Resistance

Accessions Selection

Based on the results of the detached leaf assay performed on the 15 local accessions as described in the previous section, 4 accessions (AS0060, ER0063, CSRI00004, WR0005) were selected and 17 exotic genotypes (GA/TLBD/0001, GA/TLBD/0002, GA/TLBD/0003,GA/TLBD/0006, GA/TLBD/0007, GA/TLBD/0008, GA/TLBD/0009, GA/TLBD/0010, GA/TLBD/0011, GA/TLBD/0012, GA/TLBD/0013, GA/TLBD/0014, GA/TLBD/0015, GA/TLBD/0016, GA/TLBD/0018, GA/TLBD/0020, GA/TLBD/0021) imported by the Plant Genetic Resource Research Institute from Vanuatu and other Pacific countries were used for this study. A total of 21 accessions were therefore evaluated for field resistance against TLBD.

Location of Field

The field study was carried out at Bososo (lat. 06^0 17' N, long, 01^0 01' W, 213 m above sea level) in the Fanteakwa District of the Eastern region of Ghana from March 2016 to January 2017. The location was selected based on a high record of disease incidence in the district (Fanteakwa) during the survey. Bososo lies in the semi-deciduous forest zone of Ghana with the soil type Nta series (FAO: Gleyic Arensol) (GoG, 2018). The study area is characterized by a bimodal rainfall pattern. The major season starts in March and ends in July, while the minor season is between September and mid-November.

Experimental Design and Field Layout

The 21 taro accessions were used for this experiment in a randomised complete block design with three replications. Each accession was planted in a row with a distance of 1 m within the row and 1 m between the rows on each plot. A total number of 10 plants of each accession were planted in each row. The trial was performed under natural field conditions. All the recommended practices for taro cultivation were followed for raising a good crop except plant protection and fertilizer application. The site was hand weeded to minimize phytotoxicity that might arise as a result of using herbicides. Data collected started one month after planting on lesion diameter. The lesions were measured in two directions using a rule. Five measurements were made for each accession.

Morphological Characterisation

The morphological characterization of the accessions was done using plant descriptors proposed by IPGRI (1999). The parameters examined were Leaf Blade Margin –LBM (*Undulate Sinuate, other*), Leaf blade margin colour – LBMC (*yellow, yellow green, green, other*), Leaf shape-LS (*Narrow or Broad*), Leaf Colour-LC (Green, light green, dark green), leaf surface –LS (*smooth, wrinkle*), Leaf Position-LP (*Horizontal, Cup-Shaped*), vein colour –VC (*light green, red, green, dark green*), petiole colour –PC (*whitish, dark green, purple, light green, dull red, black purple*), flowering –F (*frequent rare* Corm Shape –CS (*Conical Round Cylindrical*), Corm skin colour-CSC (*Brown Purple Blackish*)), Flesh Colour-FC (*White, Pink*) and yield. The average of five measurements per individual accession was recorded. All the observations were made at the

maximum vegetative growth stage (90 days after planting) as proposed by IPGRI (1999).

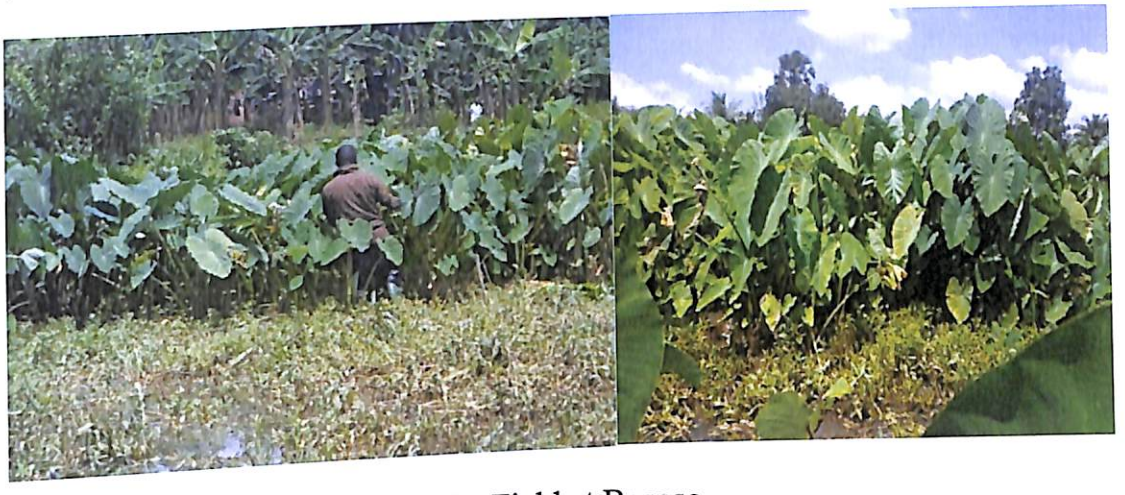


Figure 51: Taro Accessions on the Field at Bososo

Assessment of the Incidence of Corm Rot among the Taro Accessions

The percentage corm rot was determined by counting the number of harvested corms that were rotten and then expressed as a percentage of total number of harvested corms. Percentage incidence was calculated using the formular below:

$$\text{Disease incidence} = \frac{\text{Infected plants}}{\text{Total Number of plants}} \times 100$$

Figure 52.A- Researcher taking data on harvested taro plants, B Harvested accessions arranged on the field.

Determination of Corm Yield

Five plants of each accession were harvested and data on the weight, length and the diameter of the corm was measured and the mean values determined. Corm weight was determined using top pan balance (brand, country of origin), whereas corm diameter and length were measured using metre rule.

Isolation and Identification of Causal Organism of Corm Rot

The partially rotten corms were collected at harvest and the fungal organism responsible for the rot was isolated and identified at the laboratory. The isolation was conducted at the Plant Pathology Laboratory of the Department of Crop Science, University of Cape Coast, Ghana. Corms that were showing rot symptoms were selected and washed with tap water to get rid of all soil particles. The corms were then surface sterilized with 5% bleach for 5 min, washed three times with sterile distilled water, and air dried. Each treated corm was kept in a tight transparent polythene bag and incubated at 25 ^{O}C for three days to induce mycelial growth. The fungal pathogen was then sub cultured on PDA prepared as described in Chapter 4.

Statistical Analysis

The data for the mean lesion diameter were subjected to analysis of variance (ANOVA) using GenStat 12th edition. Treatment means were separated using Fisher's protected least significant difference and at statistical significance of 95% level. Percentage rot of the corm and frequency of distribution of the

morphological characteristics were calculated and presented in graph using Microsoft excel 2007.

Figure 53. A-C, Corms showing rot symptom, B-D, corm in a transparent polythene bag

Resistance Ranking

A modified relative resistance ranking based on lesion diameter by Brooks (2008) was used to group the accessions based on their resistance level. It estimates that if lesion sizes are

> 50 mm = Highly Susceptible,
41-50 mm=Susceptible,
31-40 mm=Moderately Susceptible,
21-30 mm=Tolerant, and
< 20 mm= Resistant.

RESULTS

Detached Leaf Assay for Determining Resistance of Taro to *Phytophthora colocasiae*

Figure 54 shows the pictorial evidence of symptom development on the leaf discs of some accessions on the third (A) and seventh day (B) after inoculation. Discs in each row are from the same accession. It can be observed that the lesion sizes differ on accessions as shown on the leaf discs.

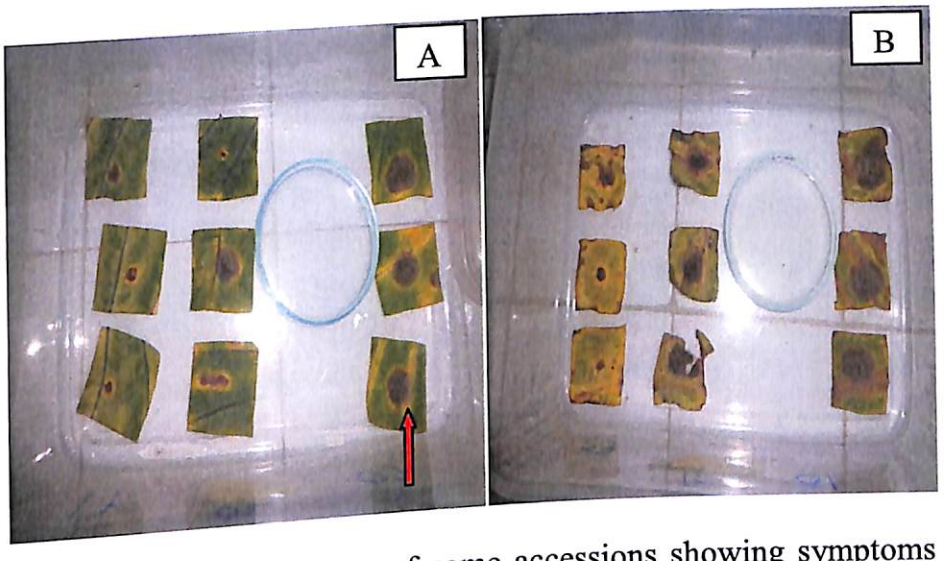


Figure 54. Leaf segments of some accessions showing symptoms (**arrowed**) of TLB disease, A- three days after inoculation, B- seven days after inoculation.

Table 5 presents the mean lesion diameter of some selected local accessions after the *in vitro* leaf disc experiment. It can be observed that the lowest lesion size (21.80 mm) was recorded on accession AS006. This was not significantly different from lesion sizes on AS0062 (23.55 mm), CSR1004 (26.75 mm) and WR0005 (28.35 mm). Accession CR0001 had the highest mean lesion size (43.25 mm) and was significantly different from the other accessions except accessions CR0091 (39.36 mm). Only 1 accession (CR0001) was identified to be susceptible, 8 (CR0091, CR0036, WR0096, ER0045, AS0009, CR0015, WR0025 and AS0020) were moderately susceptible and 6 were tolerant (AS0060, AS0062,

CSRI0004, WR0005, ER0063 and CSIR0003). Four of the tolerant accessions (AS0060, CSRI0004, WR0005, and ER0063) as indicated in Table 7 were selected to be added to the exotic varieties for field evaluation for resistance.

Table 5: Mean Lesion Diameter on Leaf Disc of Local Taro Accession established at Asuansi

Accessions	Mean Lesion Diameter (mm)	Resistance
CR0001	43.25	S
CR0091	39.35	MS
CR0036	35.45	MS
WR0096	35.15	MS
ER0045	34.00	MS
AS0009	32.50	MS
CR0015	31.95	MS
WR0025	31.55	MS
AS0020	30.90	MS
CSIR0003	29.25	T
ER0063*	28.70	T
WR0005 *	28.35	T
CSRI0004*	26.75	T
AS0062	23.55	T
AS0060*	21.80	T
L.S.D. = 6.59		
S.E.D= 3.35		

Values with different letters in a column are significantly different at $P < 0.05$ (Accessions marked * are the selected local accessions for field evaluation). S-Susceptible, MS-Moderately Susceptible, T-Tolerant and R-Resistant

Table 6 represents the results of the detached leaf disc assay performed on accessions that were established at Bososo. Accession GA/TLBD/0010 recorded the lowest mean lesion diameter of 12.15 mm but was not significantly different ($P>0.05$) from that of accessions GA/TLBD/0003 (12.85 mm), GA/TLBD/0002 (14.45 mm) and GA/TLBD/0011 (17.95 mm). The highest mean diameter was recorded for accession GA/TLBD/0009 (38.35 mm), but was also not significantly different from accessions GA/TLBD/0014 (35.35 mm), WR0005 (34.50 mm), GA/TLBD/0001 (33.55 mm), ER0063 (33.35 mm), CSRI00004 (33.05 mm), GA/TLBD/0021 (32.75 mm) and AS0060 (32.20 mm).

It could also be observed from the table that 9 accessions (GA/TLBD/0009, GA/TLBD/0014, WR0005, GA/TLBD/0001, ER0063, CSRI0004, GA/TLBD/0021, AS0060 and GA/TLBD/0016) of which 4 are local accessions were moderately susceptible, 5 accessions (GA/TLBD/0018, GA/TLBD/0020, GA/TLBD/0015, GA/TLBD/0012 and GA/TLBD0013) were tolerant whilst 7 were resistant (GA/TLBD/0006, GA/TLBD/0008, GA/TLBD/0007, GA/TLBD/0011, GA/TLBD/0002, GA/TLBD/0003 and GA/TLBD/0010).

The lesion progress curves on the leaf disc of the 21 accessions from three (3) days of inoculation to the seventh day are shown in Figure 55. It can be observed that lesion growth in the fourth day was less than 10 mm on the leaf disc of accessions GA/TLBD/0002, GA/TLBD/0003 and GA/TLBD/0010 and progressed steadily until the day 7 when the lesion growth on GA/TLBD/0010 was between 10 mm to 20 mm being the lowest. Accessions GA/TLBD/0002, GA/TLBD/0003, GA/TLBD/0007, GA/TLBD/0011 had lesion diameters of between 20 mm and 30 mm. Growth on accession GA/TLBD/0008,

GA/TLBD/0012, GA/TLBD/0013, GA/TLBD/0015 GA/TLBD/0018 and GA/TLBD/0020 progressed steadily from lesion diameter of between 10 mm to 20 mm on day four (4) to lesion diameters of between 30 mm and 40 mm in 7 days. The other accessions recorded a steady growth of between 20 to 30 mm from day 4 to 40 mm to 50 mm after 7 days.

Table 6: Mean Lesion Diameter on Leaf Disc of Accessions Established at Bososo

Accession	Mean Lesion Diameter (mm)	Level of Resistance
GA/TLBD/0009	38.35 a	MS
GA/TLBD/0014	35.35 ab	MS
WR0005*	34.50 ab	MS
GA/TLBD/0001	33.55 ab	MS
ER0063*	33.35 ab	MS
CSRI00004*	33.05 ab	MS
GA/TLBD/0021	32.75 ab	MS
AS0060*	32.20 ab	MS
GA/TLBD/0016	30.45 bc	MS
GA/TLBD/0018	25.35 cd	T
GA/TLBD/0020	24.10 de	T
GA/TLBD/0015	23.60 de	T
GA/TLBD/0012	23.35 de	T
GA/TLBD/0013	22.55 de	T
GA/TLBD/0006	20.75 def	R
GA/TLBD/0008	20.20 def	R
GA/TLBD/0007	18.55 efg	R
GA/TLBD/0011	17.95 efgh	R
GA/TLBD/0002	14.45 fgh	R
GA/TLBD/0003	12.85 gh	R
GA/TLBD/0010	12.15 h	R
LSD=6.318		
S.E.D.=3.214		

Values with different letters were significantly different at $P < 0.05$
Accessions marked * are local accessions

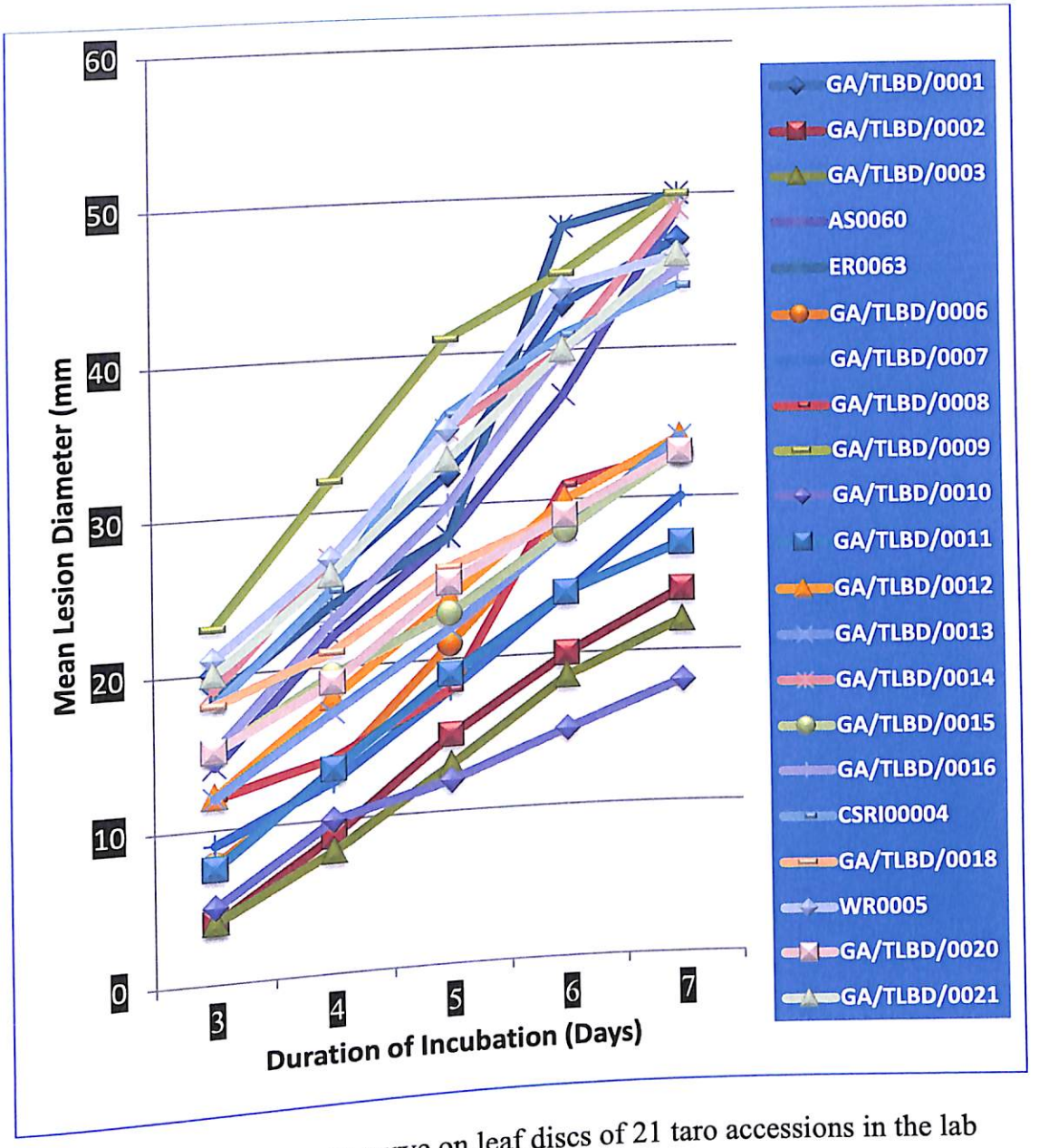


Figure 55. Lesion progress curve on leaf discs of 21 taro accessions in the lab

Table 7 represents the mean lesion diameter of the taro leaf blight disease on the leaves of 21 taro accessions established on the field. Accession GA/TLBD/0002 (1.740) had the lowest mean lesion diameter but was not significantly different (P>0.05) from accessions GA/TLBD/0007 (1.845), GA/TLBD/0010 (1.845), GA/TLBD/0012 (1.910), GA/TLBD/0003 (1.975), GA/TLBD/20 (2.100), GA/TLBD/0011 (2.170), GA/TLBD/0006 (2.185) and

GA/TLBD/0014 (2.310). The highest mean lesion diameter was recorded for accession ER0063 (4.680), but was not significantly different ($P<0.05$) from GA/TLBD/0021 (4.035). The mean lesion diameter of accession GA/TLBD/0021 was also not significantly different from accessions CSRI00004 (3.950) and GA/TLBD/0013 (3.890).

Table 7: Mean Lesion Diameter of the Accessions Established on the Field at Bososo

Accessions	Mean Lesion Diameter (cm)	Level of Resistance
ER0063*	46.80	S
GA/TLBD/0021	40.35	MS
CSRI00004*	39.50	MS
GA/TLBD/0013	38.90	MS
GA/TLBD/0016	33.70	MS
AS0060*	33.55	MS
GA/TLBD/0009	33.25	MS
GA/TLBD/0015	33.00	MS
GA/TLBD/0018	31.80	MS
GA/TLBD/0001	28.15	T
WR0005*	25.15	T
GA/TLBD/0008	24.50	T
GA/TLBD/0014	23.10	T
GA/TLBD/0006	21.85	T
GA/TLBD/0011	21.70	T
GA/TLBD/0020	21.00	T
GA/TLBD/0003	19.75	R
GA/TLBD/0012	19.10	R
GA/TLBD/0010	18.45	R
GA/TLBD/0007	18.45	R
GA/TLBD/0002	17.40	R
LSD=6.465		

'Values with different letters were significantly different at $P < 0.05$'
Accessions marked * are local accessions

The table (Table 7) also shows that 1 accession which is local (ER0063) was susceptible, 8 were moderately susceptible which included two local accessions (GA/TLBD/0021, CSRI0004, GA/TLBD/0013, GA/TLBD/0016, AS0060, GA/TLBD/0009, GA/TLBD/0015 and GA/TLBD/0018), 7 tolerant

including one local (GA/TLBD/0001, WR0005, GA/TLBD/0008, GA/TLBD/0014, GA/TLBD/0006, GA/TLBD/0011 and GA/TLBD/0020), and 5 resistant (GA/TLBD/0003, GA/TLBD/0012, GA/TLBD/0010, GA/TLBD/0007 and GA/TLBD/0002). Among the resistant varieties, none was a local accession.

Morphological Characteristics of Accessions

In Table 8 are represented the pictorial description of all the 21 accessions that were used for the final screening, including the 17 exotic varieties and 4 local accessions.

Table 8: Morphological variations among accessions

Accession	Petiole colour	Leaf texture	Surface	Leaf Underside appearance	TLBD Symptom Appearance
GA/TLBD /0001					
GA/TLBD /0002					
GA/TLBD /0003					

AS0060

ER0063

GA/TLBD

/0006

GA/TLBD

/0007

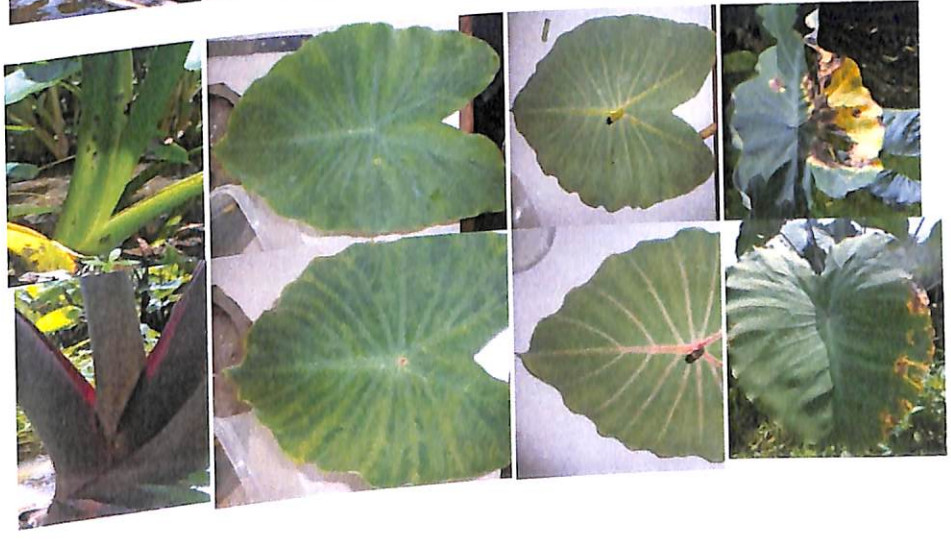
GA/TLBD

/0008

GA/TLBD
/0009

GA/TLBD

/0010



GA/TLBD /0011

GA/TLBD /0012

GA/TLBD /0013

GA/TLBD /0014

GA/TLBD /0015

GA/TLBD /0016

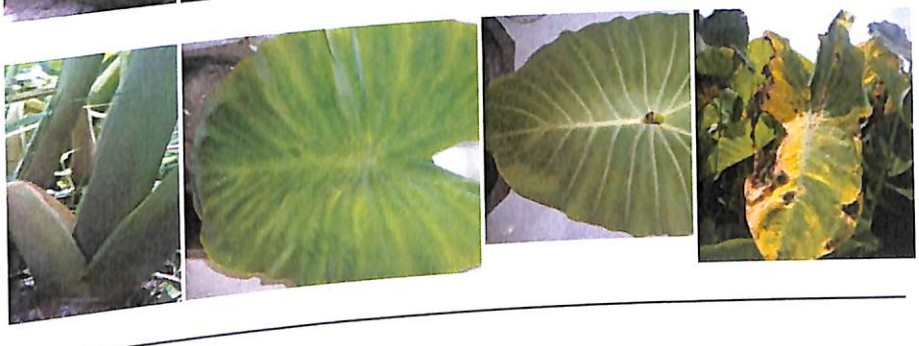
CSIR00004

GA/TLBD/0018

WR0005

GA/TLBD/0020

GA/TLBD/0021



Frequency of Distribution of Morphological characters among the Accessions

Figure 56 represents the frequency distribution of the leaf blade margin of all the accessions (21) that were screened in the experiment. It could be observed that

57.1% of the accessions had a leaf margin that was undulated whilst the rest (42.9%) had a margin that was entire.

58.4% of the accessions had a leaf blade margin colour of green, whilst the others were purple (38.1%) and brown (9.5%) (Figure 57).

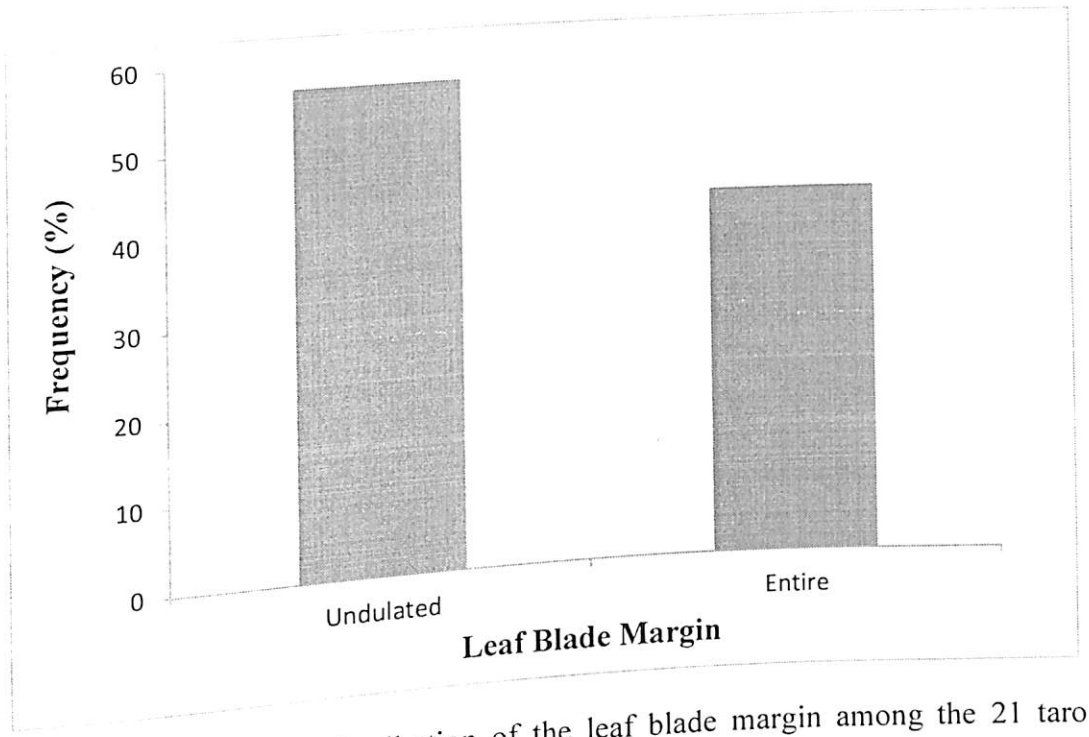


Figure 56. Frequency distribution of the leaf blade margin among the 21 taro accessions

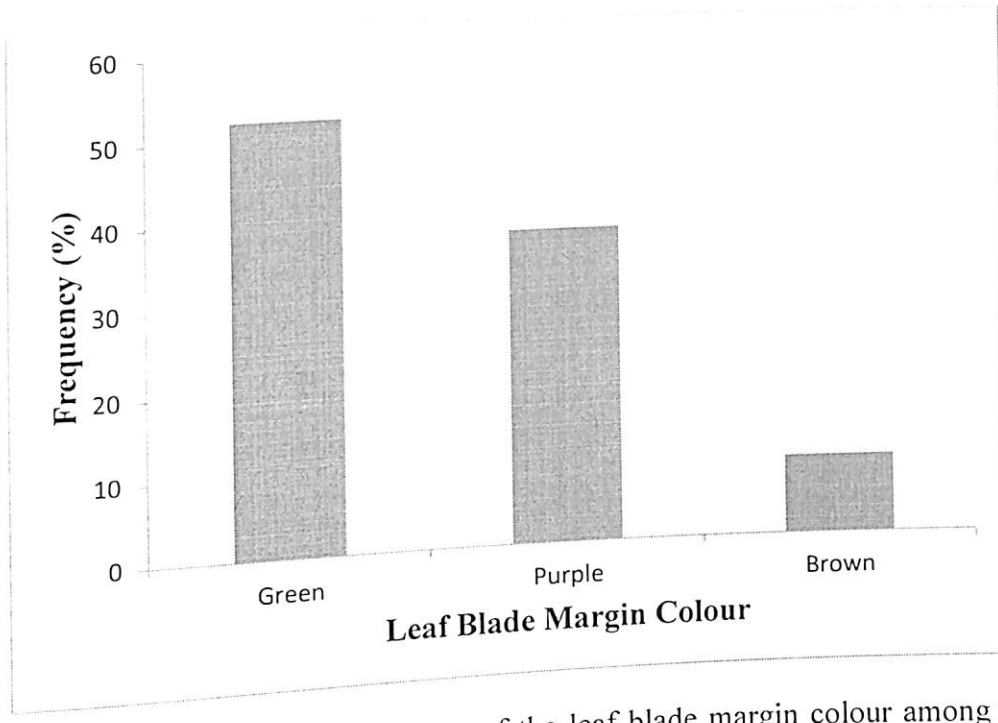


Figure 57: Frequency distribution of the leaf blade margin colour among the 21 taro accessions

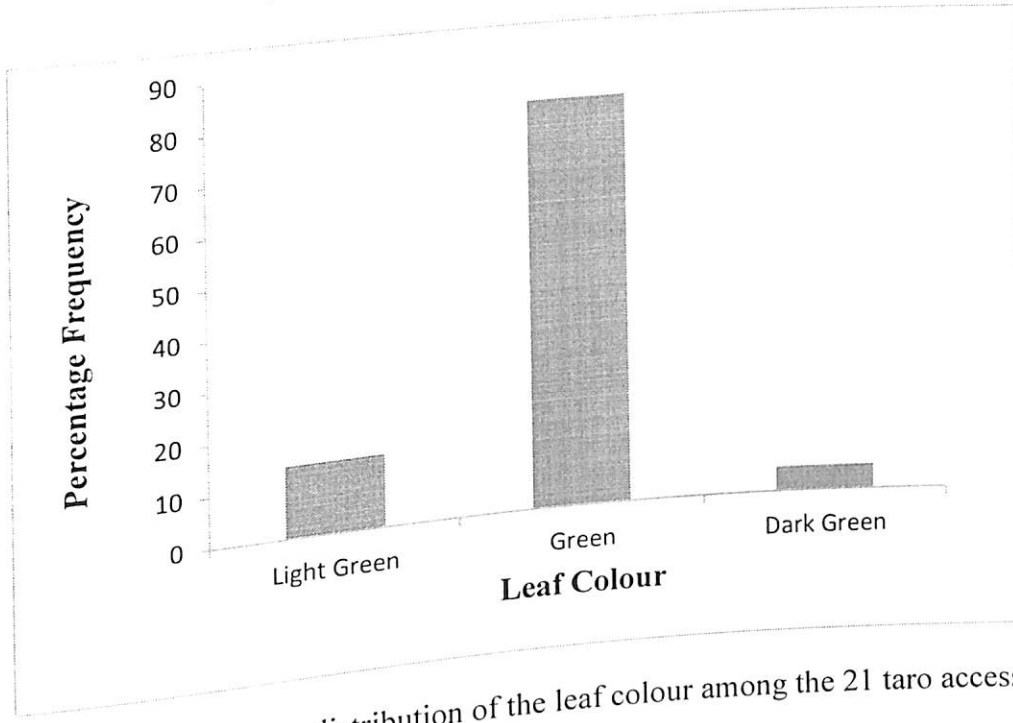


Figure 58: Frequency distribution of the leaf colour among the 21 taro accessions

Figure 58 represents the various colourations of the leaves of the accessions that were screened for the TLBD resistance. The majority (80.95%) of

the accessions had green leaf colour, 14.29% had a light green leaf colour, whilst 4.76% were dark green.

From Figure 59, 47.6% of the accessions had wrinkled leaf surface whilst 52.4% had a smooth leaf surface.

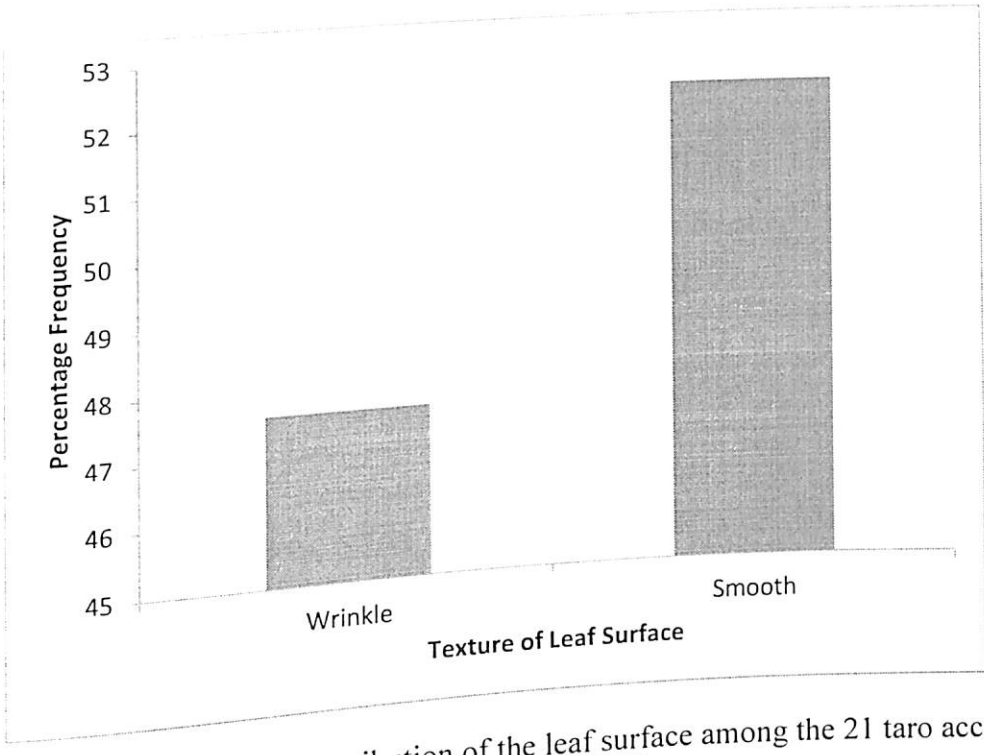


Figure 59: Frequency distribution of the leaf surface among the 21 taro accessions

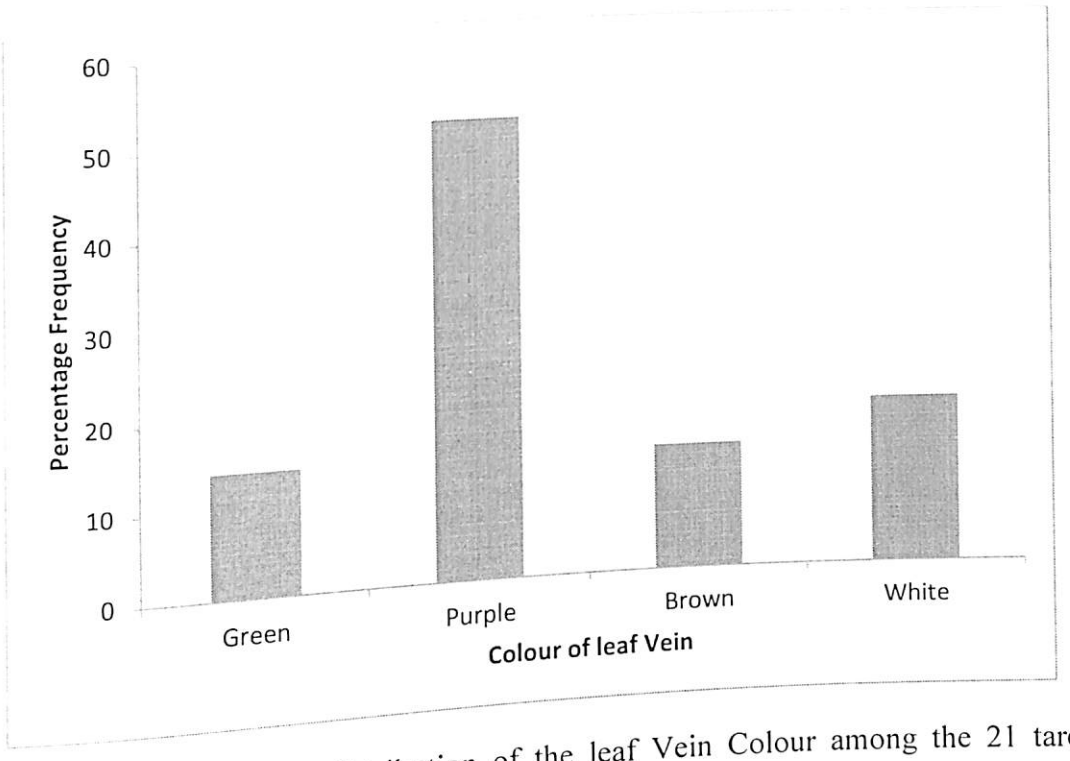


Figure 60: Frequency distribution of the leaf Vein Colour among the 21 taro accessions

From Figure 60, about 14.3% of the accessions had vein colour of green, 52.4% had purple vein colour, 14.3% brown vein colour with 19.1% having white vein colour.

From Figure 61, 4.8% of the accessions had striped (green and white) and purple petiole colour, 14.3% were yellow, 38.1% green, 14.3% dark green and 23.8% dark purple.

Majority (66.67%) of the taro accessions rarely produced flowers whilst 33.33 % flowered frequently (Figure 62).

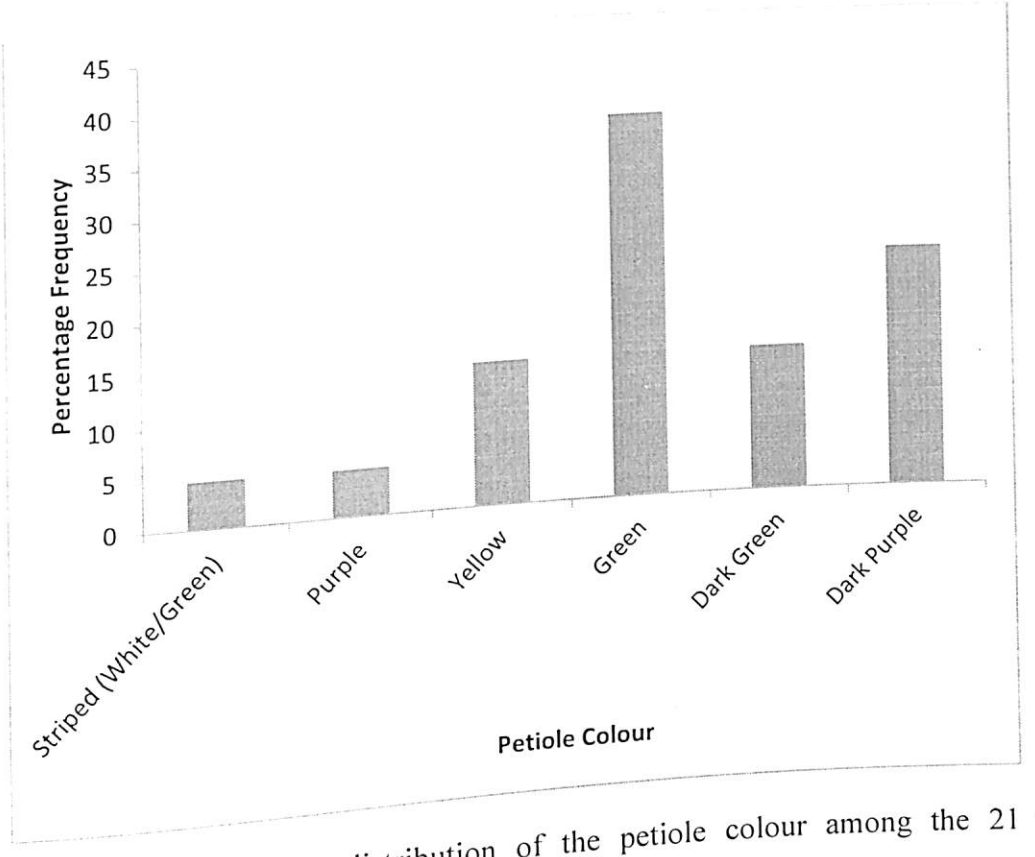


Figure 61: Frequency distribution of the petiole colour among the 21 taro accessions

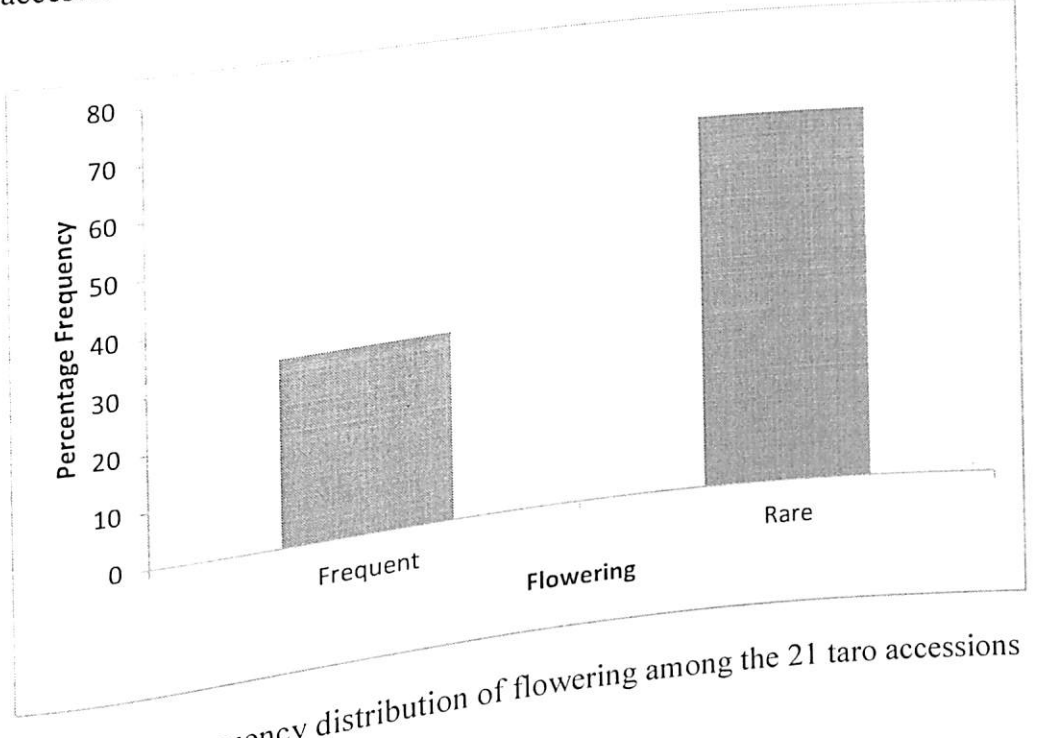


Figure 62: Frequency distribution of flowering among the 21 taro accessions

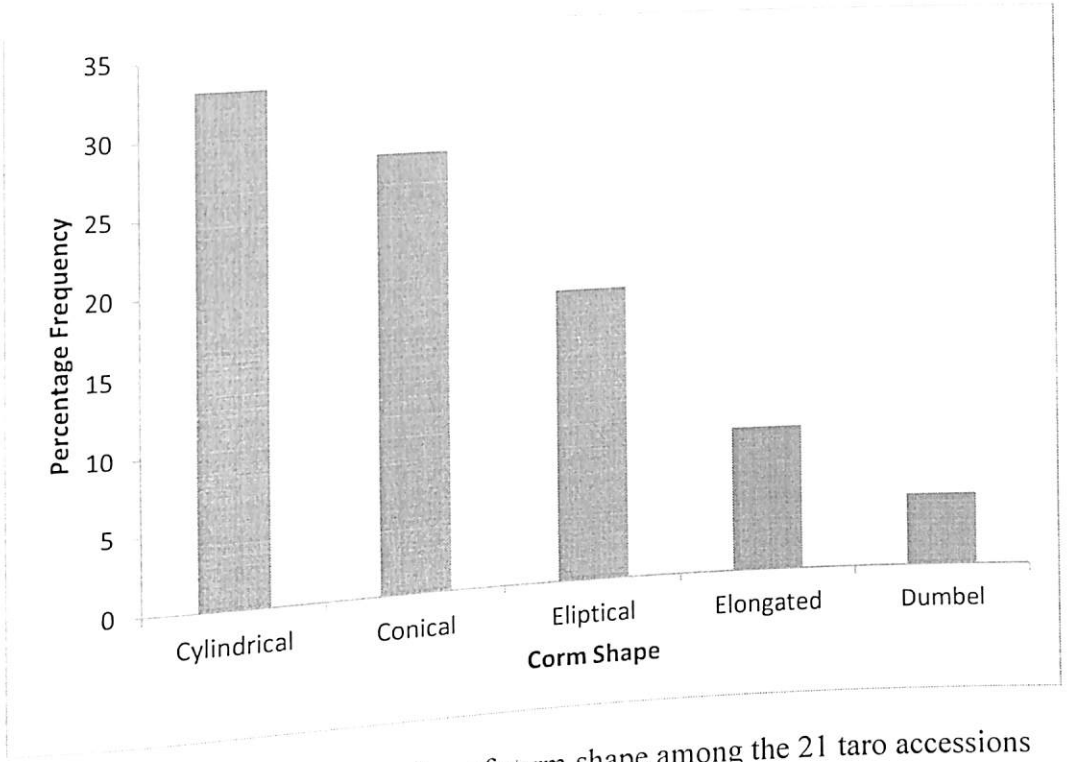


Figure 63: Frequency distribution of corm shape among the 21 taro accessions

Figure 63 represents the corm shape characteristics of the 21 accessions. Most accessions (33.1%) had cylindrical corm shape, 28.57% were conical, 19.05% elliptical, 9.52% elongated and 4.76% dumbel shaped.

In respect of the percentage corm skin colour (Figure 64), majority (66.67%) of the accessions had purple skin colour whilst the rest (33.33%) had brown skin colour.

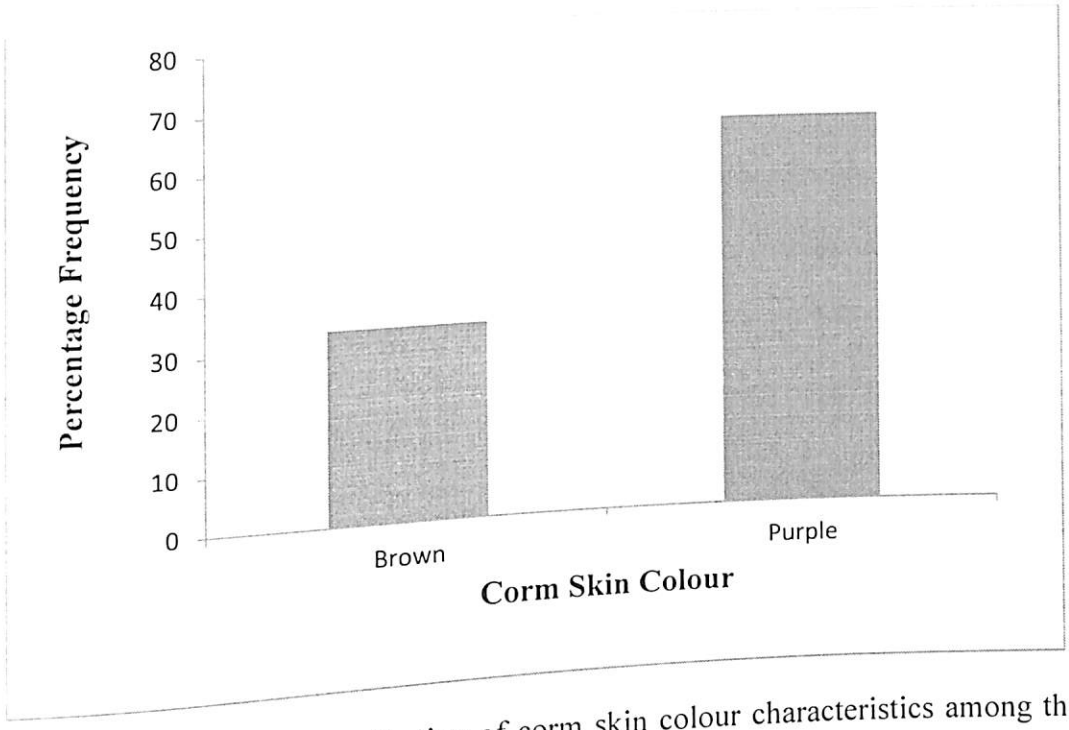


Figure 64: Frequency distribution of corm skin colour characteristics among the 21 taro accessions

From Figure 65, about 52.38% of the accessions had white flesh colour, 42.86% had purple flesh colour with 4.76% having a yellow flesh colour.

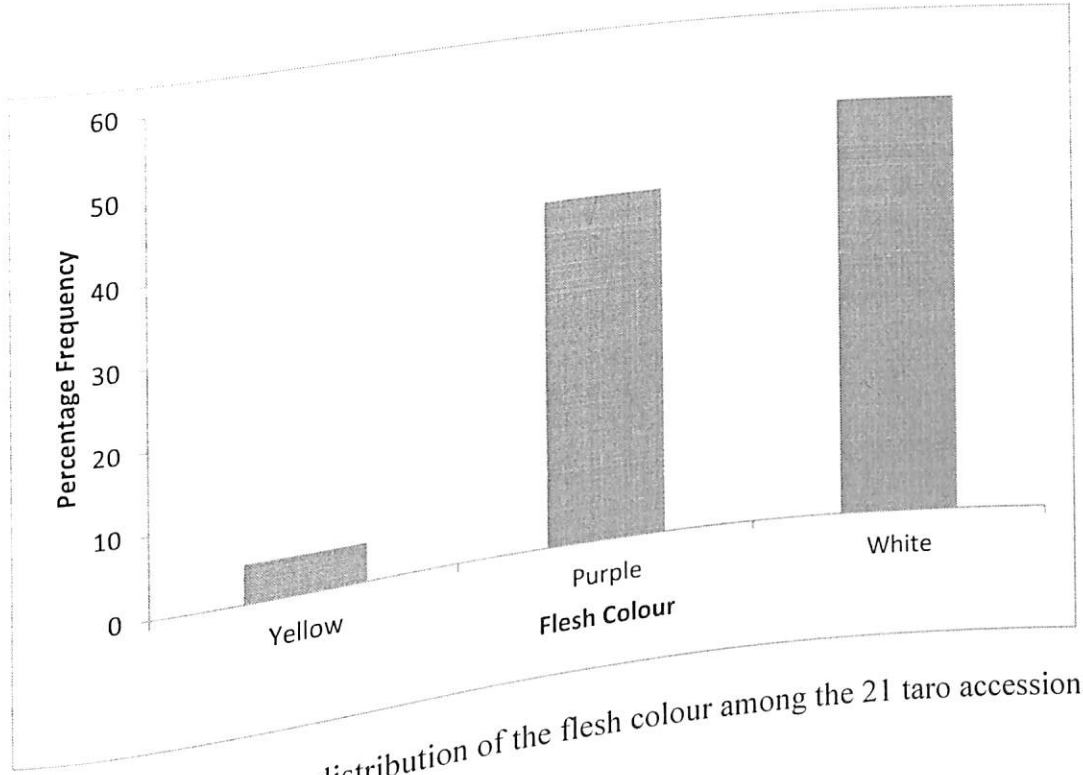


Figure 65: Frequency distribution of the flesh colour among the 21 taro accessions

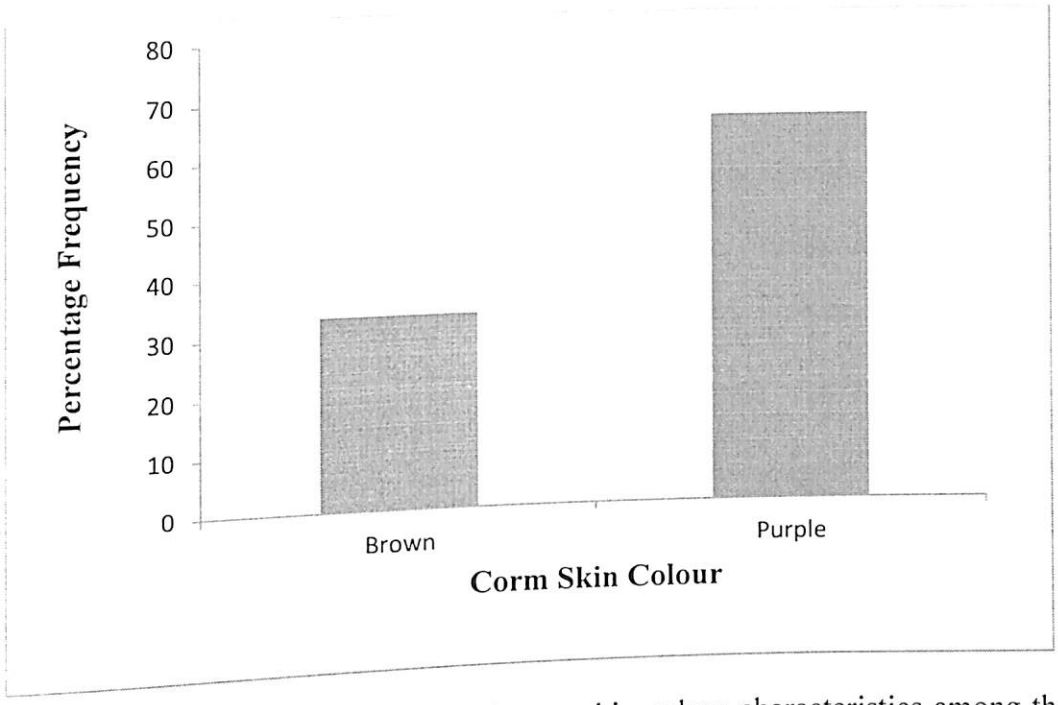


Figure 64: Frequency distribution of corm skin colour characteristics among the 21 taro accessions

From Figure 65, about 52.38% of the accessions had white flesh colour, 42.86% had purple flesh colour with 4.76% having a yellow flesh colour.

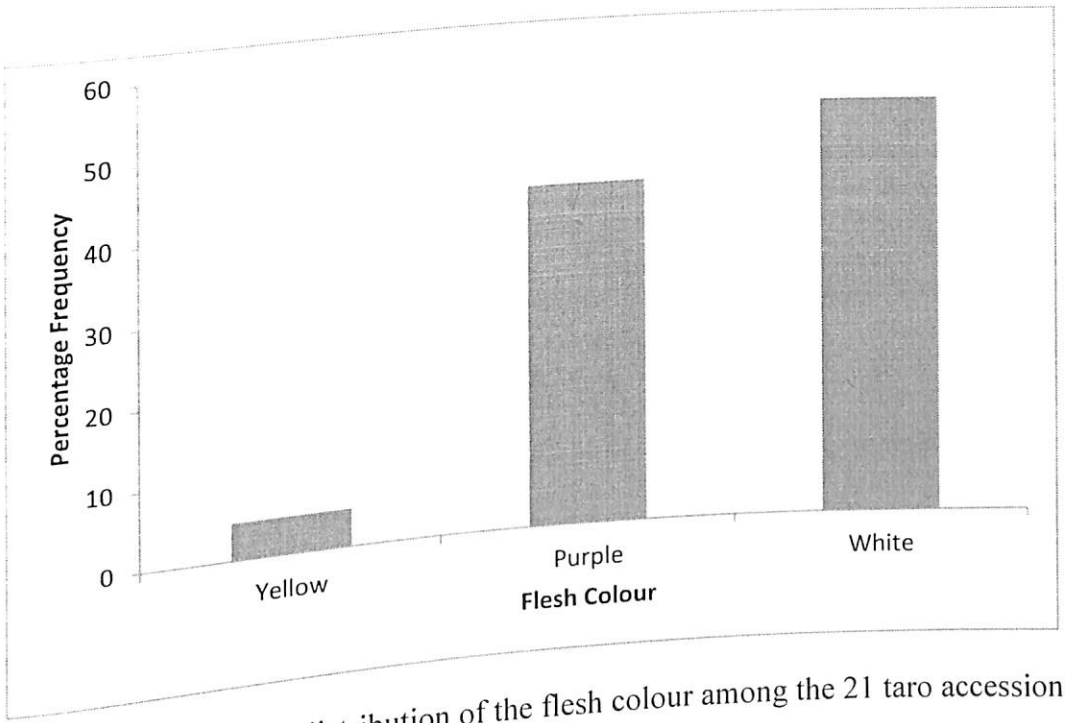


Figure 65: Frequency distribution of the flesh colour among the 21 taro accessions

Cluster and Principal Component Analysis of the 21 Accessions

Figure 66 shows the cluster analysis of the 21 accessions based on their morphological traits. Seven clusters could be observed. Accessions GA/TLBD/0014, CSRI00004, GA/TLBD/0018, AS0060 and ER0063 belonged to the same cluster (Cluster 1), accessions GA/TLBD/0007, GA/TLBD/0010 and GA/TLBD/0003 (cluster 2) are more closely related, GA/TLBD/0016 and GA/TLBD/0021 belonged to the same cluster (cluster 3), GA/TLBD/0015, GA/TLBD/0020 and GA/TLBD/0011 clustered together (cluster 4), GA/TLBD/0008, GA/TLBD/0013, GA/TLBD/0012 and GA/TLBD/0002 were also grouped together (cluster 5), with accession GA/TLBD/0009 and WR0005 also clustering together (cluster 6). Accession GA/TLBD/0001 and GA/TLBD/0006 are more distant accession from the others but which also clustered together (cluster 7).

Table 9 shows the principal component analysis of the 21 accessions using the morphological characteristics. The analysis grouped the characters into four latent factors which accounted for a total of 67.05 of variations observed with PC1, PC2, PC3 and PC4 accounting for 23.037%, 17.74%, 15.54% and 10.73% respectively. The highest contribution to PC1 was the petiole colour with a contribution of 0.725 followed by leaf blade margin (0.692) and leaf surface (0.690). Vein colour recorded the highest contribution to PC2 with an absolute value of 0.660 followed by corm skin colour (0.645). The major contributor to PC3 was flesh colour with an absolute value of 0.755 while corm shape also contributed highly to PC4 with a value of 0.809.

Dendrogram

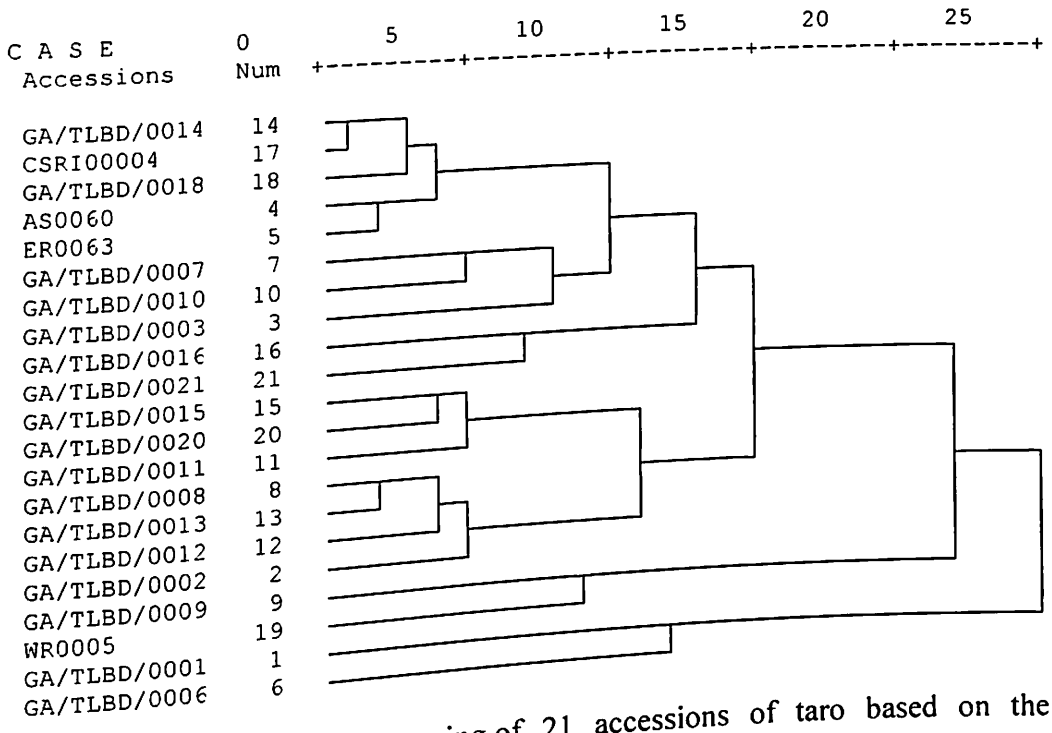


Figure 66: Hierarchical clustering of 21 accessions of taro based on their morphological characteristics

Table 9. Principal component analysis showing the contribution of the morphological characters to variations in the accessions

Variables	PC1	PC2	PC3	PC4
Petiole colour	.725		-.394	.325
Leaf blade margin	.692	-.306		
Leaf surface	.690		.459	
Leaf colour	.521	-.660	.355	
Vein colour	.397	.645		-.445
Corm skin colour	-.367	.531		
Flowering	.396		.755	
Flesh colour		.396	-.576	
Leaf blade margin colour		.438		.809
Corm shape				
Eigen values	2.304	1.774	1.554	1.073
Percentage variations	23.037	17.739	15.538	10.732
Cumulative% variations	23.037	40.776	56.314	67.046

Characterisation of the Accessions Based on Plant Height and Corm Weight

Figure 67 presents the plant height of the 21 taro accessions evaluated on the field at Bososo. Accession GA/TLBD/0010 had highest mean plant height of 1.944 m, though it was not significantly different (P>0.05) from accessions GA/TLBD/0007 (1.862 m), GA/TLBD/0008 (1.844 m), GA/TLBD/0018 (1.800 m), GA/TLBD/0013 (1.760 m), GA/TLBD/0002 (1.672 m), GA/TLBD/0003 (1.660 m), GA/TLBD/0016 (1.580 m), GA/TLBD/0020 (1.558 m), GA/TLBD/0012 (1.540 m) and GA/TLBD/0021 (1.520 m). Though accession AS0060 recorded the lowest mean height of 0.886 m, it was also not significantly different from accession CSRI00004, GA/TLBD/0015, WR0005 and ER0063 which had plant heights of 1.038 m, 1.204 m, 1.230 m and 1.260 m respectively. They were however significantly different from the others. It can also be observed that all the local accessions recorded low plant heights (red bars).

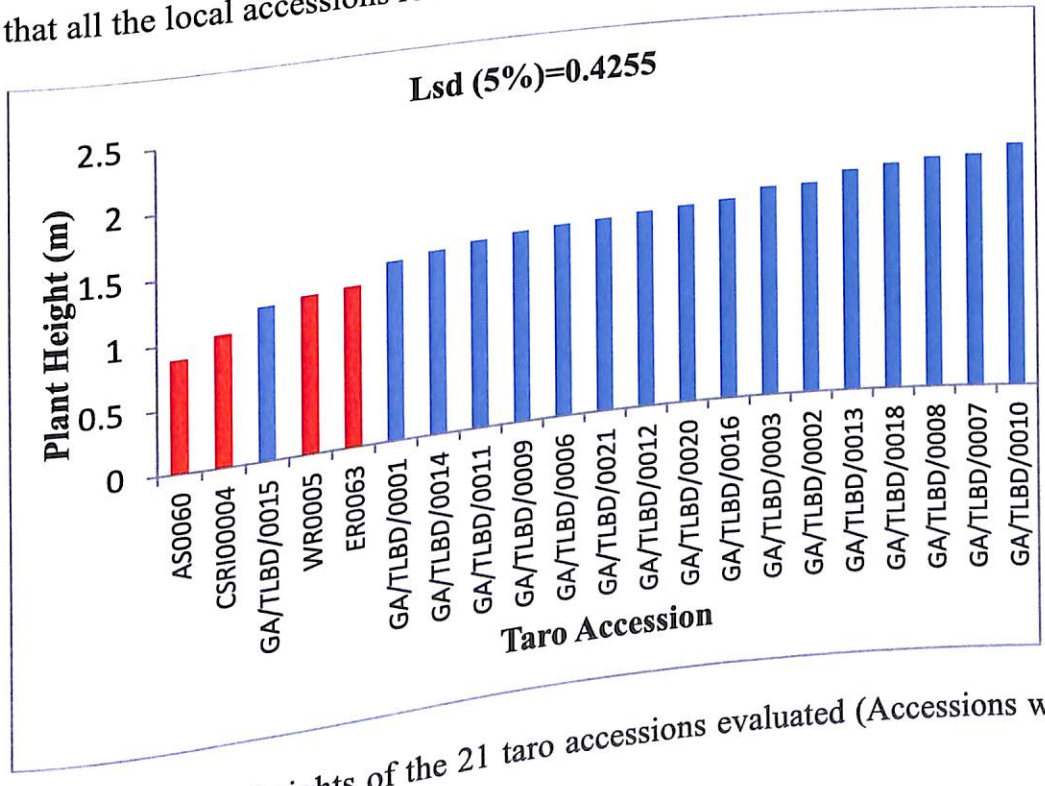


Figure 67. Plant heights of the 21 taro accessions evaluated (Accessions with red bars are local accessions).

From Figure 68, which presents the average corm weight of the 21 accessions, it is evident that accession GA/TLBD/0010 recorded the highest corm weight of 2.360 kg but was not significantly different from accessions GA/TLBD/0003, GA/TLBD/0015, GA/TLBD/0011, GA/TLBD/0018 and GA/TLBD/0014 which recorded corm weights of 2.00 kg, 1.82 kg, 1.75 kg, 1.72 kg and 1.68 kg respectively. These were significantly higher than weights recorded for the other accessions except accessions GA/TLBD/0009, GA/TLBD/0007, GA/TLBD/0002, GA/TLBD/0016 and GA/TLBD/0008. The lowest corm weight of 0.460 kg was recorded by accession WR0005, but was not significantly different from accessions GA/TLBD/0001 (0.581 kg), ER0063 (0.611 kg), GA/TLBD/0020 (0.640 kg), CSRI0004 (0.880 kg), AS0060 (0.920 kg), GA/TLBD/0021 (0.940 kg), GA/TLBD/0012 (0.950 kg), GA/TLBD/0013 (1.120 kg) and GA/TLBD/0006 (1.160 kg). Among the accessions that recorded low corm weights are all the local ones.

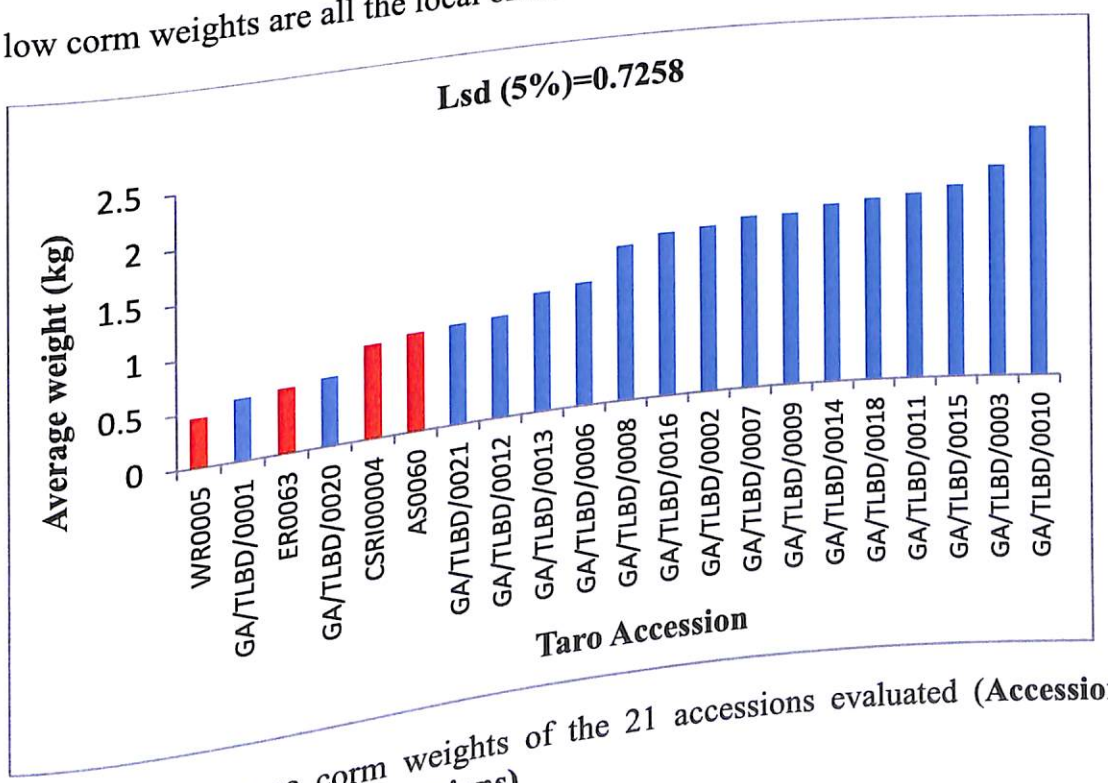


Figure 68. Average corm weights of the 21 accessions evaluated (**Accessions with red bars are local accessions)**

Assessment of the Incidence of Corm Rot among the Accessions

In Figure 69 is shown a taro corm with mycelium and sclerotia after seven days of incubation under room temperature (25^{O}C). The corm was covered with white mycelia (black arrow) and had white to dark brown sclerotia (red arrow) formed around it. The sclerotia measured between 1 to 3 mm being round to spherical in shape.

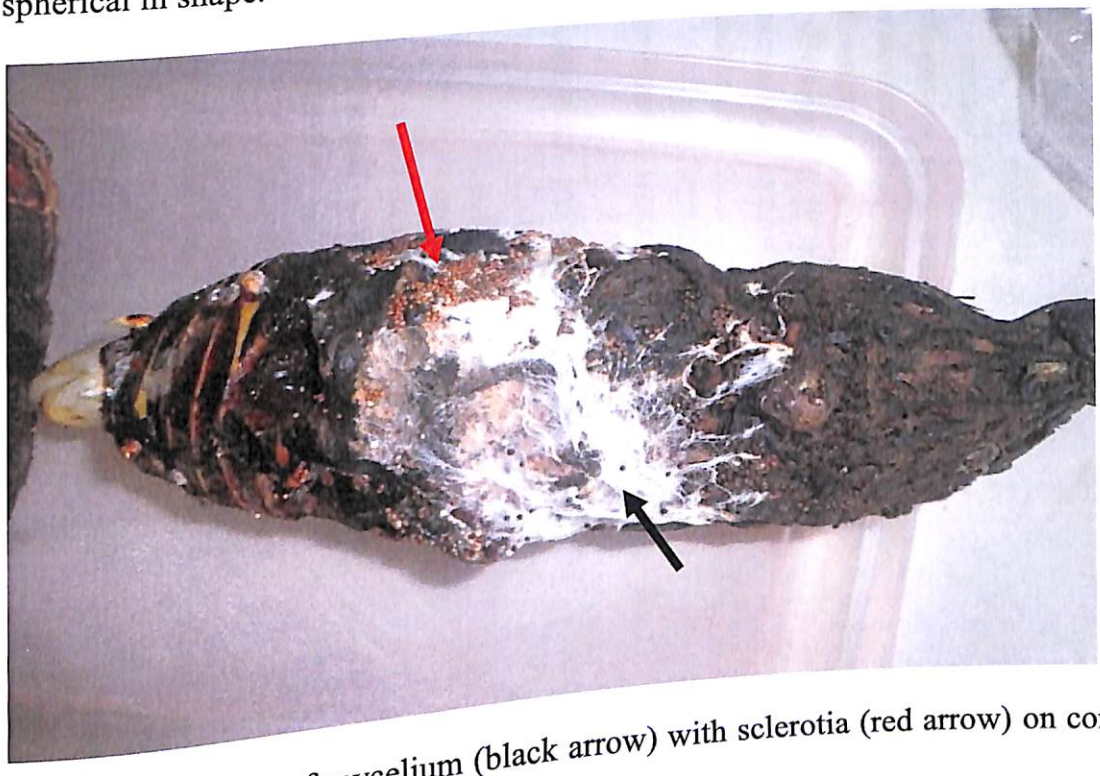


Figure 69: Growth of mycelium (black arrow) with sclerotia (red arrow) on corm of taro

Figure 70 presents the 21 accessions and the percentage incidences of corm rot disease. It can be observed that only nine (9) out of the 21 accessions did not record any corm rot, all the other 11 accessions recorded corm rots ranging from 20% to 80%. Accessions GA/TLBD/0021 and GA/TLBD/0003 had the highest rot incidence of 80% followed by accessions GA/TLBD/0010 and GA/TLBD/0014 with 60%. Amongst those that showed no incidence of rot, three were local accessions (WR0005, ER0063 and CSRI0004). Out of the 17 exotic

genotypes, only 5 (GA/TLBD/0016, GA/TLBD/0018, GA/TLBD/0009, GA/TLBD/0020 and GA/TLBD/0006) recorded no incidence of rot.

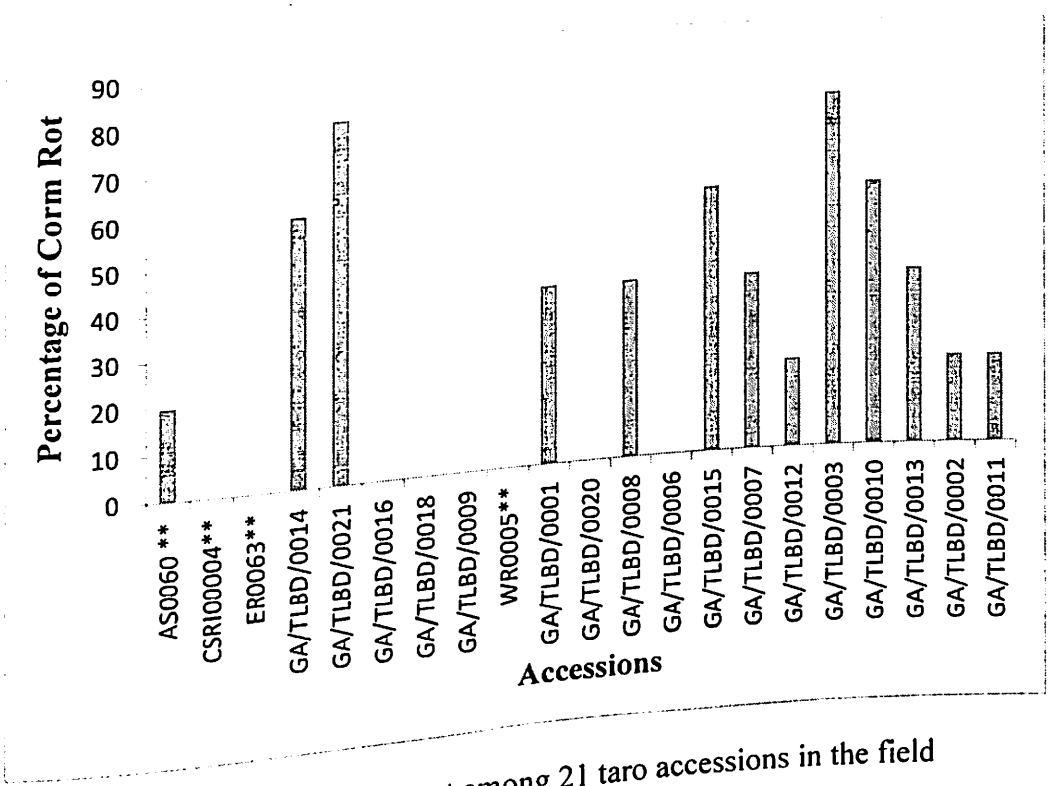


Figure 70. Incidences of corm rot among 21 taro accessions in the field

DISCUSSIONS

Difficulty in controlling TLBD using chemical and cultural methods generated interest in finding varieties resistant to the disease. The use of resistant varieties has been identified to be the best option to manage the taro leaf blight disease (Shakywar *et al.*, 2012; Ackah *et al.*, 2014).

The results of the leaf disc assay and the field evaluation demonstrates differences in response of the various accessions to the TLBD. All the accessions reacted differently to the disease through the development of lesion on the leaves.

The evaluation of the 21 taro accessions revealed the level of resistance of the accessions in both the laboratory and on the field. All the local varieties that were evaluated in the laboratory using the leaf disc assay were identified to be moderately susceptible to the disease. When the same accessions were evaluated on the field, accession WR0005 which was identified to be moderately susceptible in the laboratory was identified to be tolerant on the field and also accession ER0063 which was identified to be moderately susceptible in the laboratory was susceptible on the field. Again, all the accessions that were identified to be resistant on the field (GA/TLBD/0003, GA/TLBD/0012, GA/TLBD/0010, GA/TLBD/0007 and GA/TLBD/0002) and in the laboratory (GA/TLBD/0006, GA/TLBD/0008, GA/TLBD/0007, GA/TLBD/0011, GA/TLBD/0002, GA/TLBD/0003 and GA/TLBD/0010) were all improved exotic accessions. Among these accessions, four GA/TLBD/0003, GA/TLBD/0010, GA/TLBD/0007 and GA/TLBD/0002) were identified to be both resistant in the lab and on the field. None of the local accessions evaluated were resistant to the disease. This result indicates that though some local accessions can be identified to be tolerant to the disease, their level of tolerance may depend on the prevailing environmental conditions and also on the pathogen strains since different strains have been identified in different locations in Ghana (Adomako et al., 2016). Accessions that will be identified to be resistant or tolerant at a particular location may not exhibit the same characteristics in a different location. This supports the findings of Ackah et al. (2014) who after evaluating genotypes that were collected from two regions (Western and Ashanti) in Ghana revealed that some cultivars with meaningful resistance can be found in local germplasm in Ghana though

none of the germplasm evaluated in the study was completely resistant to the disease and that there may be no accession of taro in Ghana that may be completely resistant to the taro leaf blight disease. Sugha and Gurung (2007) made similar studies and reported that none of the genotypes evaluated in India were free from the taro leaf blight disease and based on that and other similar reports, a breeding programme was started which has now improved their local accessions. Such breeding programmes to incorporate the resistant gene from the exotic into the local accessions could be initiated to enhance resistance in the local accessions.

The results of the morphological characterisation of the 21 accessions revealed that the accessions were genetically diverse. Majority of the accessions had green leaf colour with smooth surface and undulated blade margin with green colouration. Again, majority were observed to have purple vein colouration with green petiole which rarely flowers. The corm shapes of the majority of the accessions were also cylindrical with a purple skin colour and a white flesh.

The principal component analysis revealed that petiole colour, leaf blade margin and leaf surface, vein colour, corm skin colour, flesh colour and corm shape were the major components that contributed to the clustering of the accessions.

It was observed that the local accessions when compared with the exotic genotypes were short since local accessions recorded the lowest in heights and the exotic genotypes recorded the highest in heights. Corm weight was also high among the exotic genotypes compared to the local accessions. This is because the exotic genotypes are genotypes obtained as a result of comprehensive breeding

programmes in the countries where they were imported from, but in Ghana, taro has received no such breeding programmes to improve on the local accessions and that is why the yield and height of the exotic ones are better than the local ones.

The presence of white mycelia with sclerotia on the harvested and incubated corm confirms that the rot is caused by *Sclerotium rofsii*. This corroborates the report of Kwon et al. (2013) who identified *Sclerotium rolfsii* as one of the major causes of white rot on taro in Korea. The results also revealed that all the accessions that were identified to be resistant to TLBD were also highly susceptible to the corm rot disease, but out of the four local accessions evaluated, only one was susceptible to the sclerotium rot. This shows that, though the local varieties are susceptible to the leaf blight disease, some are tolerant to sclerotium rot.

The confirmation of the level of resistance of some of the improved exotic accessions to the leaf blight disease and the local accessions to the sclerotium rot disease, suggests that a comprehensive breeding programme needs to be adopted in Ghana to improve our local accessions. Crossing these resistant exotic varieties with our local accessions will ensure the survival of our local varieties since over time they will all become highly susceptible to the leaf blight disease. The breeding programmes for TLBD resistance needs to include resistance to Sclerotium rot.

This research has revealed that resistant taro accessions exist which can be introduced to farmers for production to improve food security and their livelihood.

CHAPTER SIX

IN VITRO EVALUATION OF THE EFFECTIVENESS OF SOME FUNGICIDES AGAINST *Phytophthora colocasiae*

INTRODUCTION

Although non-chemical means of managing pests and diseases are widely recommended for health and other reasons, the use of some amount of chemicals in the form of fertilizers, insecticides and fungicides is unavoidable in the effective management of diseases on farms (Moy and Wessel, 2000). Controlling taro leaf blight with fungicides is technically feasible and successful control can be achieved if time of application and dosage of fungicides, frequency and target of application, are crucially considered. Metalaxyl, copper and mancozeb-based fungicides have proved effective in controlling the disease elsewhere (Jackson, 1999; Shakywar et al., 2012).

It is therefore important to screen some fungicides on the market for their effectiveness in managing the disease in Ghana. This research therefore evaluated the efficacy of some fungicides in controlling growth of *P. colocasiae* in vitro.

MATERIALS AND METHODS

Study Location

The experiment was conducted at the Plant Pathology Laboratory of the School of Agriculture, University of Cape Coast.

Isolation and culture of the Pathogen (*P. colocasiae*)

The *P. colocasiae* pathogen used for this experiment was the isolate obtained from Fanteakwa district as described in chapter 4.

Evaluation of selected fungicides against *P. colocasiae*

A modified bioassay technique (Sharvelle, 1961) was employed to evaluate the effects of six fungicides on mycelial growth of *P. colocasiae in-vitro*. The selected fungicides were Carbendazim (carbendazim 500 g kg^{-1}), Mancozeb (mancozeb 80%), Chemoliette (800 g kg^{-1} forsetyl-aluminium), Agro Comet (120g kg^{-1} metalaxyl + 600 g kg^{-1} copper (1) oxide) and TOPS-M (Thiophanate Methyl).

Preparation of Fungicides

Recommended weights of individual fungicides were converted to parts per million (ppm). Working concentrations of 100 ppm, 200 ppm, 300 ppm, 400 ppm and 500 ppm were then calculated and then used for the experiment.

Fungal Inoculation of PDA-amended fungicide

Each mass of the fungicide concentrations prepared was mixed with 15 ml of PDA. The mixture was poured into sterilized Petri dishes and allowed to solidify. An 0.8 cm -diameter cork borer was used in taking mycelia from the edge of a 10- day old actively growing culture of *P. colocasiae* to inoculate the modified PDA and the culture kept in an incubator at 28 °C ± 1 or 2 °C. *Phytophthora colocasiae* grown on PDA without any fungicides served as the control.

Effects of fungicides treatments on radial growth of pathogen

The radial growth of colony was recorded in each experimental plate. Colony diameters were measured in two directions (randomly and at right angles) and adjusted for the diameter of the plug. Measurements were taken each day for 7 days. Percent inhibition was determined using 'Vincent's formula' by Jamadar and Lingaraju (2011) shown below:

$$I = \frac{C - T}{C} \times 100\%$$

Where: I = Percentage inhibition

C = Radial growth in control plate

T = Radial growth in fungicide plates

Radial growth was measured to assess the toxicity of each fungicide concentration. Each set of treatments was replicated three times. The treatments were set up in a completely randomized design (CRD).

Data analysis

Mycelial growth progress curves for *P. colocasiae* response were constructed for each fungicide applied. Mean radial growth and percentage inhibition were subjected to analysis of variance (ANOVA) using GenStat 12th edition. Means were separated using Fisher's protected least significance difference method (LSD) at a probability level of 5%.

RESULTS

Growth Response of *P. colocasiae* on Fungicide -Amended PDA

From Figure 71 which presents the growth response at 100 ppm, growth generally increased from day one to day 5 on all plates although that on carbendazim was significantly lower and slow than the others. However, for the others by day 3 growths seized after completely filling the plate, whereas it continued on carbendazim.

Figure 72 shows the growth curve at 200 ppm. From the figure, growth on Carbendazim was significantly lower and slower than the others and continued to increase from day 1 to 5 whereas growth however was faster and mycelia completely filled the plate on Mancozeb, Chemolliete, Tops-M and the control on day 3 and also on Agro Comet on day 4.

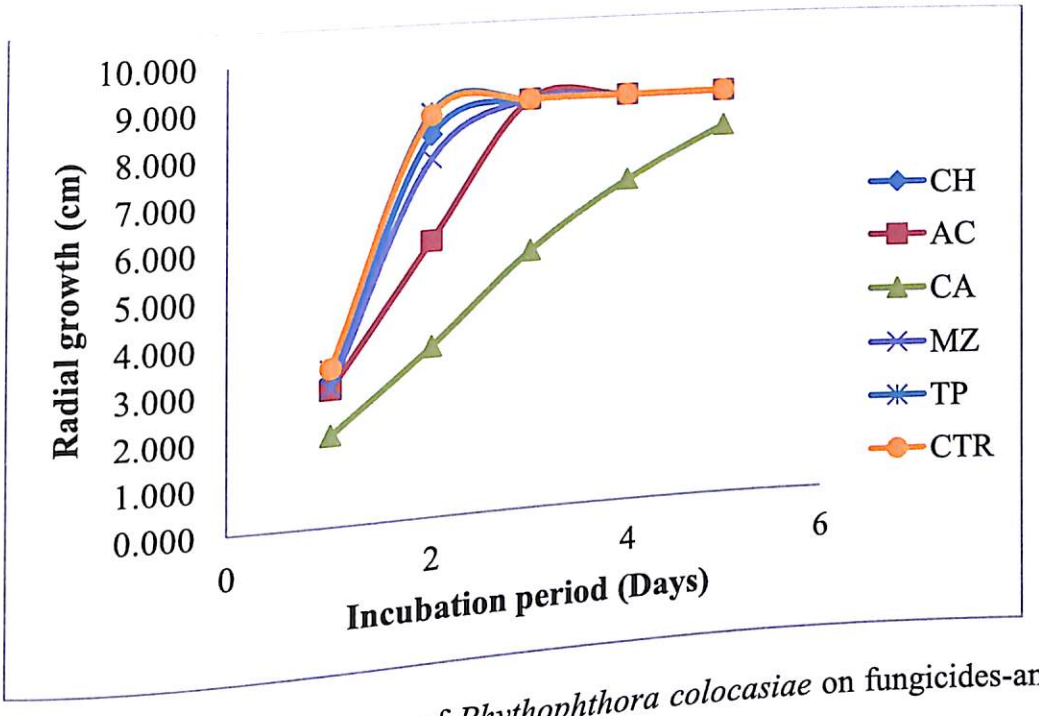


Figure 71. Growth response of *Phythophthora colocasiae* on fungicides-amended potato dextrose agar at100 ppm
(CH represents Chemolliette, AC - Agro Comet, CA - Carbenazim, MZ - Mancozeb, TP- Tops-M and CTR- Control)

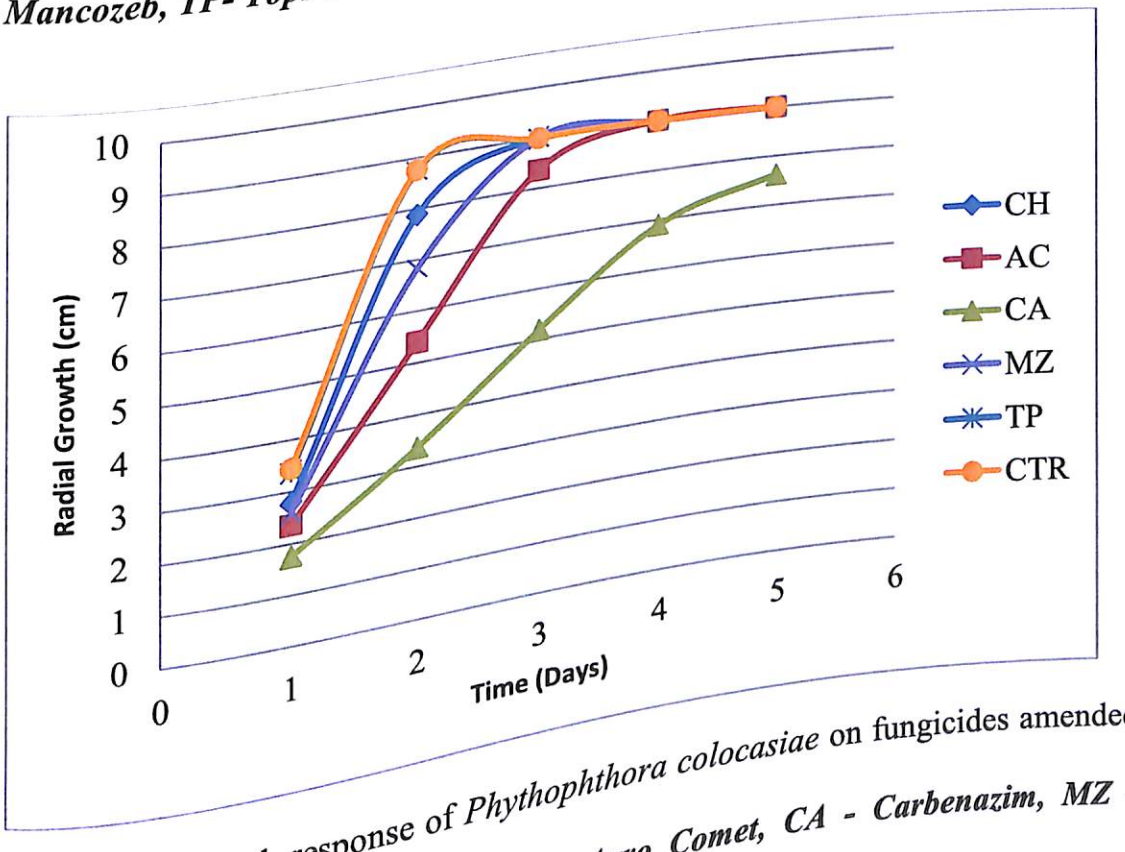


Figure 72. Growth response of *Phythophthora colocasiae* on fungicides amended PDA at 200 ppm.
(CH represents Chemolliette , AC - Agro Comet, CA - Carbenazim, MZ - Mancozeb,TP -Tops-M and CTR- Control)

Figure 73 reveals a clear shift of Carbendazim and Agro Comet from the other fungicides and the control. Radial growth on both fungicides was linear and increased slowly from day 1 to 5. Radial growth on the other fungicides (Carbendazim, Mancozeb Chemolliete, Tops-M and the Control) were fast and completely filled the plate by day 3.

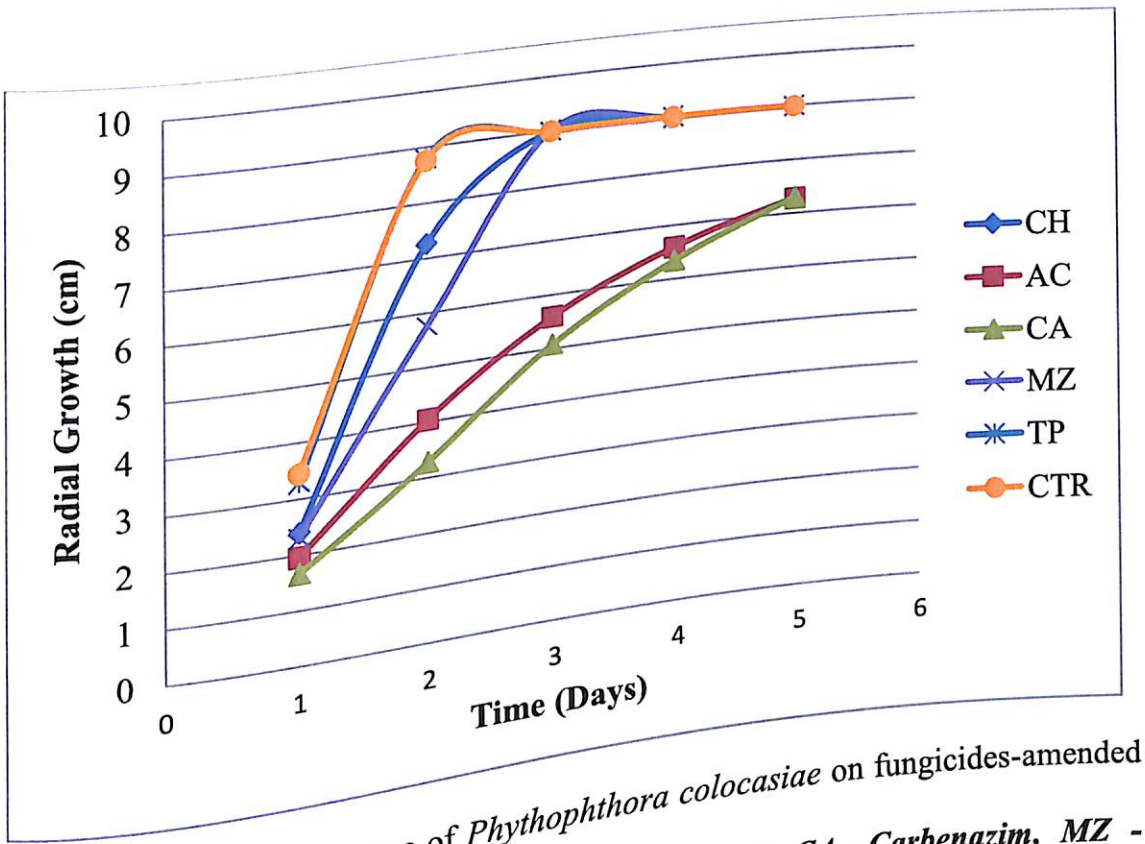


Figure 73. Growth response of *Phythophthora colocasiae* on fungicides-amended PDA at 300 ppm.
(CH represents Chemolliette , AC -Agro Comet, CA -Carbenazim, MZ -Mancozeb, -Tops-M and CTR- Control)

From Figure 74, Carbendazim and Agro Comet at 400 ppm showed a clear shift from the other fungicides and the control. The growth on Carbendazim and Agro Comet was continuous and increased slowly from day 1 to 5. Growth however was fast on Mancozeb Chemolliete, Tops-M and the Control and by day 3 the plates were completely filled.

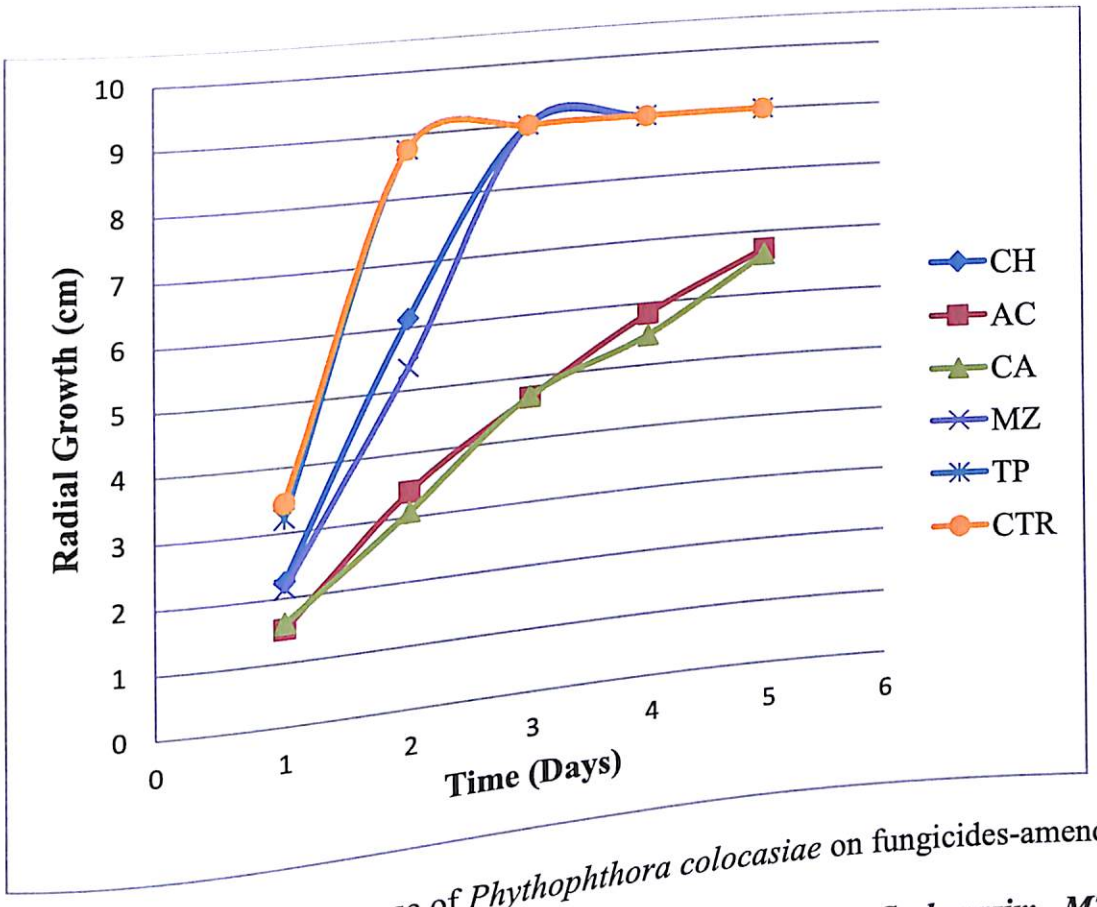


Figure 74. Growth response of *Phythophthora colocasiae* on fungicides-amended PDA at 400 ppm.
(CH represents Chemolliette , AC - Agro Comet, CA - Carbenazim, MZ - Mancozeb, TP-Tops-M and CTR- Control)

Figure 75, shows clear differences between all the fungicides. Agro Comet and Carbendazim recorded slow growth from day 1 to 5, though Agro Comet recorded the least in growth and clearly shifted from all the other fungicides. Radial growth on Chemolliete, Mancozeb, Tops-M and the control were very fast and completely covered the plate by day 3.

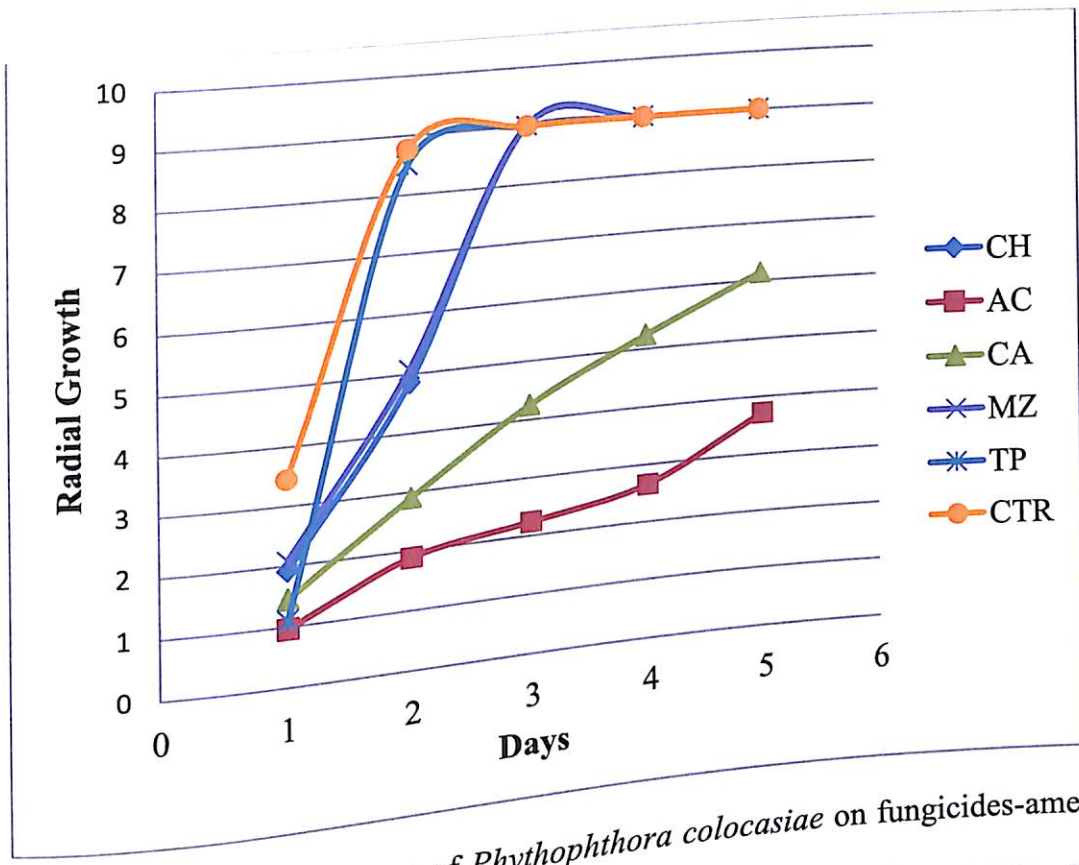


Figure 75. Growth response of *Phythophthora colocasiae* on fungicides-amended PDA at 500 ppm.
(CH represents Chemolliette , AC - Agro Comet, CA - Carbenazim, MZ - Mancozeb, TP-Tops-M and CTR- Control)

Effects of Different Rates of Fungicides on Radial Growth of *P. Colocasiae*

From Table 10, at 100 ppm and 200 ppm, there was a clear difference (P=0.005) between Carbendazim, which recorded mean radial growth of 5.343 cm, and all the other fungicides and the control. At 300, 400 and 500 ppm, there were no significance differences in radial growth on Carbendazim and Agro Comet, but growth was significantly lower than on other fungicides and the control. Radial growth on the control was highest than on all the rates of fungicides used.

Table 10. Radial Mycelial growth (cm) of *P.colocasia* on different Concentrations of fungicides

Fungicides	Mean Radial Growth (cm)				
	100 ppm	200 ppm	300 ppm	400 ppm	500 ppm
Control	7.843	7.843	7.843	7.843	7.843
TOPS-M	7.847	7.827	7.820	7.797	7.320
Mancozeb	7.690	7.287	7.570	7.077	6.833
Chemoliette	7.570	7.187	7.333	6.903	6.753
Agro Comet	7.117	6.827	5.100	4.433	3.993
Carbendazim	5.343	4.963	4.737	4.303	2.290
LSD	1.735	1.758	1.678	1.723	1.806

Figure 76, presents the mean radial growth of *P. colocasiae* mycelia on PDA amended across concentrations of selected fungicides. The least mean radial growth of 4.67 cm was recorded for Carbendazim at the end of the study, but was not significantly different ($P<0.05$) from that recorded for Agro Comet (5.15 cm). Growth was significantly higher on the other fungicides, with TOPS-M and the Control having the highest, 7.8 and 7.3 respectively.

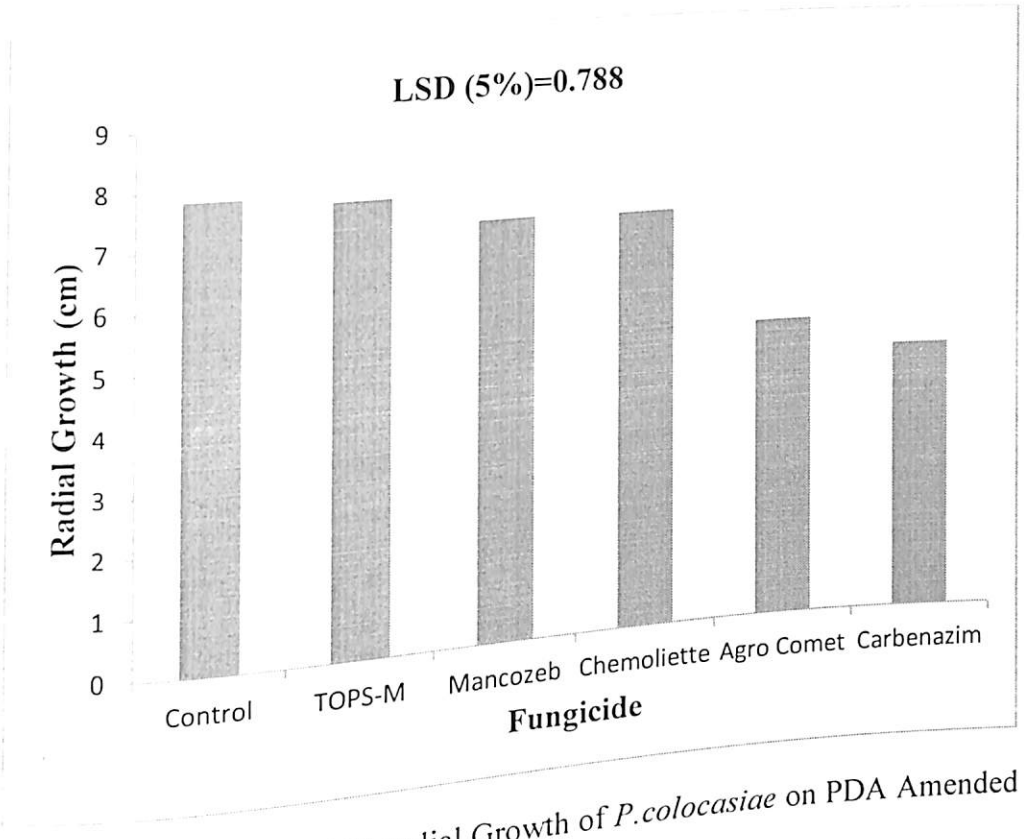


Figure 76. Mean Radial Mycelial Growth of *P.colocasiae* on PDA Amended with Different Fungicides

Percentage Inhibitions of Different Fungicides on the Growth of *P. Colocasiae.*

From Figure 77, Carbendazim had the highest percentage inhibition of 63.59% followed by Agro Comet (53.88%), Mancozeb (31.40%), Chemoliette (23.47%), and TOPS-M (3.03%). The percentage inhibitions of all these fungicides were significantly different ($P < 0.05$) from each other with TOPS-M being the least effective.

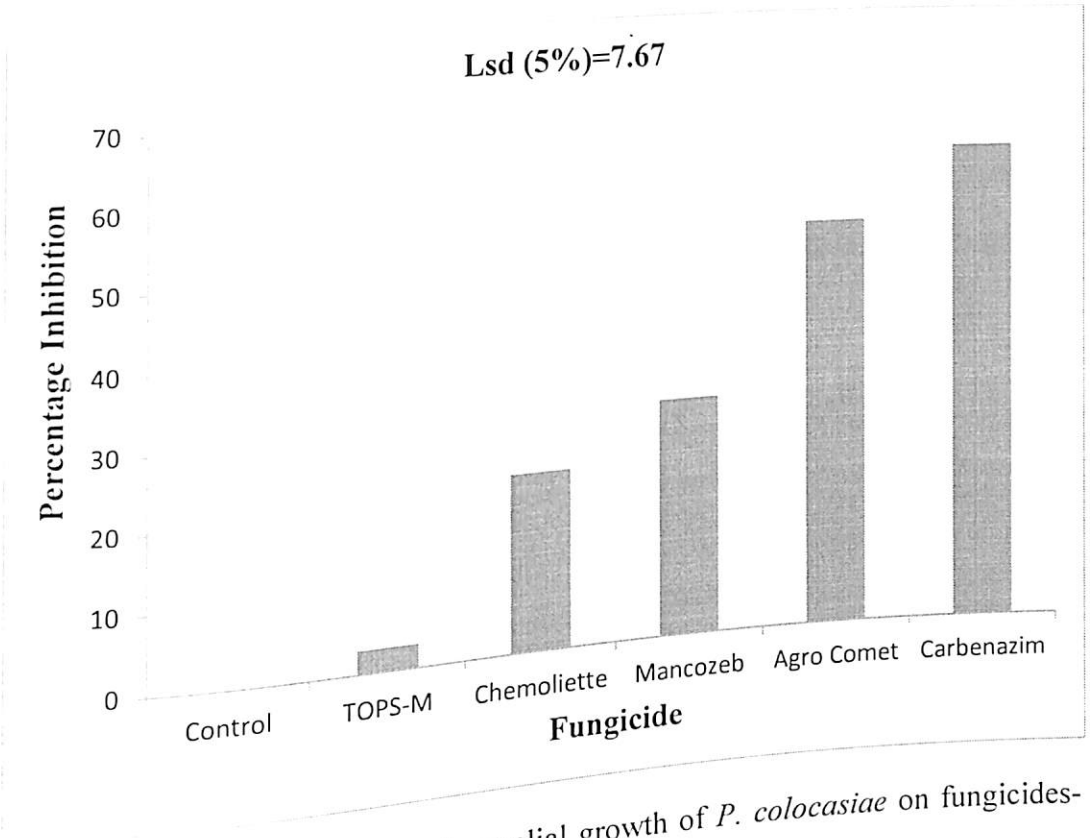


Figure 77. Percent inhibition of mycelial growth of *P. colocasiae* on fungicides-amended PDA

DISCUSSIONS

In an experiment to find effective fungicides against *P. colocasiae*, all five fungicides showed differences in their effectiveness against the pathogen. Higher concentrations of each fungicide inhibited to a certain degree, radial growth in all the plates. Carbendazim (carbendazim) and Agro Comet (Metalaxyl and Copper) were identified to be most effective. Carbendazim was effective at all the concentrations used (100 ppm to 500 ppm) but Agro Comet became effective from 200 ppm to 500 ppm. The two fungicides (Carbendazim and Agro Comet) were equally effective from 300 ppm to 500 ppm.

Again, though Carbendazim and Agro Comet were most effective in inhibiting the growth of *P. colocasiae*, Mancozeb and Chemoliette (Fosetyl Aluminum) showed no differences in their ability to inhibit growth. TOPS-M (Thiophanate Methyl) was however not effective at all since it was not able to inhibit the growth of *P. colocasiae*.

The efficacies of the active ingredients of the various fungicides may account for their effectiveness against the pathogen. Carbendazim is a systemically active benzimidazole fungicide that inhibits the synthesis of ù-tubulin. It has been reported to be effective in controlling most plant pathogens. Lopez-Herrera & Zea-Bonilla (2006) in their research to determine the effects of benomyl, carbendazim, fluazinam and thiophanate methyl on white root rot of avocado observed a 97% growth inhibition by carbendazim. Mathivanan & Prabavathy (2007) also reported of the inhibition of mycelial growth by Carbendazim on *Altenaria helianthi* in their research to determine the effect of carbendazim and mancozeb combination on Alternaria leaf blight and seed yield in sunflower (*Helianthus annus* L.). It is therefore not surprising that it exhibited great efficacy on *P. colocasiae*. Agro Comet is a combination of metalaxyl and Copper (1) oxide. These active ingredients (Metalaxyl and Copper) have been reported to be effective on *P. colocasiae*. Copper based fungicides release copper ions from copper deposits, which provide residual protection against plant pathogens (Noyce et al., 2006; Mehtar et al., 2008) whereas Metalaxyl based fungicides inhibit uridine incorporation into RNA and specific inhibition of +RNA synthesis (Sukul and Spiteller, 2000). The combined effect of metalaxyl and copper could have contributed to the efficacies recorded. This confirms the

report by Fullerton and Tyson (2004) that successful control of taro leaf blight is possible with copper and metalaxyl. Misra (1996) and Jackson (1999) in their studies have demonstrated the effectiveness of metalaxy and Copper oxychloride in controlling TLBD in field or *in vitro*. Though the percentage inhibition of Carbendazim and Agro Comet are not as high as observed by Lopez-Herrera and Zea-Bonilla (2006), they can be integrated with other control strategies for a successful management of the disease.

CHAPTER SEVEN

EFFECT OF SPACING AND PRUNING OF DISEASED LEAVES ON THE INCIDENCE AND SEVERITY OF *PHYTOPHTHORA* LEAF BLIGHT DISEASE OF TARO (*Colocasia esculenta*)

INTRODUCTION

Different cultural methods have been recommended for control of TLBD (Singh et al., 2012). Though individually each may be of limited benefit, they may play important role when integrated to manage the disease (Misra *et al.*, 2004). Some of the cultural practices that have been reported to be effective against TLBD include removal of infected leaves during the early stages of disease development and wide spacing of plants to reduce disease spread (Nelson, 2011).

Pruning of infected leaves is highly effective in controlling the disease in subsistence taro gardens, particularly when plots are relatively well separated from one another (Singh *et al.*, 2012). Pruning is effective in improving air circulation which reduces relative humidity and limits the spread of diseases. It also reduces inoculums load on the field (Esiyok *et al.*, 1994).

Spacing is also tried as one of the components in management of plant diseases. It is generally believed that closer spacing helps in quicker spread of the disease by reducing the distance of travel of zoospores through air sprays from one plant to the other which will results in epidemic condition. The present investigations were undertaken to study the effect of different spacing and pruning on the incidence and severity of TLBD

MATERIALS AND METHODS

Study Location and Land Preparation

The field trial to study the effect of plant spacing and pruning on the incidence and severity of *Phytophthora* leaf blight in taro was established from March 2016 to January 2016 at Bososo in the Eastern region of Ghana. The location was chosen after it was observed to be a taro leaf blight endemic area after a field survey was conducted as explained in chapter 4. A farmer's field was acquired for the purpose of the experiment. The land which was a marshy area was prepared by manual clearing and the removal of stumps using cutlasses and hoes.

Experimental Setup and Design

The field trial was conducted in a Factorial Design with two factors (spacing and pruning). Four taro accessions were used for this experiment (local, susceptible, tolerant and resistant) with six treatments being the planting distances with or without pruning (T1 = 0.6 m x 0.9 m, T2 = 0.75 m x 0.75 m , T3 = 1.0 m x 1.0 m , T4 = T1 + Pruning , T5 = T2 + Pruning and T6 = T3 + Pruning). Each was replicated three times. The plot sizes depended on the planting distances (0.6 x 0.9 m, 0.75 x 0.75 m and 1.0 x 1.0 m) used. Blocking was done according to the replications. Each replication contained 24 plots based on the treatments and accessions combination. A distance of 1 m was left between and within plots and 2 m between blocks/ replications. Twelve (12) plants of an accession were planted on each treatment plot.

Agronomic Practices

All the recommended agronomic practices (drainage and weed control) for taro cultivation were followed for raising a good crop except plant protection and fertilizer application.

Data Collection

Data collection started four weeks after establishment when the leaves had started unfolding and subsequently at two weeks interval for 24 weeks. Four plants were tagged and assessed on each plot. All the leaves of each of the tagged plants were assessed for the disease after which an average was determined for that plant. Pruning was also done on designated plots at 4 weeks intervals whenever there were infections on these plots. Disease severity was scored on a 0-5 scale (Prasad. 1982). Disease incidence was determined using the formula by (Shakywar, Pathak & Singh, 2012).

$$\text{Disease incidence (\%)} = \frac{\text{Infected plants}}{\text{Total plants}} \times 100$$

At harvest. corms from each plot were weighed to determine the yield.

Data Analyses

Data was subjected to analysis of variance (ANOVA) using Genstat 12th Edition and means separations was done using Fisher's Lsd at 5% probability level.

RESULTS

Effects of Spacing and Pruning Activities on the Incidence and Severity of TLBD

In Figure 78 are presented the percentage incidence of TLBD on taro plants grown at different spacing. It can be observed from the figure that, though the 0.6 m x 0.9 m spacing had the highest incidence of 91.7%, it was not significantly different from the incidences of 88.9% and 76.4 % recorded for the 0.75 m x 0.75 m and 1.0 m x 1.0 m spacing, respectively.

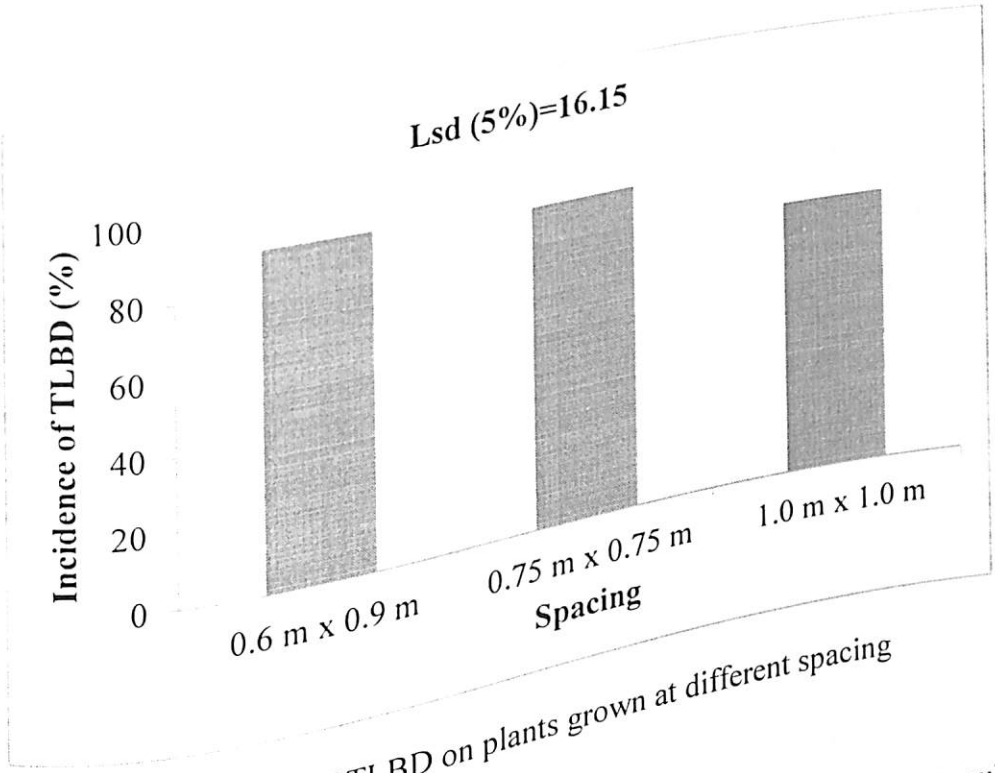


Figure 78. Incidence of TLBD on plants grown at different spacing

Figure 79 presents the percentage incidence of TLBD on plants subjected to two different pruning regimes. It can be observed that the no pruning resulted in a significantly higher incidence of 97.2% compared to the pruning, which had TLBD incidence of 74.1%.

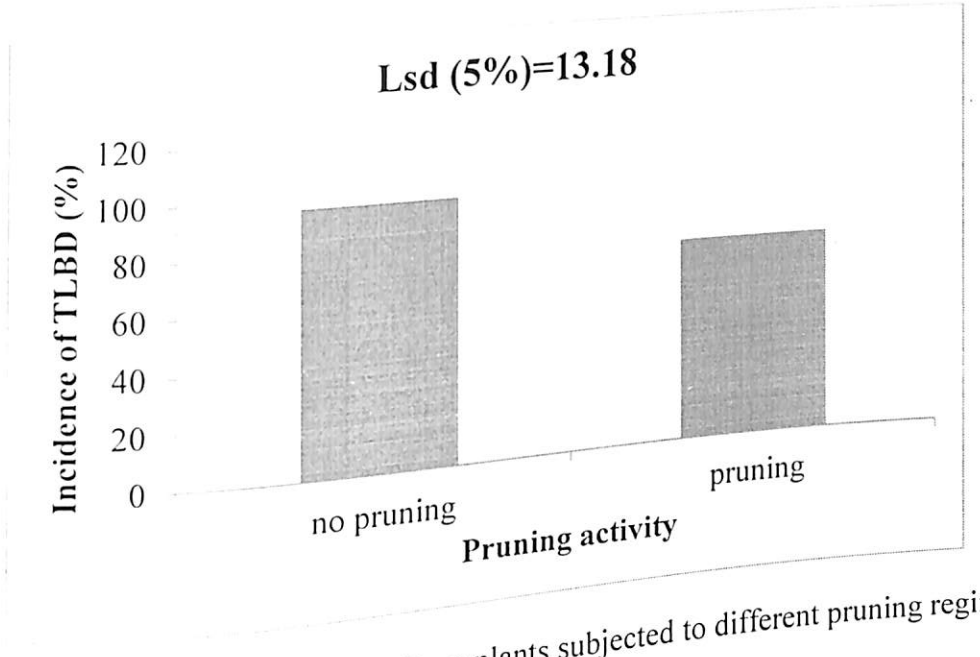


Figure 79. Incidence of TLBD on plants subjected to different pruning regimes

Figure 80 presents data on the combined effect of pruning and spacing on disease incidence. The spacing in combination with non-pruning activity recorded higher incidences of 91.7% for the 1.0 m x 1.0 m spacing, and 100% each for both the 0.6 m x 0.9 m and 0.75 m x 0.75 m spacing compared with spacing in combination with pruning. Spacing in combination with pruning recorded incidences of 83.3%, 77.8 % and 61.1% for 0.6 m x 0.9 m, 0.75 m x 75 m and 1.0 m x 1.0 m spacing respectively. No significant differences ($P>0.05$) existed among all the spacing with no pruning activity, but there were significant differences ($P<0.05$) between these spacing and two spacing (0.75 m x 0.75 and 1.0 m x 1.0 m) with pruning activity. The 1.0 m x 1.0 m spacing with pruning however had the lowest incidence which was significantly different ($P<0.05$) from all the spacings, except the 0.75 m x 0.75 m spacing with pruning.

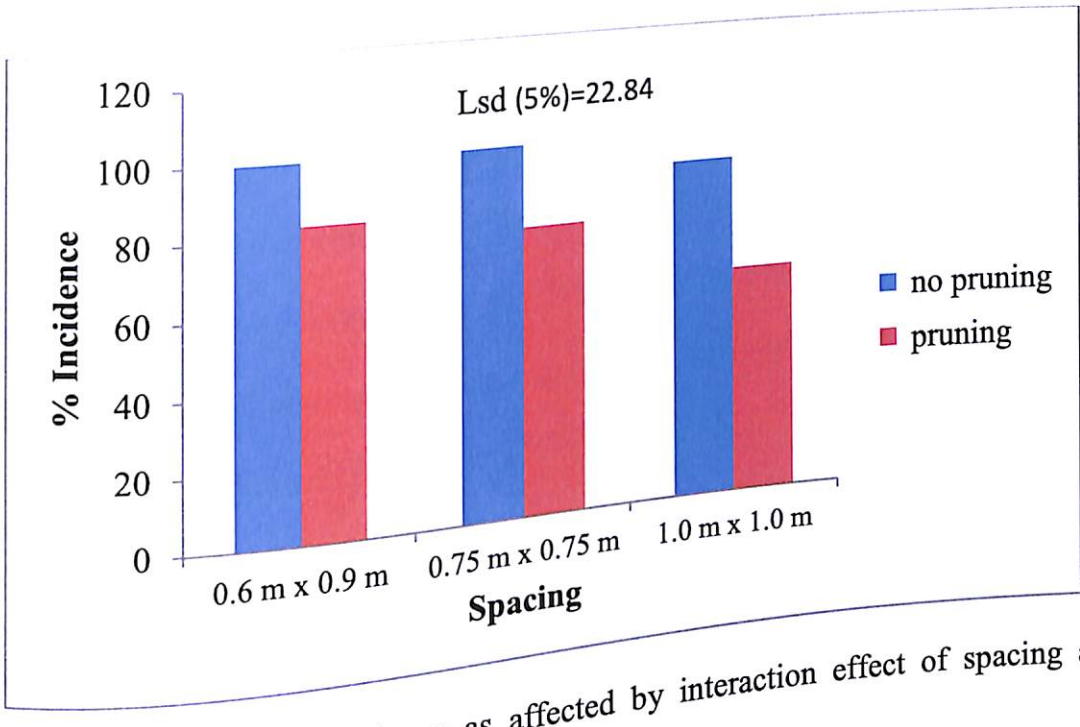


Figure 80. Disease incidence as affected by interaction effect of spacing and pruning activity

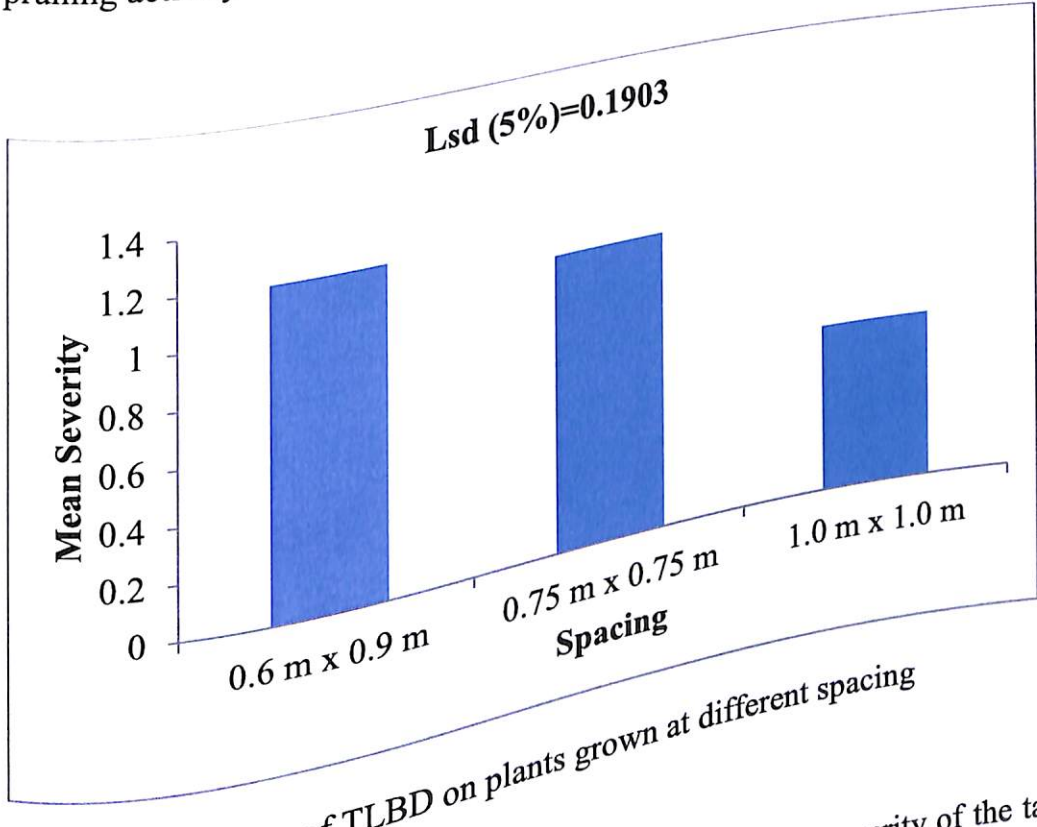


Figure 81. Severity of TLBD on plants grown at different spacing

Figure 81 represents the effects of spacing on the severity of the taro leaf blight disease. From the figure, it can be observed that the lowest severity of 0.618 was recorded for plants spaced at 1.0 m × 1.0 m and is significantly

different from the 0.75 m × 0.75 m and 0.6 m × 0.9 m which also had disease severity of 1.09 and 1.201, respectively. The 0.75 m × 0.75 m and 0.6 m × 0.9 m were not significantly different from each other.

Figure 82 represents the effects of pruning on the severity of the TLBD. It can be observed that there is a significant difference in severity, where plants were pruned and when no pruning was done (P, 0.05). Where pruning was done, severity of disease was significantly lower on taro plants (0.611)

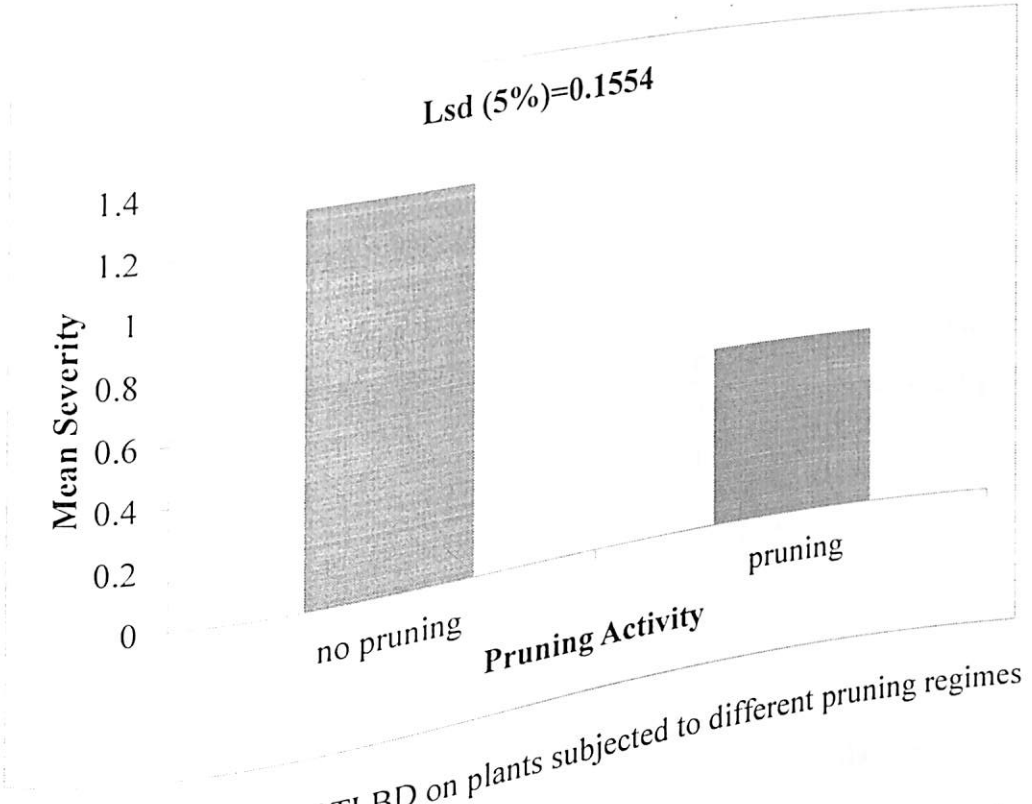


Figure 82. Severity of TLBD on plants subjected to different pruning regimes

Figure 83 presents data on the combined effect of pruning and spacing on disease severity. A significantly higher disease severity was recorded on plants that were not pruned, compared to those that were pruned. Higher mean severity was recorded for spacing in combination with no pruning, compared to the mean severity recorded for spacing in combination with pruning. Disease severity on

plots where plants were spaced at 0.6 m x 0.9 m and 0.75 m x 0.75 m with no pruning were similar but different on plants spaced at 1.0 m x 1.0 m. Similarly, the mean severity for 0.6 m x 0.9 m and 0.75 m x 0.75 m (0.778 and 0.667 respectively) were significantly different from the 1.0 m x 1.0 m spacing (0.389) where pruning was done. In comparison, the 0.6 m x 0.9 m and 0.75m x 0.75 m with non pruning are significantly different from the same spacing with pruning.

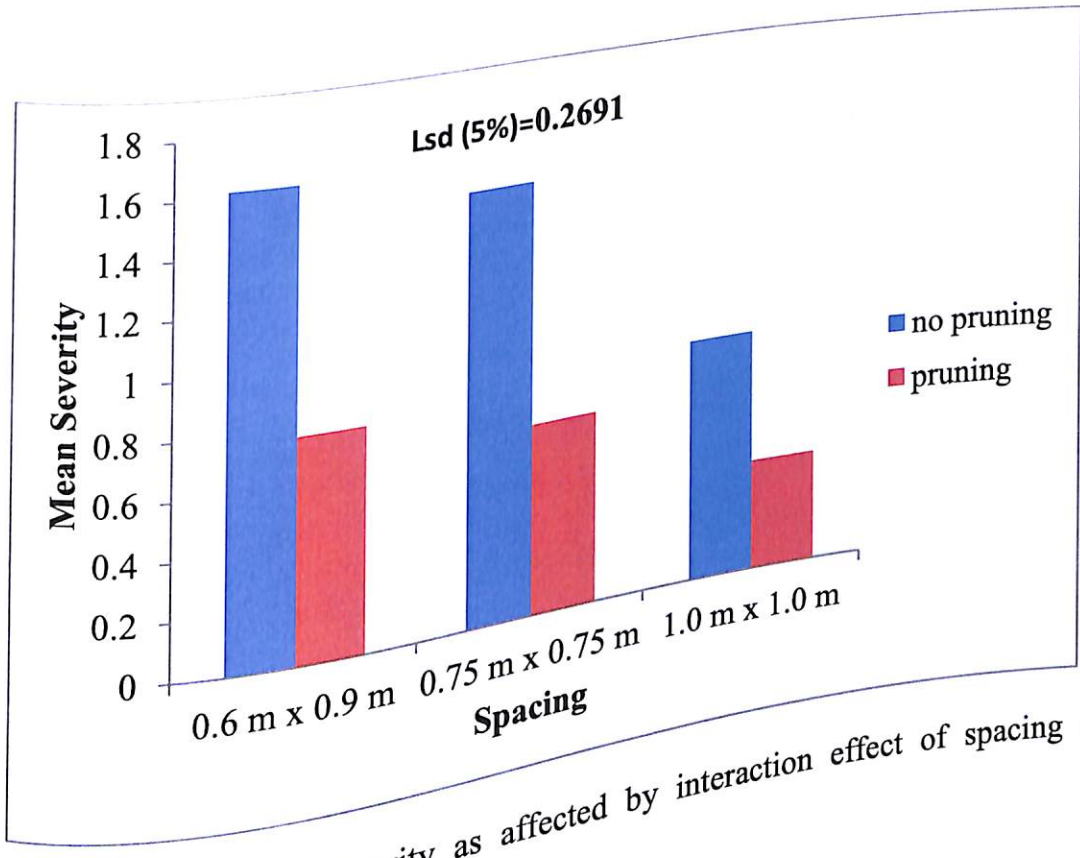


Figure 83. Disease severity as affected by interaction effect of spacing and pruning activity

Effects of Spacing and Pruning Activities on the Yield of Taro

Figure 84 shows the average weight of taro corms harvested per plot of the various plant spacing evaluated. It can be observed that yield increased with increasing planting distances with the highest (10.714 kg) obtained from plants spaced at 1 m x 1 m. This was significantly different (P=0.005) from the yield from plots where plants were spaced at 0.6 m × 0.9 m (8.813 kg) but not

significantly different from that of 0.75 m × 0.75 m spacing (10.023 kg). Yield from plots were plants were spaced at 0.6 m × 0.9 m and 0.75m × 0.75 spacing were however not different from each other.

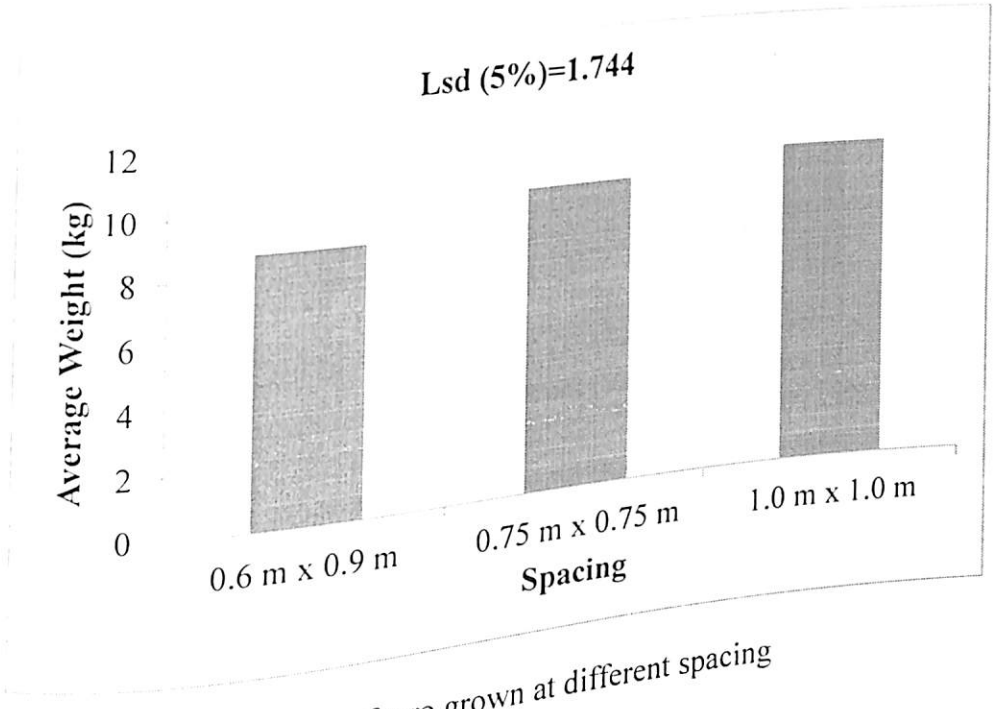


Figure 84. Corm weight of taro grown at different spacing

From Figure 85, it can be observed that there was a significant difference in weight of tubers under the pruning regimes (P=0.005) between the pruning and non-pruning activities. Average weight of tubers was significantly influenced by pruning. Corm weight was significantly higher on plots were affected leaves were pruned compared to when no pruning was done. Pruning of TLBD affected leaves resulted in a significantly higher average corm weight (10.74 kg) than no pruning (8.96 kg).

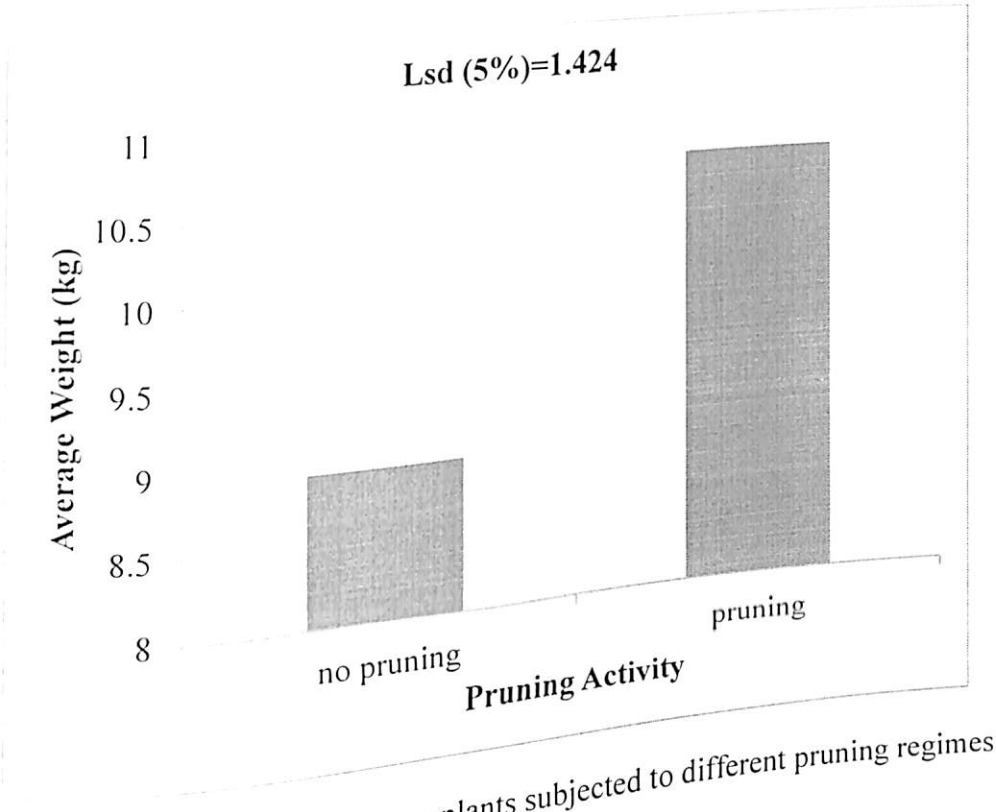


Figure 85. Corm weight of taro plants subjected to different pruning regimes

From Figure 86, which shows the interactive effect of spacing and pruning on the yield of taro, there were no significant differences in the weight among the planting distances 1.0 m x 1.0 m (9.74 kg), 0.75 m × 0.75 (9.23 kg) and 0.6m × 0.9m (7.90 kg), under no pruning activity. The average weight of 11.69 kg, 10.82 kg and 9.72 kg for the plant spacing of 1.0 m x 1.0 m 0.75 m × 0.75 m and 0.6 m × 0.9 m respectively were not significantly different from each other under the pruning activity. There were however significant differences between 0.6 m × 0.9 m spacing with no pruning and the 1.0 m x 1.0 m and 0.75 m × 0.75 m when pruning was done. The 1.0 m x 1.0 m and 0.75 m × 0.75 m spacing under no pruning was also not significantly different from the 0.6 m × 0.9 m spacing with pruning.

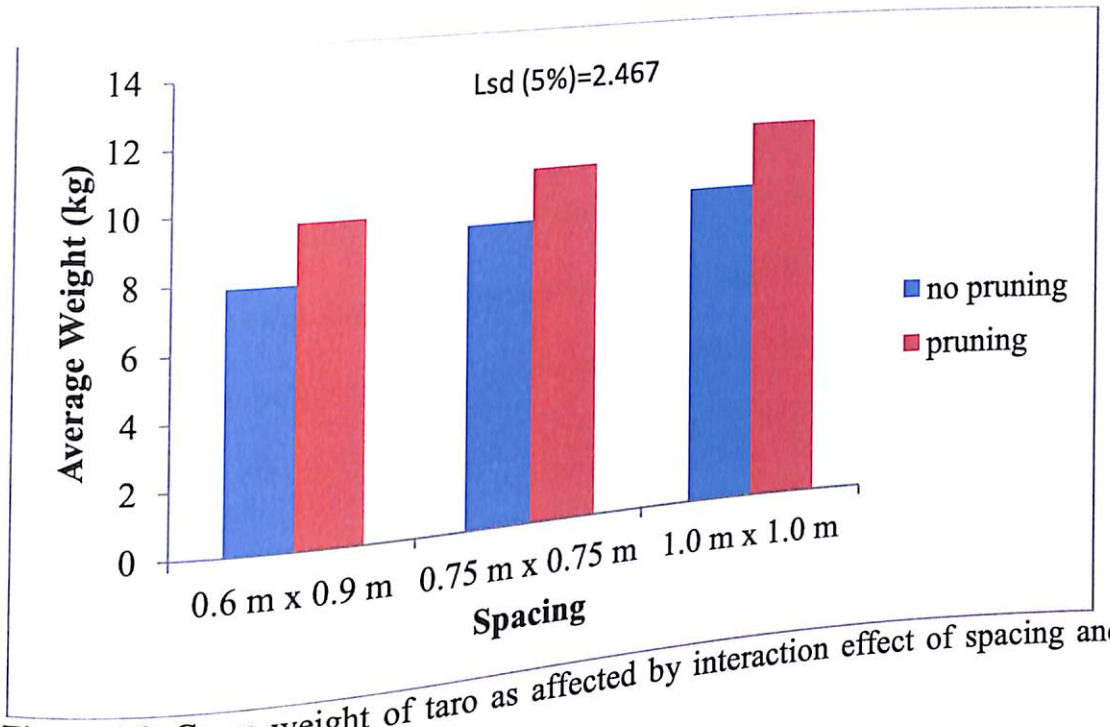


Figure 86. Corm weight of taro as affected by interaction effect of spacing and pruning activity

DISCUSSION

Growing plants in dense stands has been reported to promote disease epidemics. In the quest to study the effect of spacing and pruning and their interactive effect on the incidence and severity of leaf blight disease of taro caused by *Phytophthora colocasiae*, it was observed that, adopting wider spacing was more effective in managing the disease as compared to narrow spacing. The 1.0 m x 1.0 m spacing recorded lowest incidence and severity and therefore the most effective as compared to the incidence and severity recorded by 0.75m × 0.75 and 0.6 m ×0.9 m spacing. The 0.75 m × 0.75 and 0.6 m ×0.9 m spacing did not show any difference in terms of their effectiveness in reducing the incidence and severity of the disease. This indicates that the 1.0 m x 1.0 m spacing is more appropriate in managing *P. colocasiae* infection of taro. In an infected field, the closer the plants, the more likely it can be attacked by the disease. Misra et al. (2004) reported in their work in identifying the effect of spacing on the severity of

TLBD that closer spacing enhances the spread of the disease and also increases the total leaf area damaged as compared to wider spacing. The canopy structure of the crop also plays a role in the dispersal of sporangia (Brooks, 2005). Canopy structure is such that using closer spacing shortens the distance between plants, thus allowing easy transfer of sporangia from plants to plants. *P. colocasiae* sporangia have been reported to be dispersed through rain splash (Brooks 2005) and therefore closer spacing could assist in easy dispersal by shortening the distance over which spores can travel. In closer spacing, air movement is also reduced within the canopy, and this favours the development of the pathogen (*P. colocasiae*) leading to increased disease development. These may account for the reason why disease severity was higher in closer spacing than in wider spacing. This also confirms the findings of Berger (1975), who reported that the spread of leaf blight disease in celery caused by *Cercospora apii* was faster in closer spacing than wider spacing. Legard *et al*, (2000) also reported that wider spacing between and within a row reduced the incidence of Botrytis fruit rot of strawberries.

Pruning of infected leaves from time to time also helped in reducing the incidence and severity of the disease significantly. This was according to the findings in Figure 80 and 83 when pruning activity was compared with a no pruning activity. The significantly lower incidence and severity on plants that were indicates that pruning was more effective in reducing the severity of *P. colocasiae* on the field. This confirms the findings of Holb et al. (2009) that pruning caused uniformly significant differences in development of *Cercospora*

depazeoides in black elderberry orchards. Pruning helps in reducing the inoculums on the field and therefore prevents the spread of the pathogen on the field. It also prevents the pathogen from spreading from one part of the plant to the other parts. Pruning also improves air circulation, thereby reducing relative humidity and build up of inoculums.

Combining pruning with spacing was also observed to be more effective than using methods separately in managing the disease. The result showed that wider spacing combined with pruning was effective in reducing the severity of the disease as compared to the non pruning activity combined with spacing. The fact that there was no significant difference in incidence and severity of disease, where the spacing of 1.0 m x 1.0 m and 0.75 m × 0.75 m were combined with pruning, was however not different from 1.0 m x 1.0 m with no pruning shows that a good management system can be achieved when higher spacing of 1.0 m x 1.0 m and no pruning is done, but can be used with pruning to get almost the same result. The 0.75m × 0.75 spacing also showed similar results when combined with pruning. According to Esiyok et al. (1994) pruning is effective in improving air circulation which reduces relative humidity and limits the spread of diseases while spacing prevents or reduces the dispersal of the sporangia on the field (Brooks, 2005) . A combination of both activities can therefore be relied on to ensure good management of TLBD.

The experiment also revealed that wider spacing (1.0 m x 1.0 m and0.75 m × 0.75m) produced higher weight of corms per plot. This confirms the findings of Tumuhimbise (2015) that spacing of 0.75 m × 0.75 m produced largest corm yield

and shoot yield per plant. Similarly, Misra et al. (2004) after evaluating the effect of different spacing on the severity and yield of TLBD, observed that the yield per plant was higher in widely spaced plots as compared to closely spaced plots. Sivan (1977) had earlier reported that wider spacing produces higher yield of marketable size corms of taro.

Though wider spacing of 1.0 m x 1.0 m gave higher corm weight per plot, Pruning alone and its combination with higher spacing (1.0 m x 1.0 m and 0.75 × 0.75 m) also produced higher corm weight per plots as compared with the no pruning plots. It is evident that pruning and higher spacing as well as their combination increases corm weight of taro and therefore yield. The 1.0 m x 1.0 m and 0.75 m × 0.75 m spacing when combined with pruning gave the greater corm weight. Oga and Umekwe (2016) have also reported that wider plant spacing minimized days to 50% flowering and maximized total number of fruits, weight of fruits and total yield in water melon (*Citrullus lanatus* L.) whilst the pruned plants produced the longest vine number of leaves, number of flowers and number of fruits.

This research has demonstrated that spacing and pruning are very important in taro production and that for effective management of TLBD there is the need for the adoption of appropriate spacing and pruning activity.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. The production activities employed by majority of taro farmers in the Eastern region include; cultivation on smaller pieces of lands (0.45 acres to 1.44 acres), cultivation on flat lands or flood plains, under monocropping. using of volunteer planting materials, and also planting using scattered planting instead of rows planting. Majority of the farmers observed the disease on their farms and on other farms mostly in the rainy season. The TLBD was high in marshy areas with stagnant water than in marshy areas with flowing water. Most farmers did not control the disease, but a few used chemicals and cultural practices (pruning/rouging) to manage the disease. Insecticides and fertilizer rather than fungicides were used. The few farmers that practiced pruning did that as and when the disease appears and admitted that it was very effective in managing the disease.

2. TLBD incidence was 62.2 to 92.2% in the wet season and 69.9% to 78.9% in the dry seasons. Both New Juabeng and Fanteakwa had the highest incidence in the wet season, with the Suhum/Kraboa/Coaltar districts having lowest. Fanteakwa and Kwawu South recorded the highest and lowest incidence respectively in the dry season. Disease severity for the two seasons reveals that New Juabeng had the highest disease severity

(1.91) with Birim South (1.09), Suhum/Kraboa/Coaltar (1.11) and Fanteakwa (1.21) having low severity scores.

3. The causal organism of TLBD was confirmed as *Phytophthora colocasiae.* There were morphological variations among the *P. colocasiae* isolates from the different districts based on the sporangial shape and mycelial growth characteristics.

4. Petiole colour, leaf blade margin, leaf surface, vein colour, corm skin and flesh colour and corm shape contributed to the variations among the taro accessions. Only one (WR0005) out of the four local accessions was identified to be tolerant to TLBD, all the others were moderately susceptible and none was resistant. Four of the improved exotic varieties (GA/TLBD/0003, GA/TLBD/0010, GA/TLBD/0007 and GA/TLBD/0002) were resistant to *P. colocasiae* infection, in the laboratory and on the field. *Sclerotium* sp was also identified to be the cause of the corm rot observed on the field. The improved exotic accessions that were resistant to the TLBD were also susceptible to sclerotium rot but the local accessions were tolerant to the Sclerotium rot.

5. Carbendazim and Agro Comet (Metalaxy and Copper (1) oxide) were the most effective fungicide inhibiting growth of *P. colocasiae.*

6. The spacing of 1.0 m x 1.0 m was effective in reducing the incidence and severity of TLBD compared to the 0.75 m × 0.75 m and 0.6 m ×0.9 m spacing. Pruning activity reduced the severity of the TLBD compared to non-pruning activity. The combination of wider spacing (1.0 m x 1.0 m and 0.75 m × 0.75 m) and pruning reduced severity of the disease and resulted in higher corm yield.

RECOMMENDATION

It is therefore recommended that:

1. Similar studies should be conducted in other regions to determine the general cultivation practices employed by taro farmers in the country and to identify the kind of management practices being employed.
2. The incidence and severity in the other regions should also be assessed to determine the overall intensity of the disease in the country.
3. Molecular methods should be used to confirm the identity of P. *colocasiae* as the causal organism of TLBD in the study area and to identify genetic variability.
4. There should be a national breeding program to come out with resistant varieties of *Colocasiae esculenta* against TLBD by crossing the improved exotic varieties that were resistant to the TLBD with the local accessions that were also tolerant to the *Sclerotium* sp.
5. Field trials should be carried out to determine the efficacy of the selected fungicides.

REFERENCES

Acheampong, P. P., Osei-Adu, J., Amengo, E., Sagoe, R. (2014). Cocoyam value chain and benchmark study in Ghana. A report submitted to West African Agricultural Productivity Project (WAAPP). *Project Information Document.* 7-11 .

Ackah, F. K. (2013). *Prevalence and Management of Leaf Blight Disease of Taro (Colocasiae Esculenta (L) Schott) In the Aowin Suaman District of Ghana.* Unpublished master's Thesis. Department of Crop Science, University of Cape Coast. Ghana.

Ackah, F. K., van der Puije, G. C. and Moses, E. (2014). First evaluation of taro (*Colocasia esculenta*) genotypes against leaf blight (*Phytophthora colocasiae*) in Ghana, *HortFlora Research Spectrum, 3*(4), 390-391.

Adams, E. (1999). Farmers use both chemical and cultural methods to control TLB. *IRETA's South Pacific Agricultural News 16,* 1- 4.

Adegbola, M. O. K. (1993). *Determination of the most suitable frequency and time of fungicide spraying schedule for the adoption in the control of Phytophthora black pod (pod rot) disease of Cocoa.* Proceeding of the 11th International Cocoa Research Conference, Yamoussoukro, Cote d'Ivoire.

Adejumo, T.O. (1997). *Identification, incidence, severity and methods of control of the causal organism of false smut disease of cowpea (vignia*

unguiculata L.) Walp. Unpublished Ph.D. Thesis. University of Ibadan, Nigeria.

Adomako , J., Kwoseh, C. K., Moses E. & Larbi-Koranteng, S. (2016). Prevalence of Phytophthora Leaf Blight of Taro (Colocasia esculenta (L.) Schott) in the Semi Deciduous Forest Zone of Ghana. *American Journal of Experimental Agriculture,11* (4): 1-7, 2016.

Agyekum, E. (2004). *The effect of plant density and the relative time of planting on Colocasia /Rice intercropping system.* M.Sc. Thesis, Faculty of Agriculture and Renewable Natural Resources. Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.

Alexopoulos C. J., Mims C. W., and Blackwell M. (1996). *Phylum Oomycota. In: Introductory Mycology.* New York: John Wiley and Sons, Inc.

Amosa, F. and Wati, P. (1997). Effects of taro/maize intercropping systems on the incidence of and severity of taro leaf blight. In: *Taro Genetic Resources: Conservation and Utilisation, Annual Research Report.* The Institute for Research, Extension and Training in Agriculture (IRETA) and the School of Agriculture (SOA). (pp.1–2). Apia, Samoa: University of the South Pacific, Alafua Campus.

Anon, (1998). *Annual Report 1998/1999, AusAID/SPC Taro Genetic Resources:Conservation and Utilisation* (pp. 26). Noumea, New Caledonia: Secretariat of the Pacific Community.

Ashok, A. and Saikia, U. N. (1996). Fungicidal management of leaf blight of *Colocasia. International Journal of Tropical Agriculture 14* (1–4), 231–233.

Bandyopadhyay, R., Sharma, K., Onyeka, T. J., Aregbesola, A., & Lava K. P. (2011). First report of taro (*Colocasiae esculenta*) leaf blight caused by *Phytophthora colocasiae* in Nigeria. *Plant Diseases, 95*,618.

Berger, R.D (1975). Disease incidence and infection rates of *Cercospora apii* in plant spacing plots. *Phytopathology, 65*,485-487.

Bergquist, R. R. (1974). Effect of fungicide rate, spray interval, timing of spray application, and precipitation in relation to control of *Phytophthora* leaf blight of taro. *Annals of Botany 38* (154), 213–221.

Boakye-Acheampong, S. (2016). *Economic Analysis of Cocoyam Production in Ghana*. Unpublished *M.Phil. Thesis*. Kwame Nkrumah University Of Science And Technology (KNUST). Kumasi, Ghana.

Brooks F. E. (2000). Cultivar Resistance to Taro Leaf Blight Disease in American Samoa, *American Samoa Technical Report, 34*, 49-58.

Brooks, F. E. (2004). *List of plant disease in American Samoa* (Report No. 41). American Samoa Community College Land Grant Program, September, 2004. Land Grant Technical.

Brooks, F. E. (2005). Taro leaf blight. *The Plant Health Instructor*. DOI: 10.1094/PHI-I-2005-0531-01.

Brooks, F. E. 2008. Detached leaf bioassay for evaluating Taro resistance to *Phytophthora colocasiae*. *Plant Disease*. 92: 126-131.

Brunt, J., Hunter, D., & Delp, C. A. (2001). *Bibliography of taro leaf blight*; Secretariat of the Pacific Community. Noumea, New Caledonia. 1–10.

Butler, E. J., & Kulkarni, G. S. (1913). Colocasia blight caused by *Phytophthora colocasiae*. Memoirs of the Department of Agriculture in India, *Botanic Series, 5*, 233-261.

Carmichael, A., Harding, R., Jackson G., Kumar, S., Lal, S. N., Masamdu, R., Wright, J., & Clarke, A. R. (2008). *TaroPest: an Illustrated Guide to Pests and Diseases of Taro in the South Pacific* (No. 132, 76.). ACIAR Monograph.

Chan, E. (1997). *A summary of trials carried in the taro leaf blight control program 1996-1997, Western Samoa Farming Systems Project*. Ministry of Agriculture, Forestry, Fisheries and Meteorology, 33.

Charles, F., Mbong, G., Manju, E., Tembe, E. & Rachid, H. (2016). Screen House and Field Resistance of Taro Cultivars to Taro Leaf Blight Disease (Phytophtora colocasiae). *British Biotechnology Journal* 15(1), 1-15.

Chiejina, N. V. & Ugwuja, F. N. (2013). Incidence of Phytophthora Leaf-Blight Disease of Cocoyam in Nsukka Area of South-Eastern Nigeria. *Journal of Botanical Research, 4* (1), 21-24.

Cline, E.T., Farr, D.F., and Rossman, A.Y. (2008). *A synopsis of Phytophthora with accurate scientific names, host range, and geographic distribution.* Online publication. Plant Health Prog. Doi:10.1094/PHP-2001-0318-01-RS.

CMI. (1997). *Commonwealth Mycological Institute, Distribution Maps of Plant Diseases, Map No. 466, Edition 3. Phytophthora colocasiae.*

Commonwealth Agricultural Bureau, Wallingford, Oxfordshire, UK.

Coffey, M. D. (1991). Strategies for integrated control of soil borne *Phytophthora* species In: *Phytophthora.* J. A. Lucas, R. C. Shattock, D. S. Shaw and L. R. Cooke, (eds.), Cambridge, U. K, Cambridge University Press

Dagne, Y & Mulualem, T (2014). Exploring Indigenous Knowledge and Production Constraints of Taro (*Colocasia esculenta* L. (SCHOTT)) Cultivars Grown at Dalbo Watershed, Wolaita Zone of South Ethiopia. *Greener Journal of Plant Breeding and Crop Science, 2* (3), 047-053.

Dapaah, S. K. (1994). Contributions of root and tuber crops to socioeconomic changes in the development world: The case of Africa, with special emphasis on Ghana. *Acta Horticulture, 380*, 44-49.

Davidson, P (2014). *Poor performance of public schools worrying: The real cause.* Graphic online. Retrieved from https://www.graphic.com.gh/news/education/poor-performance-of-public-schools-worrying-the-real-cause.html.

De la Pena, R. S. (1998). *Upland Taro.* College of Tropical Agriculture and Human Resource, University of Hawaii, at Manoa, Honolulu, Hawaii.

Doku, E. V. (1984). Production potentials of major tropical root and tuber crops. In Terry, E. R. (ed.), *Proceedings of the Symposium International*

Society for Tropical Root Crops, Africa Branch, Douala, Cameroon, 14-19 August, 1983.

Drenth, A. & Sendall, B. (2004). Economic impact of Phytophthora diseases in Southeast Asia. *Diversity and Management of Phytophthora in Southeast Asia*. 10-28.

Duncan, C &Torrence, L. (1992). *Techniques for rapid detection of plant pathology.* Blackwell Scientific Publication, Oxford, London, Paris. 234.

Englberger, L., Darnton-Hill, I., & Coyne, T. (2003). Carotenoid-rich bananas: A potential food source for alleviating Vitamin A deficiency. *Food and Nutrition Bulletin, 24*, 4. The United Nations University.

Englberger, L., Darnton-Hill, I., and Coyne, T (2001). Carotenoid-rich bananas: A potential food source for alleviating Vitamin A deficiency. *Food and Nutrition Bulletin, 24*, 4. The United Nations University.

Erwin, D. C. and Ribiero, O. K. (1996). Control by host resistance. In: *Phytophthora* Disease Worldwide. American Phytopathological Society Press, St Paul, Minnesota.

Esiyok, D., Ozzambak, E., & Eser, B. (1994). The effects of stem pruning on the yield and earliness of greenhouse pepper (*Capsicum annuum L. grossum* cv. Kandil and 11B-14. *Acta Horticulturae, 366*, 293-300.

Essane, P. (2014). *Prevalence of taro leaf blight (TLB) disease in the Bibiani-Anhwiaso-Bekwai district.* Unpublished Bsc. Dissertation. Department of Crop Science, University of Cape Coast. Ghana

FAO (1987). *Yearbook of production for 1986.* Retrieved from http// www.fao.org.

FAO (2001). *Online statistical data base of the FAO.* Retrieved from http// www.fao.org.

FAO (2008). *Importance of Taro.* Retrieved from http://www.fao.org/docrep/005/ac450e/ac450e03.htm.

FAO (2010). *Plant Production and Protection Paper 126.* Food and Agriculture Organisation, Rome.

FAO (2013). *Plant Production and Protection Paper 126.* Food and Agriculture Organisation, Rome.

FAOSTAT (2010). *Food and Agriculture Organisation Statistical Database.* Retrieved from http://faostat.fao.org.

FAOSTAT (2016). *Food and Agriculture Organisation Statistical Database.* Retrieved from http://faostat.fao.org.

Fullerton, R., & Tyson, J. (2001). Overview of leaf diseases of taro. In *Proceedings of Taro Pathology and Breeding Workshop, 5–7 November* (pp. 4–7) Alafua Campus, Samoa.

Gallegly, M. E & Hong, C. (2008). *Phytophthora. Identifying species by morphological and DNA fingerprints.* APS press, St. Paul, Minnesota, USA.

GoG (2018). *Eastern Region.* Retrieved from http://www.ghana.gov.gh/index.php/about-ghana/regions/eastern-region.

Guarino, L. (2010). Taro leaf blight in Cameroon? 2010. Agricultural Biodiversity. Weblog. Retrieved from http://agro.biodiver.se/2010/07/taro-leaf-blght-in-Cameroon.

Gurr, P. (1996). The taro leaf blight situation in American Samoa. In *Proceedings of Taro Leaf Blight Seminar, Alafua, Western Samoa, 22–26 November 1993*; South Pacific Commission: Noumea, New Caledonia, pp. 35–38.

Holb, I. J., Gáll, J. M. & Fodor, B. (2009) Effect of Production System and Pruning on Temporal Development of *Cercospora depazeoides* and on Berry Yield in Black Elderberry Orchards. *Plant Diseases, 93*(6), 625-631

Hunter, D., and Pouono, K. (1998). Evaluation of exotic taro cultivars for resistance to taro leaf blight, yield and quality in Samoa. *Journal of South Pacific Agriculture, 5* (2), 39–43.

Hunter, D., Brunt, J. and Delp, C. (2001). *AusAID/SPC Taro Genetic Resources: Conservation and Utilization. A Bibliography of Taro Leaf Blight. April 2001 (pp.2-15.)* Secretariat of the Pacific Community, Noumea, New Caledonia.

IPGRI. (1999). *Descriptors for taro (Colocasia esculenta).* International Plant Genetic Resources Institute, Rome, Italy.

Ivancic, A., Kokoa, P., Gunua, T., & Darie, A. (1996). Breeding approach on testing for resistance to taro leaf blight. In *The Second Taro Symposium. Proceedings of an International Meeting*, (pp. 93-96), Faculty of Agriculture, Cenderawasih University, Manokwari, Indonesia.

Jackson, G. V. H. & Gollifer, D. E. (1975). Storage rots of taro (*Colocasia esculenta*) in the British Solomon Islands. *Annals of Applied Biology, 80*, 217-230.

Jackson, G. V. H. (1999). Taro leaf blight. In *Pest Advisory Leaflet*; the Plant Protection Service of the Secretariat of the Pacific Community: Noumea, New Caledonia. 3, 2

Jackson, G. V. H., Gollifer, D. E., & Newhook, F. J. (1980). Studies on the taro leaf blight fungus *Phytophthora colocasiae* in Solomon Islands: control by fungicides and spacing. *Annals of Applied Biology, 96*, 1-10.

Jackson, G.V.H. (1996). Taro leaf blight. *In Pest Advisory Leaflet* (No. 3, pp. 2); the Plant Protection Service of the Secretariat of the Pacific Community: Noumea, New Caledonia.

Jamadar, M. & Lingaraju, S. (2011). In vitro evaluation of fungicides, botanicals and bio-agents against *Elisinoe ampelina*. *Journal of Agricultrual Science, 24*, (2), 146-148.

Kay, D. E. (1973). *Crop and Product Digest 2. Root Crops,* London: Tropical Products Institute

Kay, D. E. (1987). Taro. In (ed.) *Root Crops*. London, UK: Tropical Development and Research Institute. 233–251.

Ko, W. H. (1979). Mating-type distribution of *Phytophthora colocasiae* on the island of Hawaii. *Mycologia, 71* (2), 434–437.

Kohler, F., Pellegrin, F., Jackson, G.V.H., & Mackenzie, E., (1997). Taro. In *Diseases of Cultivated Crops in Pacific Island Countries*; Secretariat of the Pacific Community: Noumea, New Caledonia.

Kroon, L.P., Brouwer, H., De Cock, A.W., and Govers, F. (2012). The genus *Phytophthora* (2012). *Phytopathology* 102:348-364.

Kwon J. H., Kang, D. W. & Kim, J. (2013). *Sclerotium rolfsii* causes white rot on taro in Korea. *Plant Science, 97*(7), 1000.2

Lambert, M. (1979). Taro cultivation in the South Pacific. In: *SPC Handbook (SPC)*, (no.22, pp 144). Noumea (New Caledonia), South Pacific Commission.

Lebot, V., & Aradhya, K. M. (1991). Isozyme variation in taro *Colocasiaesculenta* (L) Schott from Asia and Oceania. *Euphytica, 56*,55–66.

Legard, D. E., Xiao, C. L., Mertely, J. C., & Chandler, C. K. (2000) .Effects of Plant Spacing and Cultivar on Incidence of Botrytis Fruit Rot in Annual Strawberry. *Plant Disease*, 84 (5).

Lopez-Herreraa, C. J & Zea-Bonilla, T. (2006).Effects of benomyl, carbendazim, fluazinam and thiophanate methyl on white root rot of avocado. *Crop Protection.* 26, 1186–1192.

Loy, T. H., Spriggs, M., & Wickler S. (1992). Direct evidence for human use of plants 28,000 years ago: starch residues on stone artefacts from the northern Solomon Islands. *Antiquity, 66*,898–912.

Manrique, L. A. (1994). Nitrogen requirement of taro. *Journal of Plant Nutrition, 17*, 1429 –1441.

Manrique, L. A. (1995). *Taro, production principles and practices.* Manrique International Agrotechnology Honolulu.

Mathivanan N. & Prabavathy V. R. (2007). Effect of carbendazim and mancozeb combinationon Alternaria leaf blight and seed yield in sunflower (*Helianthus annus* L.). *Phytopathology and Plant Protection, 40*, 2.

McGregor, A. J. and Moxon, J. E. (1985) Potential for biological control of tent building ants associated with *Phytophthora palmivora* (Butl.) pod rot of cocoa in Papua New Guinea. *Annals of Applied Biology, 107*, 271-277.

McKenzie, E. H. C., & Jackson, G. V. H. (1990). *The fungi, bacteria and pathogenic algae of the Republic of Palau*. South Pacific Commission, Noumea, New Caledonia *SPC Technical Paper ,198*, 28–29.

Mehrotra R.S. & Aggarwal A. (2003). *Plant Pathology, 2nd ed.*, New Delhi, New York: Tata McGraw-Hill..

Mehtar S., Wiid, I. and Todorov, S. (2008). The antimicrobial activity of copper and copper alloys against nosocomial pathogens and *Mycobacterium tuberculosis* isolated from healthcare facilities in the Western Cape: an *in vitro* study. *Journal of Hospital Infection, 68* (1), 45.

Misra R. S. (1993). *Tropical Tuber Crops: Problems, Prospects and Future Strategies*, Oxford and IBH, 380-388.

Misra, R .S, Sriram, S., Sahu, A. K. & Maheshwari, S. K (2004). Effect of Spacing on Severity of Phytophthora Leaf Blightand Yield of Colocasiae. *Journal of Root Crops, 30*,31-36.

Misra, R. S. & Chowdhury, S. R. (1997). *Phytophthora leaf blight disease of Taro.* CTCRI Technical Bulletin Series 21.Trivandrum: Central Tuber Crops Research Institute and St Joseph Press. p. 32.

Misra, R. S. (1996). A note on zoosporogenesis in *Phytophthora colocasiae. Indian Phytopathology, 49* (1), 80-82.

Misra, R. S., Shama, K & Misra A.J (2008). Phythophthora Leaf Blight of Taro (*Colocasiae esculenta*)-A Review. *The Asian Australasian Journal of Plant Science and Biotechnology*. Global Science Book.

Misra, R.S (1996). Prevalence and assessment of yield losses of Phytopthora leaf blight of Colocasiae in Northern and Eastern part of India. In: *Tropical Tuber Crops:Problems, Prospects and Future Strategies*. Oxford and IBH, New Delhi, pp 380-388.

MoFA (2010). *The State of Agriculture in Ghana in 2009*; Accra, Ghana; Statistics, Research and Information Department (SRID) of the Ministry of Food and Agriculture (MoFA).

MoFA-SRID (2013). *Agriculture in Ghana: Facts and Figures 2012*. Accra, Ghana: Statistics, Research and Information Directorate. Ministry of Food and Agriculture.

Moy, G. and Wessel, J. (2000). Codex Standard for Pesticides Residues. Gaithersburg, MD, USA: *Aspen Publishers Incoperation*.

Nelson, S., Brooks, F., & Teves, G. (2011). *Taro leaf blight in Hawaii; Plant Disease Bulletin* (No. PD-71), University of Hawaii: Manoa, HI, USA.

Noyce, J., Michels, H. and Keevil, C. (2006). Potential use of copper surfaces to reduce survival of epidemic meticillin-resistant Staphylococcus aureus in the healthcare environment. *Journal of Hospital Infections, 63* (3), 289.

Odamtten, G.T. (1977). *Effect of metabolites of two soil fungi Aspergillus niger Tiegham and Trichoderma viride Pers. Ex Fries on some aspects of*

the physiology of Phytophthora palmivora (Butl.) and on the structure and growth of cocoa (Theobroma cacao L.) seedlings. MSc. Thesis, University of Ghana.

Odigie, E. E. & Ikotun, T. (1982). *In-vitro* and *in-vivo* inhibition of growth of *Phytophthora palmivora* (Butl.) by antagonistic microorganisms. *Fitopatologia Brasileira, 7* (2), 157-169.

Oga, I. O., & Umekwe, P. N. (2016). Effects of Pruning and Plant Spacing on the Growth and Yield of Watermelon (*Citrullus lanatus* L.) in Unwana-Afikpo. *International Journal of Science and Research (IJSR). 5* (4), 2319-7064.

Okpul, T., Singh, D., Wagih, M., Wiles, G. & Hunter, D. (2002). *Improved Taro Varieties with Resistance to Taro Leaf Blight for Papua New Guinea Farmers.* NARI Technical Bulletin Series, Technical Bulletin No. 3. National Agricultural Research Institute, Lae, Papua New Guinea.

Oliver, D. (1973). *Bougainville: a personal history.* Melbourne, Australia: Melbourne University Press.

Omane E., Oduro, K. A., Cornelius, E. W., Opoku, I. Y., Akrofi, A. Y., Sharma K, Kumar, P. L., & Bandyopadhyay, R. (2012). First Report of Leaf Blight of Taro (*Colocasia esculenta*) Caused by *Phytophthora colocasiae* in Ghana. *American Phytopathological Society. 96* (2), 292.

Onwueme, I. C. (1978). *Origin, Characteristics and Botany of Cocoyam. The Tropical Tuber crops. Yam, Cassava, Sweet Potato and Cocoyam.* New York: John Wiley and Sons.

Onwueme, I. C. (1994). *Tropical root and tuber crops - Production, perspectives and future prospects. FAO Plant Production & Protection Paper* 126, FAO, Rome. 228 .

Ooka, J & Brennan, B. M. (2000). *Crop Profile for Taro in Hawaii.* College of Tropical Agriculture and Human Resources, Manoa, University of Hawaii.

Ooka, J. J. (1994). *Taro Diseases: A Guide for Field Identification.* HITARH Research Extension Series (No.148) Honolulu, HI CTAHR Publication, University of Hawaii.

Paiki, F. A. (1996). Symptoms of taro leaf blight disease (Phytophthora colocasiae) and relationship with yield components in Biak, Irian Jaya. *Sci. New Guin*, 21, 153–157.

Petry, N. M (2002).A comparison of young, middle-aged, and older adult treatment-seeking pathological gamblers. *Gerontologist. 42* (1),*92-9.*

Prasad, S. M. (1982). *National survey for diseases of tropical tuber crops.* Regional centre of CTCRI, Bhubaneswar, India. 49.

Purseglove, J. W. (1979). *Tropical Crops—Monocotyledons.* London: Longman.

Quaye, W., Adofo, K., Agyeman, K. O. & Nimoh, F. (2010). Socioeconomic survey of traditional commercial production of cocoyam and cocoyam leaf.

African Journal of Food, Agriculture. Nutrition & Development, 10 (9).

Raciborski M. 1900. *Parasitic algae and fungi, Java.* Batavia Bulletin of the New York State Museum, pp 19:189.

Ramanatha, R. V., Matthews, P. J., Eyzaguirre, P. B., & Hunter D. (2010). *The Global Diversity of Taro: Ethnobotany and Conservation.* Bioversity International, Rome, Italy.

Raynor, B., and Silbanus, S. (1993). Ecology of *Colocasia* taro production on Pohnpei. In: *Proceedings of the Sustainable Taro Culture for the Pacific Conference.*

Revill, P. A., Jackson, G. V. H., Hafner, G. J., Yang, I., Maino, M. K., Dowling, M. L., Devitt, L. C., Dale, J. L. and Harding, R. M. (2005). Incidence and distribution of viruses of taro (*Colocasia esculenta*) in Pacific Island countries. *Australasian Plant Pathology, 34,* 327-331.

Robin, G. C (2008). *Commercial dasheen (Colocasia esculenta (L.) Schott. Production and post-harvest protocol for the OECS.* CARDI, Dominica.

Sagoe, R. (2006). *Climate change and root crop production in Ghana.* Crops Research Institute, Kumasi. Prepared for Environmental Protection Agency (EPA).

Sar, S. A.; Wayi, B. M.; Ghodake, R. D. (1998). Review of research in Papua New Guinea for sustainable production of taro (Colocasia esculenta). *Trop. Agr. Trinidad,* 75, 134–138.

Seetohul, S., Puchooa, D. & Ranghoo-Sanmukhiya, V. M (2007). Genetic Improvement of Taro (Colocasia esculenta var esculenta) through in-vitro mutagenesis. *UoM Research Journal, 13A.*

Shakywar, R. C., Pathak, S. P., Pathak, M. & Singh A. K. (2012). Evaluation of taro (*Colocasia esculenta* var. Antiquorum) genotypes against leaf blight (*Phytophthora colocasiae*) under Eastern Uttar Pradesh Condition. *Hortflora Research Spectrum*; *1*(2), 184-186.

Shange, L. P. (2004).*Taro (Colocasia esculenta (L;) Schott) Production by Small-Scale Farmers in Azulu-Natal: Farmer Practices and performance of Propagule Types Under wetland and Dryland Conditions.* Master Thesis. University of Kwazulu-Natal, South Africa.

Sharvelle, E. (1961). *The nature and use of modern fungicides.* Minnesota, USA: Burgees publishing company.

Silva, J. A, D. M., Sato, P. S., Leung, G. D. and Kuniyoshi, J. (1990): Response of chinese taro to nitrogen and potassium fertilizers; P. 60 – 70. In. *workshop on taro plant production.* University of Hawaii, Honolum.

Singh, D., Hunter, D., Iosefa, T., and Okpul, T. (2001). *Guidelines for undertaking on-farm taro breding trials in the South Pacific.* AusAID/SPC/TaroGen, Suva, Fiji. Pp39.

Singh, D., Jackson, G., Hunter, D., Fullerton, R., Lebot, V., Taylor, M., Iosefa, T., Okpul, T., & Tyson, J. (2012).Taro Leaf Blight—A Threat to Food Security.*Agriculture, 2,* 182-203.

Sivan, P. (1977). Effects of spacing in taro (*Colocasia esculenta*).In *Proceedings of the 3rd Symposium of the International Society for Tropical Root Crops* (Nigeria, 1973), 377-381. Ibadan, Nigeria: International Society for Tropical Root Crops in collaboration with the International Institute of Tropical Agriculture, 492 pp.

Sriram, S., Misra, R. S., Sahu, A. K., and Maheswari, S. K. (2003). Rhizobacteria: Potential biological control agent against taro leaf blight pathogen. *Phytophthora colocasiae* (Racib.) *Journal of Root Crops, 29*, (1), 50-53.

Stephens, J. M. (1994). *Colocasia esculenta* (L.) Schott. Fact Sheet HS-592 from a series of the Horticultural Sciences Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. May 1994.

Sugha, S. K. & Gurung, K. (2007). Evaluation of taro (*Colocasia esculenta*) germplasm against leaf blight (*Phytophthora colocasiae*). *India Journal of Agricultural Science, 77*, 68-70.

Sukul, P. & Spiteller M. (2000). Metalaxyl: persistence, degradation, metabolism, and analytical methods. National Centre for Biotechnology Information Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12587832.

Taylor, M. & Iosefa, T. (2013). *Taro leaf blight: Manual.* Noumea Secretariate of the Pacific Community.

Tilialo, R., Greenough, D., and Trujillo, E. E. (1996). The relationship between balanced nutrition and disease susceptibility in Polynesian taro. In:

Mineral nutrient disorders of root crops in the Pacific. Proceedings of a workshop. Nuku'alofa, Kingdom of Tonga, 17–20 April 1995. (pp. 105–109). ACIAR Proceedings No. 65.

Trujillo, E. E. (1965). The effects of humidity and temperature on Phytophthora blight of taro. *Phytopathology 55*, 183-188.

Tyson J. L. & Fullerton R. A. (2015). A leaf disc assay for determining resistance of taro to *Phytophthora colocasiae*. New Zealand Plant Protection *68*, 415-419.

USDA (2010). *Phytophthora Species in the Environment and Nursery Settings New Pest Response Guidelines*; Technical Report; Animal and Plant Health Inspection Services (APHIS): Riverdale, MD, USA, 2010.

USDA. (2001). *Crop profile for taro in American Samoa*. United States Department of Agriculture Washington, DC: National Agricultural Statistics Service.

Van der Puije, G. C., Ackah, F. K. and Moses, E. (2015). Prevalence of Leaf Blight Disease Caused by *Phytophthora colocasiae* in Taro in the Aowin Suaman District of Ghana, *HortFlora Research Spectrum* 4 (3), 282-284.

Wagner, W. L., Herbst, D. R. and Sohmer, S. H. (1999). *Manual of the Flowering Plants of Hawaii*. Revised edition. Vol. 2. University of Hawaii Press/Bishop Museum Press.

Wall, G. C. and Wiecko, A. T. (1998). Screening of 29 taro cultivars (*Colocasia esculenta*) propagated *in vitro*, for resistance to taro leaf blight

(*Phytophthora colocasiae*). *Journal of South Pacific Agriculture, 5* (2), 9–12.

Wawra, S., Belmonte, R., Lobach, L., Saraiva, M., Willems, A., and van West, P. (2012). Secretion, delivery and functions of Oomycetes effector proteins. *Curr. Opin. Microbial.*15:685-691.

Zhang, G., & Zhang, D. (1990). The relationship between geographic distribution and ploidy level of taro, *Colocasiae esculenta. Euphytica 47*, 25–27.

APPENDICES

Appendix 1: Passport Format Used for Germplasm Collection

1. Collection number..... .... 2. Acession No:.....

1. Crop species:..... 4: collector (s):..... 5. Date:.....

2. Country: ..... 7. Region:..... 8. District:.....

9. Town:..... 10. Precise locality:.....

11.Altitute:..... 13. Longitute:.....

14. Soil and Topography:..... 15. Others.....

16. Local name:..... 17. Ethnic group:.....

18. Precipitation: less than 450mm-----, 551-650mm------, 651-900mm----, more than 900mm

19. Sample source: Field..... Garden..... Farm store..... Market..... Institution.....

20. Donor's Name:..... 21. Donor's source: Own..... Local..... Market... Others.....

22. Cultural practices: Rainfed..... Irrigated..... Flooded.....Transplanted.....

23. Planting Period:..... 24. Harvesting period:.....

25. Associated crop: Sole..... Mixed with .....

26. Population variability: Uniform..... Low .....Medium..... High.....

27. Disease:..... 28. Insects:.....

29. Agronomic score: Very poor------, Poor------, Average------, Good-----, Very Good----

30. Remarks: (Materials, Uses, etc).

Appendix 2: Sex of respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Female	52	24.8	24.8	24.8
	Male	158	75.2	75.2	100.0
	Total	210	100.0	100.0	

Appendix 3: Age of respondents

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20-29	6	2.9	2.9	2.9
	30-39	51	24.3	24.8	27.7
	40-49	58	27.6	28.2	55.8
	50-59	35	16.7	17.0	72.8
	60-69	33	15.7	16.0	88.8
	70-79	19	9.0	9.2	98.1
	80-89	4	1.9	1.9	100.0
	Total	206	98.1	100.0	
Missing	System	4	1.9		
Total		210	100.0		

Appendix 4: Highest level of education

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	no formal education	29	13.8	15.4	15.4
	primary education	30	14.3	16.0	31.4
	literscy adult	1	.5	.5	31.9
	education	100	47.6	53.2	85.1
	JHS/MSL	22	10.5	11.7	96.8
	SHS/O Level	4	1.9	2.1	98.9
	diploma/cert,A(Agric/ teacher)	183			

	tertiary	2	1.0	1.1	100.0
	Total	188	89.5	100.0	
Missing	System	22	10.5		
Total		210	100.0		

Appendix 5: Topography of site

		Frequency	Percent	Valid Percent	Cumulative Percent
	valleys	55	26.2	36.7	36.7
	flat	92	43.8	61.3	98.0
Valid	land/plains	3	1.4	2.0	100.0
	hills/high lands	150	71.4	100.0	
	Total	60	28.6		
Missing	System	210	100.0		
Total					

Appendix 6: The type of cropping system practised

		Frequency	Percent	Valid Percent	Cumulative Percent
	monocropping	128	61.0	64.6	64.6
	mixed cropping	58	27.6	29.3	93.9
Valid	inter cropping	12	5.7	6.1	100.0
	Total	198	94.3	100.0	
Missing	System	12	5.7		
Total		210	100.0		

Appendix 7: Respondents main source of planting material

		Frequency	Percent	Valid Percent	Cumulative Percent
	sprout by itself	88	41.9	41.9	41.9
	other farmers	39	18.6	18.6	60.5
Valid	from	76	36.2	36.2	96.7

	from the wild	5	2.4	2.4	99.0
	buy them	2	1.0	1.0	100.0
	Total	210	100.0	100.0	

Appendix 8: The mode of planting

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	row	24	11.4	11.9	11.9
	scattered	178	84.8	88.1	100.0
	Total	202	96.2	100.0	
Missing	System	8	3.8		
Total		210	100.0		

Appendix 9: Farmers' response to the observation of TLBD on their farm

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	184	87.6	91.1	91.1
	no	18	8.6	8.9	100.0
	Total	202	96.2	100.0	
Missing	System	8	3.8		
Total		210	100.0		

Appendix 10: Farmers' responses on the part of farm where disease is severe

	Frequency	Percent	Valid Percent	Cumulative Percent

	marshy area with flowing water	47	22.4	29.9	29.9
	marshy area with stagnant water	95	45.2	60.5	90.4
Valid	upland/dry land	8	3.8	5.1	95.5
	4	7	3.3	4.5	100.0
	Total	157	74.8	100.0	
Missing	System	53	25.2		
Total		210	100.0		

Appendix 11.Response of farmers of the taro crop area attacked by the disease

		Frequency	Percent	Valid Percent	Cumulative Percent
	the whole farm	75	35.7	75.8	75.8
	3/4 of the farm	12	5.7	12.1	87.9
	1/2 of farm	6	2.9	6.1	93.9
Valid	1/4 of farm	5	2.4	5.1	99.0
	10.00	1	.5	1.0	100.0
	Total	99	47.1	100.0	
Missing	System	111	52.9		
Total		210	100.0		

Appendix 12: Farmer's responses of the widespread nature of the disease in their locality

		Frequency	Percent	Valid Percent	Cumulative Percent
	everybody in my locality is affected	140	66.7	74.5	74.5
	only few people are affected	16	7.6	8.5	83.0
Valid	only me and those close to me are affected	6	2.9	3.2	86.2
	it only my farm that is affected	9	4.3	4.8	91.0

	dont know of anybody's problemof TLB	16	7.6	8.5	99.5
	10.00	1	.5	.5	100.0
	Total	188	89.5	100.0	
Missing	System	22	10.5		
Total		210	100.0		

Appendix 13: Attempted controlling the TLB disease

		Frequency	Percent	Valid Percent	Cumulative Percent
	yes	53	25.2	26.4	26.4
Valid	no	148	70.5	73.6	100.0
	Total	201	95.7	100.0	
Missing	System	9	4.3		
Total		210	100.0		

Appendix 14: Farmers responses on the Use of pesticide to control TLB

		Frequency	Percent	Valid Percent	Cumulative Percent
	yes	32	15.2	18.3	18.3
Valid	no	143	68.1	81.7	100.0
	Total	175	83.3	100.0	
Missing	System	35	16.7		
Total		210	100.0		

Appendix 15: Farmers response on the types of pesticides used

		Frequency	Percent	Valid Percent	Cumulative Percent
		183	87.1	87.1	87.1
	Actellic, Dursban,	1	.5	.5	87.6
	Akati Master	1	.5	.5	88.1
	Karate	1	.5	.5	88.6
	carbodan	1	.5	.5	89.0
	Conquest	1	.5	.5	89.5
Valid	Dursban and Funguran	1	.5	.5	90.0
	OH	2	1.0	.5	90.5
	dursban	1	.5	.5	91.4
	dursban	1	.5		91.9
	Dursban				92.4
	don't remember				

Don't remember	1	.5	.5	92.9
fertilizer	1	.5	.5	93.3
fungicide	1	.5	.5	93.8
funguran-OH	2	1.0	1.0	94.8
it will help me feed my family	1	.5	.5	95.2
Karate	2	1.0	1.0	96.2
karate	2	1.0	1.0	97.1
Lambda	1	.5	.5	97.6
no idea	1	.5	.5	98.1
poison	2	1.0	1.0	99.0
sumpyrifos	1	.5	.5	99.5
sunhalothin	1	.5	.5	100.0
Total	210	100.0	100.0	

Appendix 16: Response on the Frequency of pesticides application

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	as and when the disease appears	23	11.0	74.2	74.2
	more than once a month	4	1.9	12.9	87.1
	once a month	4	1.9	12.9	100.0
	Total	31	14.8	100.0	
Missing	System	179	85.2		
Total		210	100.0		

Appendix 17: Response on the effectiveness of pesticides

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2	173	82.4	82.4	82.4
	a bit effective	2	1.0	1.0	83.3
	it was not effective at all	1	.5	.5	83.8
	no	1	.5	.5	84.3
	not effecftive	7	3.3	3.3	87.6
	not effective	1	.5	.5	88.1
	Not effective	19	9.0	9.0	97.1
		2	1.0	1.0	98.1

	Somehow	1	.5	.5	98.6
	was not effective	1	.5	.5	99.0
	Wasn't effective	1	.5	.5	99.5
	yes	1	.5	.5	100.0
	Total	210	100.0	100.0	

Appendix 18: Responses on the use of Roguing/prunned affected plants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	yes	56	26.7	37.3	37.3
	no	94	44.8	62.7	100.0
	Total	150	71.4	100.0	
Missing	System	60	28.6		
Total		210	100.0		

Appendix 19: Frequency of How often do you rogue/prunne affected plant

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	as and when the disease appears	54	25.7	96.4	96.4
	during harvesting	1	.5	1.8	98.2
	once a month	1	.5	1.8	100.0
	Total	56	26.7	100.0	
Missing	System	154	73.3		
Total		210	100.0		

Appendix 20: effectiveness of roguing or prunning

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		150	71.4	71.4	71.4
	not effective	1	.5	.5	71.9
	2	1	.5	.5	72.4
	did not work	1	.5	.5	72.9
	it rather make it worse	1	.5	.5	73.3
	it was a bit effective	1	.5	.5	73.8
	It was not effective	2	1.0	1.0	74.3
	it was somehow effective	1	.5	.5	74.8
	n	1	.5	.5	75.2
	no	1	.5	.5	75.7
	not effective	1	.5	1.0	76.7
		2	1.0	.5	77.1
		1	.5		

not at all	1	.5	.5	77.6
not effective	30	14.3	14.3	91.9
Not effective	11	5.2	5.2	97.1
NOT EFFECTIVE	1	.5	.5	97.6
NOT EFFECTIVE AT ALL	1	.5	.5	98.1
not so effective	1	.5	.5	98.6
Very effective	1	.5	.5	99.0
wasnt effective	2	1.0	1.0	100.0
Total	210	100.0	100.0	

Appendix 21: Analysis of variance of severity of TLBD

Variate: Severity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season	1	101.6263	101.6263	102.07	<.001
District	9	103.5756	11.5084	11.56	<.001
Season.District	9	58.5054	6.5006	6.53	<.001
Residual	1780	1772.2068	0.9956		
Total	1799	2035.9141			

Appendix 22: Analysis of variance of Length of Pedicel of isolates

Variate: Pedicel_Length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
District	9	273.367	30.374	11.25	<.001
Residual	20	54.000	2.700		
Total	29	327.367			

Appendix 23: Analysis of variance sporangia length of isolates

Variate: Sporangia_length

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
District	9	1861.47	206.83	6.37	<.001
Residual	20	649.33	32.47		
Total	29	2510.80			

Appendix 24: Analysis of variance of sporangia width of isolates

Variate: Sporangia_width

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
District	9	214.133	23.793	2.41	0.049
Residual	20	197.333	9.867		
Total	29	411.467			

Appendix 25:Analysis of variance of colony diameter of isolates

Variate: Mean_Colony_Diameter_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Isolates	9	1.28625	0.14292	2.15	0.057
Residual	30	1.99750	0.06658		
Total	39	3.28375			

Appendix 26: Analysis of variance of the effect of temperature on growth of *P. colocasiae*

Variate: Mean_Colony_Diameter_cm

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Temperature_C	4	103.46240	25.86560	557.45	<.001
Residual	20	0.92800	0.04640		
Total	24	104.39040			

Appendix 27: Analysis of variance of lesion diameter of accessions

Variate: Mean_Lesion_Diameter_1 Mean_Lesion_Diameter

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Plant_number stratum	4	66.35	16.59	0.63	
Plant_number.*Units* stratum	20	7500.86	375.04	14.21	<.001
Gemplasm	80	2110.98	26.39		
Residual	104	9678.19			
Total					

Appendix 28: Principal component analysis of accessions

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.304	23.037	23.037	2.304	23.037	23.037
2	1.774	17.739	40.776	1.774	17.739	40.776
3	1.554	15.538	56.314	1.554	15.538	56.314
4	1.073	10.732	67.046	1.073	10.732	67.046
5	.971	9.706	76.752			
6	.654	6.538	83.289			
7	.609	6.092	89.381			
8	.433	4.334	93.715			
9	.376	3.759	97.474			
10	.253	2.526	100.000			

Appendix 29: Analysis of variance of radial growth of *P. colocasiae* on different rates of fungicides

Variate: Radial_Growth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fungicide	5	704.366	140.873	24.51	<.001
Treatment_ppm	4	106.870	26.717	4.65	0.001
Fungicide.Treatment_ppm	20	158.405	7.920	1.38	0.128
Residual	420	2413.701	5.747		
Total	449	3383.341			

Appendix 30: Analysis of variance the percentage inhibition of fungicides

Variate: Percentage_inhibition

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
fungicides	5	50503.9	10100.8	90.51	<.001
Residual	84	9374.6	111.6		
Total	89	59878.5			

Appendix 31: Analysis of variance of the effect of pruning and spacing on corm yield

Variate: Yield_kg

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
spacing	2		133.28	66.64	2.36	0.097
pruning	1		172.59	172.59	6.12	0.014
spacing.pruning	2		1.20	0.60	0.02	0.979
Residual	209	(1)	5891.43	28.19		
Total	214	(1)	6195.10			

Appendix 32: Analysis of variance of the effect of pruning and spacing on severity of TLBD

Variate: Average_Severity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	9.3356	4.6678	13.91	
Rep.*Units* stratum	2	13.8148	6.9074	20.59	<.001
spacing	1	27.8067	27.8067	82.88	<.001
pruning	2	1.8148	0.9074	2.70	0.069
spacing.pruning	208	69.7824	0.3355		
Residual	215	122.5544			
Total					

Appendix 33: Analysis of variance of the effect of pruning and spacing on incidence

Variate: incidence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
rep stratum	2	6550.9	3275.5	5.66	
rep.*Units* stratum	2	2384.3	1192.1	2.06	0.139
Spacing	1	7233.8	7233.8	12.49	<.001
Pruning	2	439.8	219.9	0.38	0.686
Spacing.Pruning	46	26643.5	579.2		
Residual	53	43252.3			
Total					