OCCURRENCE AND FARMERS’ AWARENESS ON SISAL BOLE ROT DISEASE IN MUHEZA DISTRICT, TANZANIA

Dissertation submitted to Sokoine University of Agriculture in Fulfilment of the Requirements for the Degree of Master of Science in Crop Science

By

Mary Zakayo Meena

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Supervisor

Dr. Paul J. Njau

Department of Crop Science and Horticulture, Sokoine University of Agriculture
Morogoro, Tanzania.

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EXTENDED ABSTRACT

Sisal (*Agave sisalana* L.) produce the world's most important natural hard fiber and Tanzania is the world's third largest producer of the fiber, accounting for more than 40% of global production. Muheza district is the second largest producer of sisal, after Korogwe district, which is the center of sisal industry in Tanzania and whose production is mainly based on rural estates and smallholders. The crop has adaptive advantages to stress conditions and pests, but bole rot is one of the main disease that causes significant damage to the crop. The disease is often associated with Aspergillus fungi and it has been a burden to the crop since 1930s. To date, there are four Aspergillus species recognized as the causal agents of the disease; *A. niger*, *A. welwitschae*, *A. brasiliensis* and *A. tubingensis*, but the predominant agent is *A. niger*. The infection of fungi to sisal plantlets and matured sisal plants results into death of plants, reducing its quality and quantity. In Tanzania, no research has been conducted to assess farmers' level of awareness neither on sisal bole rot disease or ~~on~~ the assessment of disease incidence and severity in farmers' field. This study aimed at determining farmers' level of awareness of bole rot disease and disease incidence and severity in farmers' sisal farms at three wards found in different agro-ecologies in Muheza district. A questionnaire was used in obtaining information from 71 small scale sisal farmers and three sisal estates found in Muheza district. Assessment of disease incidence and severity was conducted at the same wards, where three smallholders and one sisal estate at each ward were randomly selected by systematic sampling. A one hectare farm per small scale farmer and per estate was measured and studied during dry and rainy seasons in the same sisal farms.

Majority of sisal farmers (68.92%) had moderate (39-71%) level of awareness of bole rot disease whilst 6.76% of sisal farmers had low (0-38%) level of awareness. The farmers lack in-depth knowledge regarding sisal bole rot disease probably because most of them (89.19%) rely on their fellow sisal farmers' to obtain information on sisal production and on bole rot disease. More than half (72.9%) of the farmers, their sisal fields were affected by bole rot disease presumably due to the use of infected planting materials. The disease was found in all studied wards at different intensity possibly because of diverse climatic conditions and low altitude predominant in the surveyed wards. Kigombe ward located at low altitude had high disease incidence (36.43%), severity (32.54%) and disease intensity index of (42.40) while Tanganyika ward found in high altitude had low disease incidence (19.09%), severity (12.82%) and disease intensity index of 90.4. The development of bole rot disease was higher during wet season than during dry season in both surveyed wards and Kigombe ward had the highest disease incidence (46.46%) and severity (40.24%) probably because it is found in low land with flat areas which get flooded during heavy rainfall, a conducive environment for fungal infection, growth and reproduction. It was noted that all sisal growers (100%) still use unhealthy sisal planting materials namely suckers from previous crop to raise their new crop possibly due to lack of bole rot awareness and money. Education is important for improving farmers' awareness regarding sisal production and management of bole rot disease. A prepared comprehensive training module on sisal production practices with management practices of bole rot disease should be introduced to sisal farmers as a way of increasing their awareness on sisal production and management of bole rot disease**.** Efforts are needed to improve farmers to access healthy planting materials through effective distribution. Nurseries for the production of healthy sisal seedlings should be set up in each ward to facilitate farmer access and reduce transport costs. However, further studies to assessing farmers' level of awareness on bole rot disease and on the determination of disease intensity should be done in this and other sisal growing areas in Tanzania.

DECLARATION

I, **MARY ZAKAYO MEENA**, do hereby declare to the senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

______________________________ ______________________

Mary Zakayo Meena **Date**

(MSc. Crop Science Candidate)

The above declaration is confirmed by;

______________________________ ______________________

Dr. Paul. J. Njau **Date**

(Supervisor)

LIST OF PUBLISHED PAPERS

1. Assessment of farmers' awareness on occurrence, prevalence and management of sisal bole rot disease in Muheza District.

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   International Journal of Scientific Research Updates (IJSRU) 04(01), 223-235

2. Incidence and severity of sisal bole rot disease in small scale and estate farmers' fields in Muheza District.

   Mary Zakayo Meena and Paul J. Njau (2022). Incidence and severity of sisal bole rot disease in small scale and estate farmers' fields in Muheza District. *International Journal of Agriculture, Environment and Bioresearch (IJAEB)* 07 (04), 201-213

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DEDICATION

This precious work is dedicated to Almighty God, who guided me in my studies, without him nothing would have happened. Thank you to my beloved husband Henry Thomas and my lovely two sons Tierry Henry and Newton Zakayo. My thanks also go to parents Zakayo Eliuforo Meena and Delphina Joseph Njau for their tireless encouragement, prayers and support throughout my studies.

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ORGANIZATION OF THE DISSERTATION

This dissertation was developed in the form of published papers consisting of five main chapters. The first chapter is a general introduction, the second and third chapters consists of two published papers. Chapter four is the general / integrated discussion and chapter five contains the study's conclusions and recommendations.

LIST OF ABBREVIATIONS AND SYMBOLS

^0C	Degree Celsius
ANOVA	Analysis of Variance
CV	Coefficient of variation
DI	Disease incidence
DII	Disease intensity index
DS	Disease severity
e.g.	Example
h	hour
ha	hectare
i.e.	For example
LSD	Least Significance Differences
M.a.s.l	Meters above sea level
MSc	Master of Science
n.s	no significant difference
P-value	Observed significance level
r	Correlation coefficient
RH	Relative humidity
S.d	Standard deviation
S.e	Standard error of means
SUA	Sokoine University of Agriculture
t	tones
TARI	Tanzania Agricultural Research Institute
TMA	Tanzania Meteorological Agency
TV	Television
USD	United State Dollar
UV	Ultra Violet light

CHAPTER ONE

1.0 Introduction, Justification and Objectives

1.1 Introduction

Sisal ((*Agave sisalana* L.) is a plant which grows on dry and semi-arid soil. It is monocotyledonous, xerophytic, tender and perennial plant of the family Asparagaceae. It is a crop grown for hard fibres extracted from its succulent leaves. About 75% of world's hard natural fiber is obtained from sisal (Durte *et al*., 2018). The largest producer of sisal is Brazil with over 40% of total production worldwide, followed by Tanzania, Kenya, Madagascar and China (Mwaniki, 2018). The crop was introduced from Mexico by Hamburg in 1893, grown as commercial plantations in East and Central Africa, distributed to Kenya, Mozambique, Madagascar and Angola (Kivaisi and Mshandete, 2017). In Tanzania, sisal is among the six (6) major cash crops (Tanzania Agriculture, 2016) and the industry employs over 100 000 people (Tanzania Sisal Board, 2019). The sisal producing regions in Tanzania are Tanga, Morogoro, Kilimanjaro, Arusha, Shinyanga, Mwanza, Mara, Lindi, Mtwara and Coast (Tanzania Sisal Board, 2019). In Tanzania, most of the sisal is cultivated in Korogwe and Muheza districts in Tanga region. Two main sisal species are mostly planted, the Agave hybrid 11648 and *Agave sisalana*, with different amount of productivity, 17.6 t and 12.5 t correspondingly of dry fibre for a hectare (Nerini *et al.,* 2016). In the country, sisal is produced in large corporate estates and by small scale farmers as individuals or in groups. Sisal crop is more advantageous than other fiber crops as it develop on land unsuitable for other agricultural activities other than grazing, endures many environmental conditions, needs minimal maintenance and produces incessant fibers for about fifteen years with good management (Mwaniki, 2018). The crop is drought tolerant and can be mixed with other crops during the early growth phase (Mwaniki, 2018).

The economic future of sisal is promising as it produces the world's most important natural hard fibers with multiple industrial and agricultural uses and some are environmentally attractive. It is used in the manufacture of baled cord, carpets, hand bags, stacks, yarn, and other cordages. Additionally, it is used as a reinforcing fiber for laminated glass, rubber and cement products and in manufacturing anti-inflammatory, antimicrobial, anti-parasitic and antiseptic functions (Davis *et al*., 2017; Durte *et al*., 2018). Sisal wastes are used in the manufacture of electricity, organic fertilizers, alcoholic beverages and animal feeds (Durte *et al*., 2018).

In the 1960s, Tanzania was the largest sisal producer in the world with a production of 234 000 tons of dry fiber (Tanzania Agriculture, 2016). Then, in the 1970s, the sisal industry started to shrink and production dropped dramatically in 2015 to 15 200 tons of sisal and in 2019 production increased slightly to 17 900 tons (Tanzania Sisal Board, 2019**).** Regardless of the small increase in sisal production, crop productivity is still below the potential yield of at least 3 tons of sisal fiber per hectare (Catherine, 2019). The production of sisal fiber per unit area is still low (0.8 - 1.1 t / ha for small scale farmers and 2 - 2.5 t / ha for plantations (Catherine, 2019), while the potential yield (dry fiber / ha) 17.6 t / ha is 17.6 t / ha for the Agave 11648 hybrid and 12.5 t / ha for *Agave sisalana* (Nerini *et al*., 2016). Factors such as abiotic, economic and biotic factors contribute to the decrease in sisal production. One of the biotic factors responsible for huge losses in sisal cultivation is bole rot disease. This has been a burden on the sisal production industry in Tanzania since the 1930s (Cruz-Magalhãesv *et al*., 2019). The disease can affect both seedlings and adult plants and kill the entire plant consequently reducing its quality and quantity (Duarte *et al*., 2018)**.** Cruz-Magalhãesv *et al*., 2019 found that in sisal growing areas of Bahia Province in Brazil, the disease was present in all studied farms (100% prevalence) and on average, 35% of plants were affected with the disease. The levels of farm management within small-scale and estates farmers with respect to their productivity and bole rot disease management vary significantly. This variability has been due to different levels of bole rot awareness especially, regarding the occurrence, prevalence, and management practices. The challenge now is to provide the right technology for the control of bole rot to sisal farmers so as to increase their level of awareness of the disease for its effective management. Therefore, understanding the level of awareness among farmers and the extent of damage caused by bole rot pathogen will aid in the development of effective management strategies. The results of this study will undoubtedly lead to increased farmers' awareness of the disease, which is a key in guiding the development of disease intervention strategies that will improve sisal productivity and thereby fortifying the livelihoods of sisal farmers in Muheza district.

1.2 Justification

Tanzania's sisal subsector is one of the oldest agricultural enterprises in the country (Kivaisi and Mshandete, 2017). Natural fiber cultivation play an important role in our country's economic development. Their production, processing and export are very important for improving our country's economic performance and improving the livelihoods of farmers (Mwaniki, 2018). Sisal production is a source of income and employment for much of the population, and its cultivation is both beneficial and environmentally sound (Mwaniki, 2018). In 2016, the country reportedly earned $20.6 million from importing sisal fibers and its products (Kivaisi and Mshandete, 2017). The Muheza district produces 69% of all sisal grown in Tanzania, with a total harvested area of 47,648 ha in 2016 (Catherine, 2019). Still, its productivity is hampered by bole rot disease. This contributes to loss of sisal production as it can infect plants and lead to death (Duarte et al., 2018). Sisal hybrid (Agave hybrid11648) are more susceptible to bole rot than *Agave sisalana*, with pathogens found in plant stems and in soil near the rhizosphere of plants (Cruz-Magalhães *et al.,* 2019). The spread of disease within and between sisal farms is faster due to the fact that most farmers rely on suckers from previous crop to establish new fields of sisal (Cruz-Magalhães *et al.,* 2019).

There have been no previous studies in Tanzania on farmers' awareness on sisal bole rot or assessment of disease intensity (incidence and severity) in farmers' farms. Hounge *et al*. (2018) found that most studies focused primarily on yield and productivity and less attention paid on changes in farmers' awareness. Building knowledge among sisal farmers is perhaps the most important strategy for combating the disease, and the first step in building this knowledge is to understand the current state of farmers' awareness on bole rot disease (Houngue *et al.,* 2018). Therefore, to understand what farmers know about the disease, the disease prevalence in farmers' sisal farms and its impact on crop yield are important for development of effective agricultural extension services for efficient bole rot disease management.

1.3 Objectives

1.3.1 Overall objective

To evaluate the prevalence and farmers' perception of sisal bole rot disease in Muheza district with a view to developing sustainable strategies for managing the disease.

1.3.2 Specific objectives

i. To assess farmers' awareness on occurrence, prevalence, and management of bole rot disease in Muheza District.

ii. To determine the incidence and severity of sisal bole rot disease in small scale farmers and sisal estate fields in Muheza District.

CHAPTER TWO

Paper One

Assessment of Farmers' Awareness on Occurrence, Prevalence and Management of Sisal Bole Rot Disease in Muheza District

Mary Zakayo Meena[1], * and Paul J. Njau[1]

[1]Department of Crop Science and Horticulture, Sokoine University of Agriculture, P.O. Box 3005, Chuo Kikuu, Morogoro, Tanzania

* Corresponding author email: ladymazakayo74@gmail.com

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Abstract

In Tanzania, sisal is a good source of income and employment to many rural residents whose livelihoods depend on agriculture. For many years, Tanzania has been promoting sisal industry especially by encouraging small scale farmers' participation in the sisal industry. One of the important diseases threatening sisal production is bole rot, a disease that is commonly associated with fungus of the *Aspergillus* species. Four species of Aspergillus have been identified to be the causative agents of the disease; these are *A. niger*, *A. welwitschae*, *A. brasiliensis and A. tubingensis*, but *A. niger* is the most important agent. This study aimed to determine farmers' level of awareness on bole rot disease. A questionnaire was employed to obtain both qualitative and quantitative data from 71 small scale farmers and three sisal estates from three major sisal growing wards found in different agro-ecologies of Muheza district. Data was collected using ODK Collect *v2021*.2.3 tool and were inputted using SPSS 20 software, transformed using Arcsine and analyzed using both descriptive and inferential statistics. A Students t-test was carried out to check on the effect of sources of information on farmers' level of awareness on bole rot disease. Majority of sisal farmers (89.19%) depend on their fellow sisal farmers to get information on sisal bole rot disease with the least source of information been sourced from posters (2.70%). The results revealed that most sisal farmers (68.92%) have moderate (39-71%) level of awareness on bole rot disease whilst 6.76% had low (0-38%) level of awareness. The famers' lack of a more knowledge of the disease is probably due to the fact that they rely heavily on their fellow sisal farmers to get information on sisal bole rot disease, who may have little or incorrect information. Pearson product moment correlation was used to find the relationship between production practices, some selected social-demographic variables with farmers level of awareness on bole rot disease. The results revealed that, the correlation between full time farmers and the level of awareness was 78.4%. Accordingly, Farmers who spend more time at farm tend to have high level of awareness as they are able to identify any unusual problems at their farm and seek appropriate solution. High correlation (86%) was observed between experienced sisal farmers with level of awareness on bole rot disease as they gain more knowledge based on their long years of experience. The results also revealed that, there is a significant and positive relationship (78.80%) between farmers' education and level of awareness on sisal bole rot disease. The educated sisal farmers are more likely to be aware of recommended sisal production practices which reduce bole rot disease than those with less or no education. The research suggests that training on the use of integrated management practices against sisal bole rot disease should be given to sisal farmers. Extension officers should be empowered to deal with sisal bole rot disease so that they can help the farmers. Extension officers should increase the participation of farmers in extension programs so to increase the level of awareness among farmers

Key words: *Agave sisalana,* Aspergillus, awareness, bole rot, Muheza, sisal

2.1 Introduction

Sisal (*Agave sisalana* L.), is a plant originated from Northern and Central America, being cultivated in tropical countries. In Tanzania, the sisal land use is basically a high input, large-scale monocropping system, dominating the hotter and drier areas below 900 m.a.s.l. (Kimaro, 1994). In Tanzania, the crop is mostly grown in large plantations owned by companies and currently there are 48 sisal estates (Catherine, 2019). Cruz-Magalhães *et al.* (2019) reported that, sisal, although is tolerant to drought stresses and resistant to most pests and diseases, it is being attacked by a fatal fungal disease known as bole rot. The disease has become increasingly important in the last few years and it is one of the factors responsible for the decline of sisal production (Duarte *et al.,* 2018).The disease has been reported in Brazil and in Tanzania by Duarte *et al.* (2018) and Cruz-Magalhães *et al.* (2019). It is caused by black aspergilli, including *A. niger*, *A. welwitschae*, *A. brasiliensis and A. tubingensis*, but *A. niger* is the most important agent (Santos *et al.,* 2014). The diseased plants exhibit wilting and yellowing of the aerial parts and brown to a red-colored rot of the bole that leads to plant death (Duarte *et al.,* 2018).

Farm management levels within the small scale and estate farmers pertaining to their production practices, management of bole rot disease and productivity vary considerably and much of variability has been attributed to their different level of awareness on bole rot disease**.** The challenge now is to deliver the correct technology for the management of bole rot disease in order to uprising farmers' level of awareness of bole rot disease**.** Rogers *et al.* (2014) and Anane (2020) indicated that, awareness and knowledge of a new technology is the first step in the adoption process. Through lack of awareness, farmers' evaluation of an innovation may not agree with an expert's**.** Several reports have found that, higher level of awareness of farmers results into better adoption of management practices of diseases of plants. Amon-Armah *et al*. (2020) reported that higher knowledge about black pod disease of cocoa was significantly translated into adoption of the proper way of disposing the diseased pods compared with farmers with lower knowledge. Bua (2017) reported that, lack of awareness on disease recognition and management of Cassava Brown Streak Disease (CBSD) among smallholders in Northern Uganda contributed significantly to rapid spread of the disease. A survey conducted in Philippines by Heong and Ho (2019) found that, most rice farmers were able to describe tungro disease symptoms of rice but gaps existed in their understanding of the causes and modes of spread. Most of them were unaware of the risk of leaving infected plants in the field, which can act as a source of disease inocula, which in turn became a threat to new planting. It is important to assess farmers' level of awareness on bole rot disease so as to be able to design effective extension services that will improve their level of awareness on bole rot disease. Thus, this study was conducted to determine farmers' level of awareness on occurrence, prevalence, and management of bole rot disease.

2.2 Materials and Methods

2.2.1 Description of the study area

The study was carried out in three wards selected randomly at different altitudes of Muheza district. The three wards are: Ngomeni located at the altitude of 107m.a.s.l, longitudes of 38.9191 S and latitudes of -5.1866 E; Tanganyika ward located at altitude of 200 m.a.s.l, longitudes of 38.8055 S and latitudes of -5.1613 E and Kigombe ward located at the altitude of 22 m.a.s.l, longitudes of 39.0018 S and latitudes of -5.2907 E (Fig.2.1).

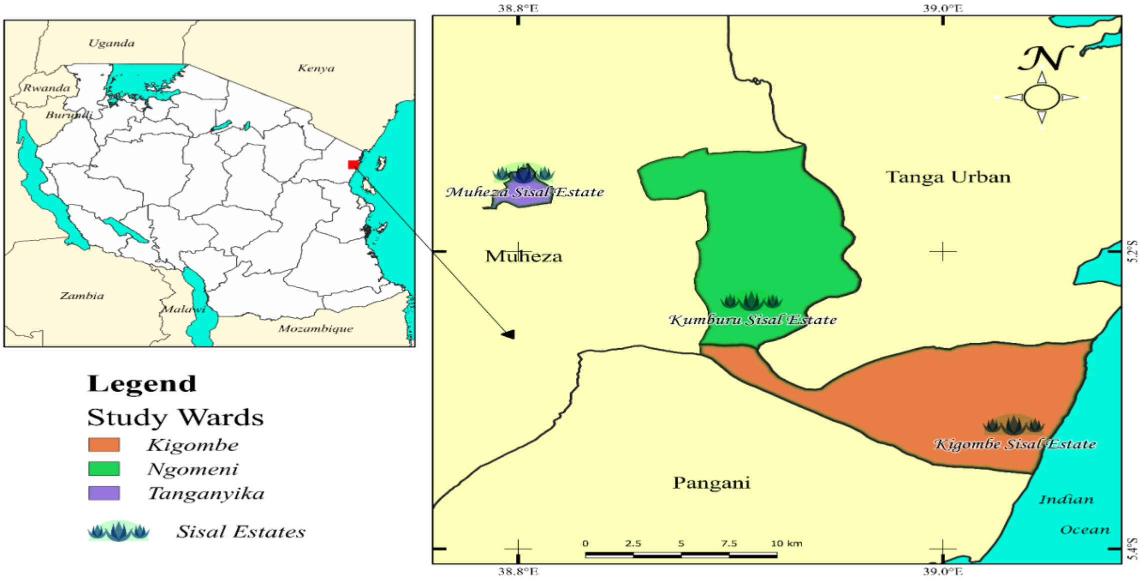

Figure 2.1: A map of Muheza district showing the study area

2.2.2 Survey, data collection and analysis

2.2.2.1 Assessment of farmer's awareness on occurrence, prevalence and management of bole rot disease

The study on assessment of farmers' awareness on sisal bole rot disease in Muheza District was carried out by obtaining the total number of farmers who grows sisal from ward offices through ward agricultural officers. The population of study consisted of 55 small scale farmers from Ngomeni ward, 13 small scale farmers from Kigombe ward, three small scale farmers from Tanganyika ward and three sisal estates, one sisal estate per ward. The study employed a survey research methodology of using a structured self-administered questionnaire to collect data on farmers' socio-demographic characteristics, production practices and awareness on occurrence, prevalence and management of bole rot disease. A total of ten (10) questions with twenty one (21) answers about farmers' awareness on bole rot disease were developed. Initially, the questionnaire was pre-tested to ascertain its suitability and/or reliability where a total of 10 farmers were interviewed. Based on the feedback from the pre-test, the questionnaire was revised into its final format. The questionnaires were written in Swahili and some in English language to make easy for the non-Swahili speaking participants to understand. For those participants that were unable to read, the investigator read each question and the participants responded verbally. The type of information and specific data collected from the questionnaire plus the questionnaire are presented in Appendix 1 and 2 respectively.

2.2.2.2 Statistical analysis

Collected data from sisal farmers were coded and entered into Microsoft Excel 2016, transformed using the arcsine square root transformation formula as described by Mousanejad *et al.* (2010) as: $Y = \text{Arcsine} \sqrt{P}$, where, Y is transformed data, and P is the observed proportion. Analysis was done by using Statistical Package for Social Science (SPSS 20) software using descriptive and inferential statistics. Descriptive analyses such as frequencies, percentages and means were employed to clarify the general data of the study. Quantification of farmers' level of awareness on occurrence, prevalence and management of bole rot disease was made by giving one score and zero score for correct and incorrect answers respectively. The score of all the individual items was summed to get the final awareness score of the farmers. Based on the total score obtained, farmers were categorized into three categories of low, moderate and high level of awareness. A student t-test was carried out to check on the effect of sources of information on farmers' level of awareness on bole rot disease In addition, to fulfill the objective of identifying any relationship that might exist between production practices, some selected social-demographic variables with farmer's level of awareness, inferential analysis (Pearson product-moment correlation) was applied.

2.3 Results

2.3.1 Assessment of farmers awareness on bole rot disease

Responses from the assessment of farmers' socio-demographic information, awareness on occurrence, prevalence and management of sisal bole rot disease, and the relationship between production practices, some selected social-demographic variables with farmers level of awareness on sisal bole rot disease done in three wards of Muheza district are presented in Table 2.1-2.5.

2.3.1.1 Socio-demographic information of farmers

Social-demographic data of the surveyed sisal farmers in Table 1 demonstrates that, majority of the farmers were males as they represent 63.5% compared to only 36.5% of female. A total of 31.1% sisal farmers were in the age above 50 years, followed by 29.7% who were in the age of 41-50 years. Farmers with the age of 31-40 years were 21.6% and those with age between 21-30 years were 17.6%. None of the farmer interviewed was in the young category age of ≤ 20 years. The mean age of the farmer's was 45.8 years old. The results revealed that, 55.4% of farmers interviewed in all wards had attained primary education, followed by 27% who possessed secondary school qualification while 17.6% had tertiary education (colleges and university). There was no sisal farmer who did not have any formal education. More than half of the sisal farmers (59.5%) were not full time sisal producers as most of them were self-employed and working on other business such as farming other crops (40.9%), businessmen (27.3%), government and private employees (25.0%), livestock keepers (15.9%), other occupations (15.9%) and fishermen (4.6%). The results revealed that, 68.9% of the farmers family income was obtained from farming, followed by business (18.9%) and livestock keeping which was 16.2%. It was noted that, 62.2% of the interviewed farmers' positions in the household are fathers, 29.7% are mothers and children are 8.1%. The study found that 63.5% of the small scale sisal farmers cultivate sisal on land of an average of one to two (1-2) hectares, followed by 27.0% with three to four (3-4) hectares, 5.4% farmers with five to six (5-6) hectares of sisal farms and 4.1% (all three sisal estates) had more than six hectares of sisal farms. The average size of land of the small scale farmers was 2.6 ha.

Table 2.1: Socio-demographic profile of sisal farmers in Muheza District

Categories	Frequency (N)	Percentage (%)	Mean Scores
Gender			
Male	47	63.5	
Female	27	36.5	
Age (years)			45.8
<20	00	0.0	
21- 30	13	17.6	
31- 40	16	21.6	
41- 50	22	29.7	
> 50	23	31.1	
Level of Education			
Primary school education	41	55.4	
Secondary school education	20	27.0	
Tertiary education	13	17.6	
Full time sisal farmer			
Yes	30	40.5	
No	44	59.5	
Other occupations			
Farmers	18	40.9	
Livestock keepers	07	15.9	
Businessmen	12	27.3	
Fishermen	02	4.6	
Government/private sector employee	11	25.0	
Other occupations	07	15.9	
Sources of family income			
Farming	51	68.9	
Livestock keeping	12	16.2	
Business	14	18.9	
Contribution of sisal in farmers economy			
Provide income	62	83.8	
Improve living standards	57	77.0	
Provide self-employment	53	71.6	
Used as a field marker	26	35.1	
Size of sisal farm (ha)			2.6
1-2	47	63.5	
3-4	20	27.0	
5-6	04	5.4	
> 6	03	4.1	

Source: Own compilation from field survey data (2022), the total number of respondents is not 74 due to multiple selection of answers

2.3.1.2 Influence of sources of information on farmers' level of awareness on occurrence, prevalence and management of sisal bole rot disease

Results indicated that, majority of sisal farmers depend on their fellow sisal farmers (89.19%) and extension officers (81.08%) for information on sisal bole rot disease with the least source of information been sourced from posters (2.70%). A Students t-test was carried out to check on the effect of sources of information on farmers' level of awareness on bole rot disease. A null hypothesis "Sources of information had no influence on farmers' level of awareness on bole rot disease" tested at 95% confidence interval. Results revealed that, different sources of information used by farmers on sisal bole rot disease have significant influence on farmers' level of awareness on bole rot disease at ($p<0.05$). These includes the use of friends (18.92%, t =4.12), fellow sisal farmers (89.19%, t =24.89), extension officers (81.08%, t =17.20), village leaders (6.76%, t =2.29), school during studying (6.76%, t =2.29), TV/radio (9.46%, t =2.76) and other sources such as phones (21.06%, t =4.83) and internet (9.50%, t =2.97). At ($p>0.05$), source of information such as posters (2.70%, t =1.42) had no significant influence on farmers' level of awareness on sisal bole rot disease (Table 2.2).

Table 2.2: Influence of sources of information on farmers' awareness on occurrence, prevalence and management of sisal bole rot disease

Sources of information	(n)	(%)	S.d	t- value	p-value
Friends	14	18.92	0.39	4.12	0.0001
Sisal farmers	66	89.19	0.31	24.89	0.0000
Posters	2	0.03	0.16	1.42	0.1587
Radio/TV	7	9.46	0.29	2.76	0.0073
Extension officers	60	81.08	0.40	17.20	0.0000
Village leaders	5	6.76	0.25	2.29	0.0243
School	5	6.76	0.25	2.29	0.0243
Phone	16	21.06	0.43	4.83	0.0000
Internet	7	9.50	0.31	2.97	0.0040

N=74, S.d=Standard deviation. The total number of respondents is not 74 due to multiple selection of answers

2.3.1.3 Farmers awareness on occurrence, prevalence and management of sisal bole rot disease

Results of farmers' awareness on occurrence, prevalence and management of sisal bole rot disease are presented in Table 2.3. Results shows the correct and incorrect answers by sisal farmers based on a total of 10 questions with 21 answers related to occurrence, prevalence and management of sisal bole rot disease. It is revealed that, almost all farmers (98.7%) responded that they have heard about sisal bole rot disease and more than half (64.9%) of farmers were aware that sisal plantlets at the nursery stage are mostly infected by bole rot pathogen and all farmers (100%) were able to identify the symptoms of bole rot disease at their field. The analysis indicated that 72.9% of all farmers reported that they had bole rot disease in their sisal fields and majority of the farmers (78.4%) did not know that bole rot disease is caused by fungus. All sisal farmers, 100% managed to answer correctly the spread of bole rot disease from infected to new sisal fields and 58.1% of farmers were able to identify methods of infection of the fungus to the crop. Further, the results revealed that 98.7% farmers (small scale farmers and estates) across all the three wards were able to recognize the effect of bole rot disease in their yield as they all experience losses in sisal production in terms of quantity and quality. It was also observed that, 98.7% of sisal farmers were using various sanitation practices and all were using different management practices in their fields to reduce the incidence of bole rot disease. Therefore, results in (Table 2.4) revealed that few farmers (6.76%) had low level of awareness regarding occurrence, prevalence and management of bole rot disease followed by 68.92% that belong to moderate level and 24.32% of farmers had high level of awareness on occurrence, prevalence and management of bole rot disease.

Table 2.3: Farmers' response on different questions measuring awareness on occurrence, prevalence and management of sisal bole rot disease

Statements/questions	Farmers responses			
	Correct answer		Incorrect answer	
	n	%	n	%
Heard of sisal bole rot disease by farmers	73	98.7	01	1.4
Plant stage mostly affected by bole rot disease	48	64.9	26	35.1
Symptoms of the disease to sisal crop	74	100.0	00	0.0
Presence of bole rot disease in the sisal field	54	72.9	20	27.0
Cause of the sisal bole rot disease	16	21.6	58	78.4
Methods of infection of fungus to sisal crop	43	58.1	31	41.9
Spread of bole rot disease in the field	74	100.0	00	0.0
Effect on sisal yield due to bole rot disease	73	98.7	01	1.4
Sanitation practices used to reduce bole rot	73	98.7	01	1.4
Management practices of sisal bole rot	74	100.0	00	0.0

Source: Own compilation from survey data (2022)

Table 2.4: Categorization of farmers based on their level of awareness on occurrence, prevalence and management of sisal bole rot disease

Level of awareness	% level of awareness	Frequency (n)	(%) frequency
Low (0-8 scores)	0-38	5	6.76
Moderate (9-15 scores)	39-71	51	68.92
High (16-21 scores)	72- 100	18	24.32

n= 74, Minimum score =8 and Maximum score =21

2.3.1.4 Pearson correlation of some selected social-demographic variables, production practices with farmer's awareness on bole rot disease

Pearson product-moment correlation analysis was conducted to identify the relationship between some selected social-demographic variables, production practices with farmers' awareness on bole rot disease. Results in Table 2.5 revealed that social-demographic factors such as age, gender, education level have significant relationship at 5% and 1% level of significance with farmers' level of awareness on bole rot disease. Production practices such as experience in sisal production, full time sisal farmers, kind of planting material used to establish sisal field, consideration of mother plants age during selection of planting materials, times for carrying weeding in sisal field, harvesting season of sisal crop, removal and destruction of infected plants, ever attended training on sisal production, and adoption of new technology on sisal production have significant relationship at 5% and 1% level of significance with farmers level of awareness on bole rot disease. Factors such as farm size, hiring of labour, use of fertilizers with Calcium to prevent plant stresses, disinfection of tools/machines/cloth/ shoes/hands and number of adopted new technology on sisal production were identified to be non-significant at 5% and 1% level of significance with farmers' level of awareness on bole rot disease as they were not correlated.

Table 2.5: Pearson correlation between selected social-demographic variables, production practices with farmers' level of awareness on bole rot disease

Variables	Correlation coefficient (r)
Age	0.610**
Gender	0.635**
Education	0.787**
Experience (years) in sisal production	0.860**
Full time sisal farmer	0.784**
Hire labour to conduct farm work	0.002 ns
Kind of planting material used to establish sisal field	0.766**
Selection of planting materials	0.652*
Disinfection of tools/machineries/cloth/shoes/hands	0.012ns
Application of lime in acidic soil, water logging areas	0.461**
Use of fertilizers with (Ca) to prevent plant stresses	0.183ns
Times in a year for carrying out weeding in sisal field	0.583*
Season of harvesting sisal crop	0.510**
Removal and destruction of diseased plants	0.584*
Attended training on sisal production	0.809**
Adopted any new technology on sisal production	0.932**
No. of adopted new technology on sisal production	0.481ns

**Correlation is significant at 1% level, * Correlation is significant at 5% level (2-tailed) and ns is no significant correlation at 1% or 5% level of significance

2.4 Discussion

2.4.1 Farmers' awareness on occurrence, prevalence and management of bole rot disease

2.4.1.1 Socio-demographic characteristics of sisal farmers

The study on socio-demographic characteristics of sisal farmers revealed that most of the sisal farmers were males. This result tally with those of Marechera *et al.* (2014) who reported that, males in Tanzania are more active in agricultural activities than females. Additionally, this finding is supported by those of Anitha *et al*. (2019) who found that high proportion of farmers in Ghana are males rather than females due to cultural differences. Furthermore, most of the sisal farmers were older farmers with no involvement of younger generation in sisal production sector. This results are consistent with most of the local studies on agriculture conducted in Malaysia by Adnan *et al.* (2017) who found that, in Malaysia there are still having inadequate number of young farmers. Parthiban *et al.* (2017) indicated that most of the oil palm smallholders were older farmers with less involvement of younger generation in the oil palm sector. Furthermore, Sebaggala and Matovu (2020) in their research indicated that, although older farmers may be more experienced, which could have a positive effect on access to information; younger farmers are wanted in crop production as they may have a longer planning horizon hence vibrant in searching for information. The research found however that, there was no farmer who did not have any formal education.

This finding was in agreement with that of National Bureau of Statistics (2013) in Tanzania who reported that over 80% of the populations in Tanzania mainland have attained primary education. Education level was directly related to farmers' level of awareness on bole rot disease. In addition, the study conducted by Rizwan *et al*. (2020) found that people who are more educated are more aware of the risks associated with plant diseases compared to less educated people. More than half of the sisal farmers were not full time sisal producers and most of them are self-employed and working on other business such as farming other crops, businessmen, public and private employees, livestock keepers, fishermen among other occupations. Majority of sisal farmers acknowledged the contribution of sisal in their economy as source of family income, improve in family living standards and provide self-employment. The average size of sisal farms for small scale sisal farmers is 2.9 ha. Majority of the farmers were small scale, having farm size of 1-2 ha and most of them have recently entered in sisal production sector. Previously, sisal cultivation was done by estates only. This finding is supported by Catherine, (2019) and Tanzania Sisal Board, (2018) who indicated that sisal crop is mostly grown in large plantations owned by companies and currently there are 48 sisal estates but small scale farmers also plant sisal. FAO (2013) as cited in Mwaniki (2018) and Baleko (2020) commented that, approximately 25% of sisal is produced by small scale farmers.

2.4.1.2 Influence of sources of information on sisal production and bole rot disease among small scale and estate farmers in three wards of Muheza district

The study revealed that, majority of the sisal farmers depend mostly on their fellow sisal farmers and extension officers to obtain information on sisal production. This finding suggested that extension officers and farmers themselves play an important role in disseminating information. Farmers themselves play a big role in disseminating information to each other especially if they have got the right information. Furthermore, some farmers were sourcing information from their friends and with the least amount of information sourced from village leaders, schools, posters, radio and Television and other sources included phones and internet. Radio and television are very effective in communicating to farmers who cannot read. This finding is in agreement with that of Mittal and Mehar (2016) reported that, farmers extensively rely on other farmers and face-to-face interactions as their sources of information. Additionally, Javaid (2017) reported that, friends and village leaders are among the most preferred and trusted source of agricultural information among rural community as it is easily and frequently available.

2.4.1.3 Farmers' level of awareness on occurrence, prevalence and management of sisal bole rot disease

All sisal farmers interviewed had moderate level of awareness on occurrence, prevalence and management of bole rot disease and almost all sisal farmers have heard about the disease and it is present in their sisal fields. This might be due to the fact that they all uses suckers/stolons which might have probably been infected when establishing their new fields. This finding is in agreement with those of Cruz-Magalhães *et al.* (2019) saying that, infected plant materials contributes to the spread of the disease to new areas.

Additionally, majority of the sisal farmers had a basic understanding on sisal bole rot disease as they were able to identify the symptoms of bole rot disease which are wilting of leaves, yellowing of leaves starting at the stem base, plant internal tissues become brown, with a reddish border, bole starts to rot and death of plant. Furthermore, they managed to list different ways of spreading bole rot disease which are planting of affected planting materials, using contaminated tools/machines and through contaminated clothes, shoes and hands. Majority of farmers were correctly able to identify methods of infection of the fungus and different management practices (preventive measures) for reducing sisal bole rot such as washing and disinfection of tools and machinery before and after farm work, disinfection of shoes, cloth, and hands before and after farm work, weeding of the sisal farms, uprooting and destruction of infected plants, using of health planting materials, do harvest when it is dry, application of lime material in areas with acidic soil and water logging areas and the use of fertilizers enriched with Calcium effectively in the fields to reduce the incidence of bole rot disease. These results are in agreement with those of Jacobsen *et al*. (2019) saying that, the establishment of new areas using healthy plant materials is thought to be one of the most effective ways to prevent the introduction of the pathogen together with removal and destruction of diseased plants from the plantations, avoid nutritional stresses through balanced fertilization to prevent stresses and disinfection of the tools used in diseased plants are other measures recommended to decrease the incidence and avoid the spread of the disease to new areas. Additionally, the results are supported by Cruz-Magalhães *et al.* (2019) who indicated that, for the moment, preventive measures should be employed to avoid the establishment of the pathogen in the area. On the other hand Parthiban *et al.* (2017) indicated that, there are few numbers of disease control and management techniques that can be applied to reduce long term losses due to Ganoderma disease and preventive control such as sanitation by removal of diseased palms and usage of biofertilizer. Contrariwise, most of the sisal farmers were not aware that sisal plantlets at the nursery stage are mostly infected by pathogens and also unaware that bole rot disease is caused by fungus. This might be due the fact that most of the sisal farmers had a basic understanding on bole rot disease and not in-depth knowledge on bole rot disease because most of them were obtaining information from their fellow farmers and some from their friends who might have limited information on bole rot disease. The finding is being supported by those of Parthiban *et al.* (2017) indicating that most of the respondents interviewed had a basic understanding on basal stem rot (BSR) rather than in-depth knowledge due to the fact that most of the respondents were referring to their friends as one of the source of information who themselves might have a limited knowledge on BSR. Therefore, extension services need to be easily and frequently available to sisal farmers as a way to encourage them to sought information from extension agents.

2.4.1.4 Correlation of selected social-demographic variables, production practices with farmers awareness on occurrence, prevalence and management of bole rot disease

Results for the correlation analysis revealed that, there was significant and positive relationship between education level and farmer’s level of awareness on sisal bole rot disease. The educated sisal farmers are more likely to be aware of recommended sisal production practices which reduce bole rot disease than those with less or no education. Results are similar to those obtained by Muddassir *et al.* (2019) found that educated farmers are more likely to adopt the recommended crop production practices than those with less or no education. The educated farmers could expedite technology uptake and impact positively on any developmental program executed in the management of diseases. Additionally, Grimaccia and Naccarato (2019) said that, education plays a vital role because it is easy to understand and getting required information by educated farmers than the illiterate ones. Ashraf *et al*. (2015); Rahaman *et al.* (2020) documented significant relationship between education and awareness and indicated that, education develops sense among farmers to implement the cost effective technologies.

Furthermore, the results indicate that, there is existed positive relationship between age and awareness of sisal farmers on bole rot disease. Farmers who have more age had high level of awareness than the young ones. This finding is in line with those of Ashraf *et al.* (2015) which infer that, as the age of the farmers’ increase, maturity increase which may boosts the interest to acquire new information. This finding differs from that of Bagheri *et al*. (2019); Chia *et al.* (2020) and Khan *et al.* (2022) who were of the view that, age and awareness of farmers have a negative association. These authors said that, as the age increase, interest to seek new information goes down. The analysis also revealed that farmers who work full time on their farm tend to have high level of awareness on disease as they are more committed in seeking knowledge compared to non-full time farmers. Parthiban *et al.* (2017) reported that, farmers who spend more time at farm tend to have high level of awareness as they are able to identify any unusual problems at their farm and seek appropriate solution. Experienced farmers in production tend to have high level of awareness on bole rot disease as they gain more knowledge based on their long years of experience. These results coincide with the findings reported by Šūmane *et al*. (2018) that, extensive training need to be given to farmers as a way to increase their experience which will eventually result in to higher level of awareness. The analysis of correlation between production practices with farmers level of awareness revealed that farmers who are able to carry out production practices, which are management practices for reducing bole rot disease such as to consider the kind of planting material to be used to establish sisal field, the age of the mother plants before harvesting planting materials, application of lime in acidic soil and water logging areas to reduce plant stresses, removal of infested plant materials from the fields, carrying out weeding in sisal field to keep the farms clean, do harvesting during dry seasons, attended training and adoption of any new technology on sisal production are the farmers with high level of awareness on occurrence, prevalence and management of bole rot disease because they have managed to apply different management practices in their sisal farms to reduce the disease prevalence but sisal farmers with low level of awareness are unable to carryout management practices in their sisal fields during sisal production. This coincides with sisal production guideline, (2015), which recommended that, application of calcium-rich fertilizers in waterlogged, application of agricultural lime in highly acidic soils, removal of infested materials from the field and harvesting under dry conditions reduces the disease incidence. These production practices could only be done by sisal farmers with high level of awareness on bole rot disease. It is clearly shown that, farmers who have attended training on sisal production have better level of awareness on bole rot disease as compared to farmers who have never attended any training. Similarly, adoption of new technologies by farmers on sisal production have significant correlation to the level of awareness on bole rot disease. Parthiban *et al.* (2017) indicated that, adoption of new technology contribute significantly towards the level of awareness. This is so because farmers who are adopting new technologies are always acquiring the latest information thus increasing their awareness. Parthiban *et al.* (2017) also indicated that, higher number of technology adopted by farmers resulted into higher level of awareness.

2.5 Conclusions and Recommendations

The objective of this study was to identify farmers' level of awareness of bole rot disease in small scale and sisal estates in Muheza district. The study revealed that more than half of the interviewed sisal farmers had moderate and some had high and few with low level of awareness regarding the sisal bole rot disease. It was revealed from the correlation analysis that, some selected social-demographic variables such as age, education and gender, together with several sisal production practices done by farmers in their sisal fields had significant relationship with the level of awareness on bole rot disease. Farmers who are able to carry out production practices in their sisal fields had high level of awareness on bole rot disease than those who are not able to practice identified production activities. The study also revealed that, main source of information on sisal bole rot disease and sisal production among farmers are their fellow sisal farmers and extension officers. Therefore, extension services need to be easily and frequently available to sisal farmers as a way to increase their participation in extension programs to increase their awareness. Based on the findings of this study, it has been recognized that education is important for improving farmers' awareness on bole rot disease. Therefore, extension office in Muheza district should introduce the prepared training module on bole rot disease to sisal farmers as a way to increase their awareness. One of the limitations of this study is that it only involved sisal farmers from three wards of Muheza district rather than farmers from all areas of sisal production in Tanzania. While the study greatly helped in identifying level of farmers' awareness on sisal bole rot disease in three wards of Muheza district, it is difficult to generalize the results to the entire sisal growers in Tanzania. Therefore, further study should be conducted comprising respondents representing farmers from all sisal growing areas in Tanzania.

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CHAPTER THREE

Paper Two

Incidence and Severity of Sisal Bole Rot Disease in Small Scale Farmers and Sisal Estate Fields in Muheza District

Meena, Mary Zakayo[1*] and Paul J. Njau[1]

[1]Department of Crop Science and Horticulture, Sokoine University of Agriculture, P.O. Box 3005, Chuo Kikuu, Morogoro, Tanzania

* Corresponding author email: ladymazakayo74@gmail.com

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Abstract

Sisal (*Agave sisalana* L.) yields the world's main natural strong fiber used to produce several industrial products and its cultivation plays an important and diverse role in the economic development of many countries around the world. In Sub-Saharan Africa, sisal plays a crucial role economically, socially and environmentally. However, sisal production is under threat due to sisal bole rot disease which is responsible for a great loss of sisal in most areas whereever the crop is produced. A survey was conducted during dry and wet seasons in sisal producing areas in Muheza district with the aim of determining the incidence and severity of bole rot disease. The assessment of disease incidence and severity was done in three wards. In each ward, one sisal estate and three small scale sisal farmers were selected through systematic random sampling and a one hectare farm per farmer's sisal field and estate was measured and surveyed on January for dry season and May for the wet season in the same sisal farms. Monthly weather data (temperature, relative humidity and rainfall) of January to May of the three wards were recorded from Tanzania Meteorological Agency (TMA). Before analysis, data were transformed using the arcsine square root transformation formula and analysis of variance and comparison of means for sisal bole rot parameters were performed using GenStat® Executable release 16 Statistical Analysis Software. Means were compared by Duncan Multiple Range Test (DMRT) at 5% level of probability. Duncan Multiple Range Test (DMRT) was used to check the effect of altitude and season on bole rot disease parameters. Regression (R^2) between climatic factors and bole rot disease parameters was done and a Student's t-test was used to compare mean for disease incidence (DI), disease severity (DS), and disease intensity index (DII) for the wet and dry season. The results revealed that, bole rot disease was present in all surveyed wards but with different intensity. Disease incidence, severity and disease intensity index were significantly different at ($P<0.05$) amongst the surveyed wards in both dry and wet seasons. Kigombe ward located in lower altitude (22 m.a.s.l) had the highest disease incidence (36.4%), severity (32.54%) and disease intensity index (425.4) while Tanganyika ward located in higher altitude (200 m.a.s.l) had the least disease incidence (19.09%), severity (12.82%) and disease intensity index (90.4)**.** Disease incidence, severity and disease intensity index among the recorded climatic conditions was significantly different at ($p<0.05$). A significant high incidence (46.46%), severity (40.24%) and disease intensity index (619.3) was observed at a temperature of 28.1ºC, relative humidity of 78.8% and rainfall of 118.2 mm at Kigombe ward during wet season. Low disease incidence (14.38%), severity (11. 55%) and disease intensity index (59.30%) was observed at a temperature of 27.9ºC, relative humidity of 80.2% and rainfall of 122.8 mm in Tanganyika ward during wet season. Campaigns and plans are needed to improve farmers' access to improved disease-free planting materials through efficient dissemination pathways. Extension officers should encourage and direct sisal farmers to buy healthy planting materials from the research institutes and or recognized places. Additionally, nurseries for production of seedlings should be established in every ward for easy access by farmers and to reduce transport costs. In addition, extension services need to be more focused on increasing the level of awareness among sisal farmers especially on practicing integrated disease management to mitigate the incidence of bole rot disease.

Key words: *Agave sisalana*, *Aspergillus niger*, bole rot, incidence, Muheza, severity.

3.1 Introduction

Sisal (*Agave sisalana* L.) is adapted to warm environments with low rainfall and it is cultivated in semiarid conditions, characterized by low and irregular precipitations of 300–800 mm/ year, long drought periods and annual mean temperatures as high as 32 °C where no other crops can be grown (Sarkar, 2017). It is one of the main sources of hard natural fibre and raw materials for the industry, medicine and handicrafts. Produces a coarse and strong fibre that is used in composite materials for automobiles, furniture, construction, plastic and paper products. Extracts of sisal plants consists of substances with anti-inflammatory, antimicrobial and anthelmintic activities (Cruz-Magalhães *et al.*, 2019). Sisal has several distinguishing characteristics which makes it to be a 'speciality crop' for conservation agriculture since it does not produce pesticide load to the environment because it is not much infested by many disease and insect pest; and therefore the use of chemicals is minimum (Sarkar, 2017). Furthermore, sisal plants reduce soil erosion through its extensive root system and contribute positively to watershed management (Sarkar, 2017). Sisal is a labour-intensive crop with great socio-economic importance as it serves as a source of employment, income for the farmers and provides country foreign currency (Beleko, 2021). The disease was first observed in areas of sisal production in Tanzania in the 1930s and reported first in the 1952 (Cruz-Magalhães *et al.,* 2019). The disease is caused by species of the genus *Aspergillus*, especially the ones belonging in the section Nigri. *Aspergillus niger* has been reported to be a major cause of the sisal bole rot disease and Agave hybrids are more susceptible to bole rot disease (Durte *et al.*, 2018), though according to the research done by Santos *et al.* (2014), there is additional of three species of *Aspergillus* causing bole rot disease; these are *A. tubingensis*, *A. brasiliensis* and *A. welwitschiae* which belong to the Nigri complex section.

The infected sisal plants exhibit wilting, yellowing of leaves and reddening of the bole and base of the leaves to rotting followed by death of a plant (Durte *et al.*, 2018). The spread of disease is faster because the pathogens are found on plant stems and in the soil around the plant rhizosphere. Majority of farmers in Muheza district rely on suckers/stolons from previous crop for propagation of new sisal fields which increases the chances of spreading the inocula from infected plants and soils to the new fields. The pathogen can also be spread through the use of contaminated tools/machinery, clothes, shoes and human body during farm activities and harvesting of the crop especially when it is wet. In Tanzania, research on epidemiology of bole rot disease has not been done but such information is available in other sisal growing countries such as Brazil and Mexico where bole rot prevalence has been reported to be as high as 100% whilst the average field incidence is up to 35% in some sisal plantations (Damasceno *et al.,* 2019). Hence, in Tanzania, information is therefore lacking on the incidence and severity of bole rot disease. It is expected that, information from this study will guide the development of intervention strategies against the disease that will safeguard livelihood of sisal farmers in Tanzania.

3.2 Materials and Methods

3.2.1 Selection, description of the study area and duration of the study

The survey was done in three wards selected randomly at different altitudes of Muheza district. The three wards are: Ngomeni located at the altitude of 107 m.a.s.l, longitudes of 38.9191 S and latitudes of -5.1866 E; Tanganyika ward located at altitude of 200 m.a.s.l, longitudes of 38.8055 S and latitudes of -5.1613 E and Kigombe ward located at the altitude of 22 m.a.s.l, longitudes of 39.0018 S and latitudes of -5.2907 E (Fig. 3.1 pg7). The assessment of the disease incidence and severity was done in two seasons:-January 2022 for the dry season and May 2022 for the wet season.

3.2.2 Survey and data collection

3.2.2.1 Anatomy of the infected sisal plants in farmer's field

Anatomy of the infected sisal plants in farmer's field was done by randomly identification of the infected sisal plants in the field and the external changes in the plants morphology were observed. The boles/stems of the infected sisal plants were cross-sectionally cut and the internal changes of the diseased stem tissues were observed by using naked eyes.

3.2.2.2 Determination of incidence, severity and intensity index of bole rot disease in farmer's sisal fields

In each ward**,** four farms were randomly selected; three farms for small scale farmers and one for sisal estate. In each sisal farm, a one hectare sisal farm was measured and surveyed for bole rot disease incidence and severity in two seasons (January for dry season and May for wet season). The bole rot incidence and severity were assessed along the odd sisal rows, systematically. Disease incidence was evaluated by counting and recording the total number of healthy and infected plants present in all sisal rows inspected. The percentage of disease incidence was calculated as per Yeh *et al.* (2019) as follows;

$$\text{Disease Incidence (\%)} = \frac{\text{Number of infected sisal plants}}{\text{Total number of assessed plants}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots.\text{i}$$

For disease severity, the infected sisal plant stems/boles were cross-sectionally cut and the disease severity was recorded according to the disease severity scale proposed by Damasceno *et al*. (2019), of 0 to 3 where (0) no = symptom, (1) = initial symptoms, (2) = advanced symptoms, and (3) = plant death, bole completely rot.

Disease Severity (%) was calculated as per Damasceno *et al.* (2019), where

$$\text{Disease Severity (\%)} = \frac{\text{n} \times \text{v}}{3\text{N}} \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\text{ii}$$

Where, (n) = Number of plants in each category, (v) = Numerical values of symptoms category, (N) = Total number of plants assessed, (3) = Maximum numerical value of symptom category (Fig. 3.1).

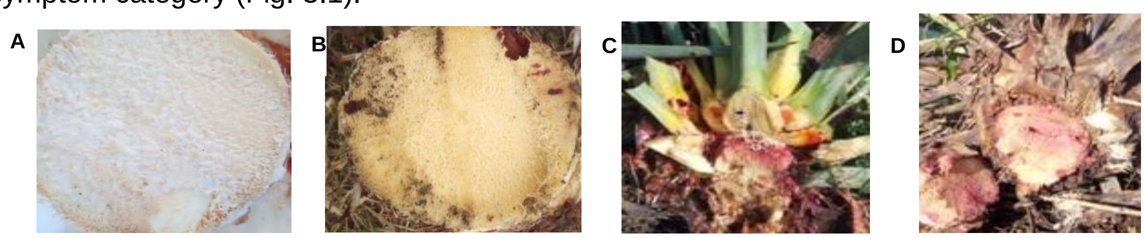

Figure 3.1: Disease severity scale; A= (0) no symptoms, B= (1) initial symptoms, C= (2) advanced symptoms but not dead and D= (3) plant death.

Disease Intensity Index (DII): According to Damasceno *et al*. (2019), Disease Intensity Index (DII) was estimated as the product of incidence and severity

$$\text{Disease Intensity Index (DII)} = \frac{\text{I} \times \text{S}}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots..\text{iii}$$

Where, I= Incidence, S= Severity and (3) = Maximum numerical value of symptom category

3.2.3 Statistical analysis

Before analysis, data were transformed using the arcsine square root transformation formula as described by Mousanejad *et al.* (2010) as shown: Y = Arcsine √P, where, Y is transformed data, and P is the observed proportion. Analysis of variance and comparison of means for sisal bole rot disease incidence, severity and disease intensity index were performed using GenStat® Executable release 16 Statistical Analysis Software. The means were compared by Duncan Multiple Range Test (DMRT) at 5% level of probability. Duncan Multiple Range Test (DMRT) was used to check the effect of altitude and season on the incidence, severity and disease intensity index on bole rot disease. Regression (R^2) between weather factors and disease incidence, severity and disease intensity index was established and a Student's t-test was used to compare means for disease incidence, severity, and disease intensity index for the wet and dry season.

3.3 Results

3.3.1 Anatomy of bole rot affected sisal plants in farmers' fields

The survey observed that, plants with bole rot disease exhibited a number of external symptoms such as wilting and yellowing of leaves starting from the leaf base (Fig. 3.2 C-D), brownish to reddening of the stem (bole) and base of the leaves (Fig.3.2 E-F). Healthy plants did not show these symptoms (Fig. 3.2 A-B). The internal symptoms were observed as necrosis in the bole (stem) and leaf base and all exhibited brownish to reddish rot tissue (Fig. 3.2 E-F). The progression of the disease lead to plant death (Fig.3 F). The transversal sections of the bole indicated that the disease was disseminated along the ground parenchyma from the cortex to the vascular bundle (Fig. 3.2 E-F).

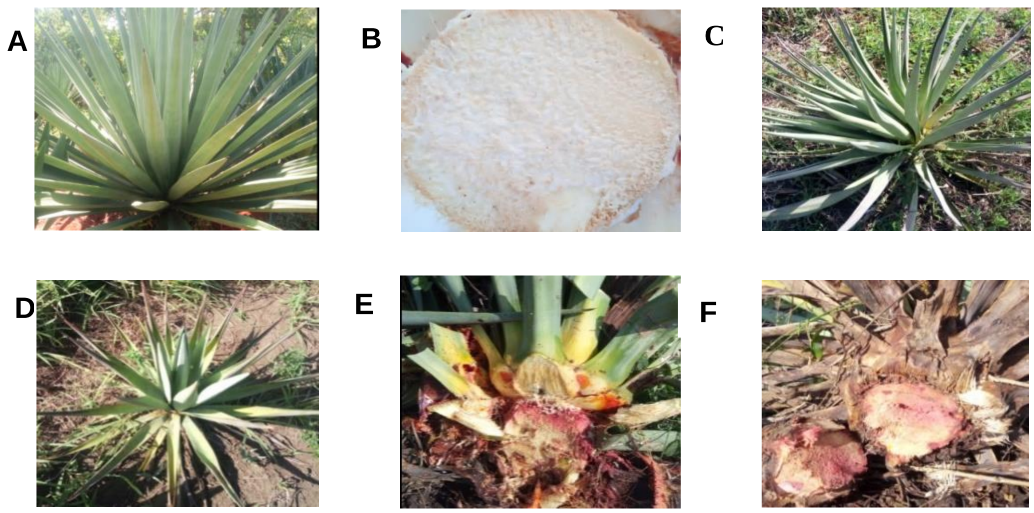

Figure 3.2: Anatomy of the healthy and bole rot affected sisal plants

Key: Healthy plant (A), stem of healthy Sisal plant (B), infected sisal plants with wilting and yellowing leaves starting at the stem base (C-D), infected sisal plant stems with brownish and reddish colour (E-F), dead sisal plant (F)

3.3.2 Disease incidence and disease severity dispersion among the surveyed wards

The survey for the study of bole rot disease incidence and severity was done in three wards of sisal growing areas in Muheza district. There was significant difference on bole rot disease in terms of incidence, severity and disease intensity index among the three surveyed wards. Kigombe ward was having the highest disease incidence (36.4%) followed by Ngomeni ward (28.5%) and Tanganyika ward with the least disease incidence of 19.1%**.** A significant variation in disease severity was observed between the wards surveyed for the bole rot disease. Kigombe and Ngomeni wards had significant high disease severity, 32.54% and 28.94% respectively while Tanganyika ward had the lowest disease severity of 12.82%. The same trend was observed on disease intensity index where Kigombe and Ngomeni wards had significantly high disease intensity index of 425.4 and 311.4 respectively while Tanganyika ward had the least disease intensity index of 90.4. Disease severity (32.54^b) and disease intensity index (425.4^b) of Kigombe ward did not vary significantly with disease severity (28.94^b) and disease intensity index (311.4^b) of

Ngomeni ward at (P<0.006) and (P<0.016) respectively with the exception of Tanganyika ward in which disease severity (12.82[a]) and disease intensity index (90.4[a]) was significantly different with other wards at (P<0.006) and (P<0.016) respectively (Table 3.1).

Table 3.1: Bole rot disease parameters based on surveyed wards in Muheza district

Ward	Incidence (%)	Severity (%)	Disease Intensity Index
Kigombe	36.43[b]	32.54[b]	425.4[b]
Ngomeni	28.52[ab]	28.94[b]	311.4[b]
Tanganyika	19.09[a]	12.82[a]	90.4[a]
Grand mean	28.00	24.80	276.0
SED	5.75	5.67	104.9
CV%	6.20	18.80	20.7
p-value	0.025	0.006	0.016

Means carrying the same letter along the column were not significantly different under Duncan Multiple Range Test (DMRT) at p<0.05.

3.3.3 Influence of location on bole rot disease parameters

The height above the sea level (altitude) of a ward had significant influence on disease incidence, severity and disease intensity index at (p<0.05. Disease incidence and Disease severity were high in lower altitudes than in higher altitudes in both surveyed wards. Ward located in lower altitude (22m.a.s.l) had high disease incidence (36.43%), severity (32.54%) and disease intensity index (425.4). On the other hand, Ward located in high altitude (200m.a.s.l) had lower disease incidence (19.09%), severity (12.82%) and disease intensity index (90.4) (Table 3.2).

Table 3.2: Influences of location on bole rot disease parameters in three wards of Muheza district

Ward	Altitude (m)	Incidence (%)	Severity (%)	Disease Intensity Index
Kigombe	22	36.43[b]	32.54[b]	425.4[b]
Ngomeni	107	28.52[ab]	28.94[b]	311.4[b]
Tanganyika	200	19.09[a]	12.82[a]	90.4[a]
	Grand mean	28.00	24.80	276.0
	SED	5.75	5.67	104.9
	CV%	6.20	18.80	20.7
	p-value	0.025	0.006	0.016

Means carrying the same letter along the column were not significantly different under Duncan Multiple Range Test (DMRT) at p<0.05.

3.3.4 Effects of climatic conditions on disease parameters

Climatic conditions such as temperature, relative humidity and rainfall per area were analyzed in combination to evaluate their influence on disease incidence, severity and disease intensity index. The analysis revealed that the disease incidence, severity and disease intensity index varied from one locality to another due to different climatic conditions prevailing in each locality. Disease incidence, severity and disease intensity index among the recorded climatic conditions was significantly different at (p<0.05). A significantly high incidence (46.46%), severity (40.24%) and disease intensity index (619.3) was observed at a temperature of 28.1^{o}C, relative humidity of 78.8% and total rainfall of 118.2 mm. Low disease incidence, severity and disease intensity index was observed at a temperature of 27.9^{o}C, relative humidity of 80.2% and rainfall of 122.8 mm (Table 3.3).

Table 3.3: Bole rot disease parameters based on climatic conditions in three wards of Muheza district

Ward	Temp.	RH	Rainfall	DI	DS	DII
Tanganyika (dry)	27.9	80.2	122.8	14.38[a]	11.55[a]	59.3[a]
Tanganyika (wet)	25.8	70.5	60.6	23.80[a]	14.09[ab]	121.6[a]
Kigombe (dry)	30.0	82.6	97.0	26.40[a]	24.83[abc]	231.5[a]
Kigombe (wet)	28.1	78.8	118.2	46.46[b]	40.24[c]	619.3[b]
Ngomeni (dry)	28.8	81.1	54.4	27.99[a]	27.36[abc]	291.7[a]
Ngomeni (wet)	26.3	74.0	76.4	29.05[a]	30.52[bc]	331.1[a]
Grand mean				28.00	24.80	276.0
SED				6.83	7.76	126.6
CV%				6.20	18.80	20.7
p-value				0.009	0.021	0.008

Means carrying the same letter along the column were not significant different under Duncan Multiple Range Test (DMRT) $p<0.05$, SED= Standard error of difference, RH = Relative Humidity and CV= Coefficient of Variance

3.3.5 Comparison between dry and wet seasons on disease incidence and severity

A t-test was carried out to compare dry and wet seasons on disease parameters. A null hypothesis "Mean of disease parameters during wet season is equal to the mean of disease parameters during dry season" tested at 95% confidence interval. For disease incidence, null hypothesis was rejected ($p<0.05$, t= -2.13) with dry season having mean disease incidence of 22.92% and wet season having mean disease incidence of 33.10%. The null hypothesis was accepted on disease severity ($p>0.05$, t= -1.25). This signifies that, mean disease severity during wet season (28.28%) was not significantly different from mean disease severity in dry season (21.25%). For disease intensity index, null hypothesis was accepted ($p>0.05$, t=-1.74) with dry season having 194.2 while wet season had 357.3 (Table 3.4).

Table 3.4: Student's t-test to compare dry and wet seasons with disease parameters

Parameter	Season	Mean	Variance	SD	t-test	p-value
Incidence	Dry	22.92±2.88	99.4	9.97	-2.13	0.045
	Wet	33.10±3.82	175.3	13.24		
Severity	Dry	21.25±3.27	128.6	11.34	-1.25	0.224
	Wet	28.28±4.57	250.2	15.82		
DII	Dry	194.20±50.80	30969.0	176.00	-1.74	0.095
	Wet	357.30±78.56	74059.0	272.10		

Means (Mean ± SE); SE=Standard error of means, SD=Standard deviation, DII= Disease Intensity Index

3.3.6 Regression relationships between climatic factors, altitude and disease parameters

The regression of climatic factors and height above sea level (altitude) against disease parameters was done. All climatic factors had no significant ($p>0.05$) relationship with bole rot disease parameters (Table 3.5). Significant and positive relationship was observed between the height above sea level and quantified disease parameters at ($p<0.05$). All disease parameters had moderate and positive relationship with altitude where disease incidence had 33% (R^2=0.331, p= 0.003) relationship, severity had 35.5% (R^2=0.355, P=0.002) relationship, and disease intensity index had 34.4% (R^2=0.344, P=0.003) relationship (Table 3.5).

Table 3.5: Regression relationship between climatic parameters, altitude and disease parameters

Factor	**Disease Incidence**	**Disease Severity**	**Disease Intensity Index**
Temperature	P=0.742, R^2=0.005	P=0.452, R^2=0.026	P=0.601, R^2=0.013
Altitude	P=0.003, R^2=0.331	P=0.002, R^2=0.355	P=0.003, R^2=0.344
Relative humidity	P=0.994, R^2=0.0002	P=0.514, R^2=0.020	P=0.652, R^2=0.009
Rainfall	P=0.683, R^2=0.008	P=0.752, R^2=0.005	P=0.492, R^2=0.022

3.3.7 Relationship between disease incidence, severity and disease intensity index

Disease incidence, severity and disease intensity index was correlated against each other. All parameters were highly significant correlated to each other at (p<0.001). The relationship between disease incidence and severity was 63.11% which is a strong and positive relationship. Disease incidence and disease intensity index had very strong positive relationship of 83.23% while disease severity and disease intensity index had very strong positive relationship of 88.79% (Fig. 3.3).

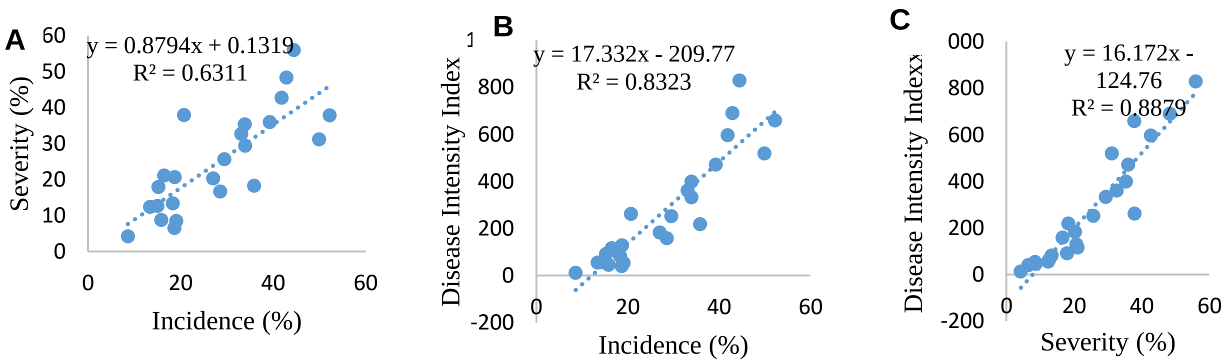

Figure 3.3: Correlation relationships between (A) incidence and severity, (B) incidence and disease intensity index and (C) severity and disease intensity index.

3.4 Discussion

3.4.1 Anatomy of the infected sisal plants in farmer's field

Although bole rot disease was recognized in the country since 1950s, there is no information on its quantification in sisal growing areas in the country to date. Disease quantification is essential for epidemiological studies, surveys, and management decisions. A result pertaining to anatomy of the infected sisal plants in farmer's field shows that plants with bole rot disease exhibit external symptoms such as wilting and yellowing of leaves, brownish to reddening of the bole and base of the leaves. Healthy sisal plants do not show these symptoms. The internal symptoms were observed as necrosis in the boles and leaf bases and all of which exhibited brownish to reddish rot tissue and the transversal sections of the bole shows that the disease is disseminated along the ground parenchyma from the cortex to the vascular bundle. The progression of the disease caused plant death. This result coincides with those obtained by Cruz-Magalhães *et al.* (2019) who pointed out that, sisal plants with bole rot disease produce leaves that are not suitable for fibre extraction as they lose their turgescence, and although these diseased plants survive for some time, they die with the progress of the disease. He pointed out that, plants at advanced stages of the disease are identified by the symptoms which include wilting and yellowing of the aerial part. The main internal symptom of the disease is rotting of the stem with reddening of the tissues, a response of the plant to fungal colonization. Durte *et al.* (2018) commented that, once sisal plants are infected by *Aspergillus niger*, bole starts to rot and plant internal tissues become brown, surrounded by a reddish border. After some months, the plant meristem is completely affected, interrupting the communication between the bole and leaves, making leaves yellow and collapsing when bole is completely rotten, causing plant death. De Souza *et al*. (2021) observed that, infected sisal plants exhibit wilting and yellowing of leaves and reddening of the bole and base of the leaves followed by plant death.

3.4.2 Disease incidence and severity dispersion among the surveyed wards

The survey for disease incidences and severities revealed that, sisal bole rot disease was prevalent in all the surveyed areas but with varying intensity. The highest disease incidences and severities were along the coastal area, in Kigombe ward followed by Ngomeni ward and Tanganyika ward the least. It was also noted that, the distribution of disease in the surveyed fields was randomly scattered. This finding is in agreement with those of Abreu (2010), as cited in Damasceno *et al.* (2019) who studied the spatiotemporal distribution of sisal bole rot in producing areas of Bahia Province in Brazil and found that the disease was present in all the studied farms with disease prevalence of 100% and on average, 35% of the plants were infected by the pathogen.

Additionally, Duarte *at el.* (2018) in a research done in Bahia Province in Brazil observed that, the incidence of sisal bole rot disease can vary from 5% to 40% in the production areas. Hong *et al*. (2013) indicated that, species of Aspergillus can cause devastating disease in sisal, with incidence in the field varying from 5% to 65%. Similarly, Santos *et al*. (2014) indicated that the incidence of the bole rot disease was 100% for *A. niger* in production areas.

3.4.3 Influence of location on bole rot disease parameters

The results show that the level of disease incidence and severity was highly influenced by altitude. Kigombe ward located at lower altitudes, near the coastal areas had high disease incidence and severity compared to Ngomeni and Tanganyika wards located at higher altitudes. Tanganyika ward being at higher altitudes than Ngomeni and Kigombe wards had the least level of disease incidence and severity. The sisal lands in Kigombe ward are situated in flat areas where during heavy rainfall the soils get wet easily and water logged favoring bole rot pathogens to grow, proliferate and cause infection. Furthermore, the condition of water logging in Kigombe ward allow leaching of major minerals such as Calcium and subject the sisal plants to stresses, easily to be attacked by bole rot pathogens. On the contrary, sisal farms in Tanganyika ward are situated in higher altitudes which do not allow water logged and leaching of Calcium minerals, unfavorable conditions for the bole rot fungi to grow, sisal plants remain strong with no stress and with high resistance to disease infection. The results are in agreement with those of Cruz-Magalhães *et al.* (2019) who pointed out that the occurrence of sisal bole rot disease was linked to environmental conditions and the nutritional status of the plants. Gashaw *et al*. (2014) in the study of finger millet blast disease in Ethiopia observed that both disease incidence and severity varied significantly across the surveyed districts, altitude groups and climate zones. They found that, the sampling site of Awi zone which was characterized by higher altitude, low temperature, and low humidity did not favor the spread of the pathogen, it had low disease incidence and severity.

3.4.4 Effects of climatic conditions on disease parameters

The analysis revealed that the disease incidence and severity varied from one locality to another due to different environmental conditions prevailing in each locality. Sisal is a drought resistant plant that can grow well in the arid and semi-arid regions with rainfall amount suitable for its growth is in the range 1000-1250 mm, temperatures ranging from 10^oC to 30^oC

and it can also endure temperatures of 40-50°C (Saxena *et al*., 2011). Excessive rains causing water stagnation and very low temperature causing frost tend to damage the plantation (Sarkar, 2017). It was noted that, in all surrveyed wards, disease incidence and severity was high during wet season than during dry season. This was due to decrease in temperature and relative humidity favoring growth, multiplication and infection of bole rot pathogens. The result is in agreement with those of Cruz-Magalhães *et al.* (2019) pointed out that the occurrence of the bole rot disease was linked to environmental conditions and the nutritional status of the plant. Dennis and Fisher (2018) indicated that, a change in temperature could directly affect the spread of infectious disease and survival between seasons. Additionally, Priyanka *et al.* (2020) pointed out that, environment do affect plant pathogen survival, rate of multiplication, sporulation, direction, distance of dispersal of inoculum, rate of spore germination and penetration. Velásquez *et al*. (2018) indicated that, there are three basic elements required for the development of an infectious disease: a susceptible host, a virulent pathogen and favorable climatic conditions for infection, host colonization and propagule production. Furthermore, Yáñez-López *et al*. (2012) observed that, plant diseases develop under a well defined, optimal range of climatic variables such as temperature, rain, and relative humidity; however, the occurrence and severity of a disease in an individual plant is defined by the deviation of each climatic variable within the optimal range for disease development. Climatic conditions influence the incidence as well as temporal and spatial distribution of plant diseases.

3.4.5 Relationships between disease incidence, severity and disease intensity index

The knowledge of the functional relationships between incidence, severity and disease intensity index is important because it improves understanding of the epidemiology of the disease. The relationships between disease incidence, severity and disease intensity index were very strong positive**.** The results are being justified by Bock and Chiang (2019) who studied incidence– severity relationships for other disease and obtain positive relationship. Furthermore, the result shows that, severity and disease intensity index increased with increasing incidence. This result is justified by Bock and Chiang (2019) who studied the analysis of incidence–severity relationships for strawberry powdery mildew and obtain a highly significant relationship between powdery mildew incidence and severity. These results shows that the conditions were favoring auto-infection rather than disease spreading to other areas, which reflected to increased severity for the same level of incidence. Since, field estimation of severity is time consuming and requires well-trained personnel, which may limit the adoption of integrated management programs that require information on disease levels in fields, estimation of disease severity from the incidence level will therefore facilitate quantification considerably because it is easier to assess incidence than severity (Carisse *et al.,* 2012).

3.5 Conclusions and Recommendations

This study revealed 100% prevalence of the sisal bole rot disease in the surveyed sisal growing wards of Muheza district. Incidence and severity of the sisal bole rot disease varied significantly among the wards under wet and dry seasons, with highest incidence and severity shown during the wet season in all surveyed wards. The disease incidence and severity was highest in Kigombe ward followed by Ngomeni ward and Tanganyika ward being the least. Variation on disease incidence and severity among the wards was contributed by differences in locations (altitude) and environmental conditions prevailing in each ward. It was observed that, in regardless of the advantages of production of healthy sisal planting materials at Tanzania Agricultural Research Institute (TARI) Mlingano in Muheza District, majority of sisal farmers in Muheza district are still using unhealthy planting materials. Therefore, extension services need to be more focused on increasing the level of awareness among sisal farmers especially on practicing integrated field management practices which will reduce the incidence of bole rot disease. Together with that, extension officers should encourage and direct sisal farmers to buy healthy planting materials from the research institutes and or recognized places. This study was limited to three wards of Muheza district and did not cover other sisal production areas in the country. A study should therefore be undertaken to determine the disease intensity in other sisal production areas.

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CHAPTER FOUR

4.0 General/Integrated Discussion

4.1 Introduction

Sisal plants have the advantage of being able to adapt to stressful conditions and pests, but one of the main diseases that threatens sisal crop is sisal bole rot. The disease leads to the death of infected plants in both seedlings and adult plants, reducing its importance to stakeholders. This chapter covers the overall objective of the research, results of each paper, the strong points and limitations of the papers, impacts of the results on agricultural practices, the policy makers, the research, and the overall conclusions/recommendations.

4.2 The purpose of the Study

The aim of this research was to determine the level of farmers' awareness on bole rot disease and the intensity of the disease in farmers' sisal farms. The goal was to gain insights that would help to develop a dissemination manual which will raise awareness among sisal farmers and apply it to the sisal production sector to reduce the disease incidence and improve their lives. Rogers *et al*. (2014) and Anane (2020) pointed out that awareness is the first step in the acceptance process of a new disease management practice. Several reports have found that increased farmer awareness leads to better adoption of disease management methods and reduced disease intensity in crops. Amon Arma *et al*. (2020) report that the high awareness of black pod disease in cocoa has contributed significantly to less conscious farmers adopting proper disposal methods for infected pods. A study conducted in the Philippines by Heong and Ho (2019) found that while most rice farmers can describe the symptoms of tungro disease in rice, there are gaps in understanding the causes and how it spreads. Most of them were unaware of the risks of leaving infected plants in the field. This became an inoculum for disease and a threat to new plantings. Bua (2017) found that the lack of disease detection and control of cassava brown streak disease (CBSD) among smallholder farmers in northern Uganda contributes to the rapid spread of the disease and increased incidence of the disease. Therefore, studying farmers' awareness and the extent of damage in farmers' farms will guide the development of intervention strategies against the disease.

4.3 Findings of the Research

The results of these studies indicate that, majority of sisal farmers (68.92%) had moderate (39-71%) level of awareness on bole rot disease and 6.76% of sisal farmers had low (0-38%) level of awareness on bole rot disease. They do not have in-depth knowledge on bole rot disease. This is probably because they rely heavily on their fellow sisal farmers and friends for information on disease management whose knowledge on sisal production and disease may be limited (Parthiban *et al*., 2017). A positive relationship exists between farmers' education with farmers' level of awareness on the disease. Educated sisal farmers are more likely than uneducated farmers to understand recommendations for sisal farming practices that reduce disease intensity because they are ready to understand and more conscious than uneducated farmers (Muddassir *et al*., 2019; Grimaccia and Naccarato, 2019 and Rizwan *et al*., 2020). We also found that experienced, full-time farmers had a higher awareness of bole rot disease. This is due to their many years of work on the farm, and in case of any challenge or problem arises on a sisal farm, they find it easier to find the right solution compared to inexperienced farmers (Parthiban *et al*., 2017). Moreover, the adoption of new techniques for sisal production farmers significantly correlated with the level of farmers' awareness probably because they obtain the latest information on sisal production (Parthiban *et al*., 2017). Moreover, there was a positive association between production practices and farmers' awareness. In other words, farmers who were able to implement production practices that reduced the disease had higher awareness than those who did not (Cruz-Magalhães *et al*., 2019).

It was also observed that the disease was present in more than half of the fields of interviewed farmers, and that it was randomly distributed in the fields (Abreu, 2010) probably because most farmers were using suckers from the previous sisal crops which might have been infected (Cruz-Magalhães *et al*., 2019). Furthermore, the results also indicated that the disease was present at varying intensities at all wards studied, possibly due to dissimilar altitudes and climatic conditions prevalent at each ward (Cruz-Magalhães *et al*., 2019). A major impact of the disease was observed in Kigombe ward which is located in a lowland area 22 masl (meters above sea level). Together with that, the condition of water logged leads to leaching of important minerals such as calcium, stressing plants and making them more susceptible to infection (Gashaw *et al.,* 2014). The Tanganyika ward, located at an altitude of 200 masl (meters above sea level), had the lowest disease intensity (incidence and severity). Disease intensity was higher in the wet season than in the dry season in both studied areas. This is probably due to the low temperature and relative humidity which favor the growth, multiplication and infection of plant pathogens (Cruz-Magalhães *et al.,* 2019). There is a strong positive relationship between disease incidence and severity, where the increase in disease incidence lead to increase in disease severity, a condition favoring auto-infection rather than spreading of the disease (Bock and Chiang, 2019). Therefore, the amount of disease in farmers' sisal fields can be reduced by impacting knowledge of disease management into sisal farmers.

4.4 Strengths and Limitations of the Research

The studies had strengths and limitations and one of the strength encountered during the assessment of farmers' level of awareness on bole rot disease is that, the goal was achieved as we managed to group farmers into different level of awareness on bole rot disease in all the studied wards. Bias was also avoided as all small scale farmers and sisal estates present in each ward studied were used in the study. A difficulty in this study was seen in extracting the sample size of small scale farmers. The number of small-scale sisal farmers engaged in sisal production in the three surveyed wards is still small (71), and for the purpose of the survey I was forced to use all small scale sisal farmers' present in the three wards. This meant that I was unable to obtain a representative sample for pre-testing of the questionnaire**.**

One of the strengths encountered during the disease assessment in farmers' fields is that, the purpose was fulfilled by providing reliable estimates of the extent of disease damage in farmers' field in the three wards under the study based on the known symptoms of the disease. Furthermore, disease assessment is reliable and disease estimates or measurements are accurate, and reproducible. Not only that, data accuracy was maintained by ensuring that the sample mean of the ratings was close to the true mean of the population. Farmers were selected by random systematic sampling and farms used in the study were selected randomly and measured accurately to avoid bias. The limitations encountered in assessing disease incidence and severity in farmers' sisal fields lies in quantifying the disease. Quantification of disease is one of the most difficult tasks. Once the symptoms are apparent, it is often easy to identify the diseased plant or group of diseased plants. Infested sisal plants show symptoms of sisal bole rot after longer periods of infestation. Therefore, infected sisal plants that were in early stages of infection without external symptoms were not quantified in the evaluation.

The assessment of disease incidence was actually simple counting task but its limitation was related to the sample size to be used and for the assessment of disease severity, its limitations were on how to obtain accurate and precise measurements because samples are required to be representative to the study population and adequate in number. Not only that, assessing severity was a difficult task, time consuming, prone to visual and measurement errors if not paid attention, and was the most costly part of the study. The cost is divided into the time required to plan and conduct the survey, the equipment required, and the level of crop destruction caused by the survey.

4.5 Implications of the Findings in Agricultural Practices, Policy Decisions and Research

The knowledge gained in this study will be used to improve agricultural practices by increasing farmers' awareness on good sisal production practices through training to be conducted at various conferences/workshops and through various pamphlets, magazines and written booklets prepared for sisal farmers. Good practice will increase the production and productivity of sisal plants. At the same time, there will be production of high-quality sisal fiber and its products that will attain good market and high prices. This will increase incomes for everyone involved and help many households live better lives. In addition, the increase in sisal production will result in more people being employed in the sisal fields and sisal processing industry. The increase in sisal production will led to ample supply of raw materials in the sisal agricultural processing industry, increased demand for machinery for processing sisal, and increased demand in the industry for manufacturing machinery and various spare parts. Employment will increase. Business will increase especially for small businessmen who buys sisal leaves from small scale farmers for processing and sell to big companies, they will get permanent employment. Furthermore, there will be an improvement on the country economy through trading or exporting of sisal fibres and its products to foreign countries through earning of foreign currency to the country.

The results of this research will help guide policy decisions. Education has been found to be very important to improve farmers' awareness of sisal production and reduce the disease intensity on farmers' sisal farms. To raise farmers' awareness on sisal production and productivity, the government of Tanzania under the Ministry of Agriculture should initiate various programmes such as front line demonstrations and extension throughout the country by using different networks reachable by sisal farmers freely with the aim of restructuring and strengthen agricultural extension to enable delivery of appropriate sisal technologies and improved sisal agronomic practices to sisal farmers. The study recommends the use of mass media such as telephones where farmers will be able to obtain information of sisal production and management of sisal bole rot disease every time with no cost. Not only that, but purchasing healthy seedlings by sisal farmers from Mlingano Sisal Research Institute is expensive, so most of the sisal farmers in the Muheza district still use unhealthy planting material (suckers) from previous crops. So, Tanzanian government should subsidize healthy sisal planting materials produced by the Mlingano Research Institute to encourage farmers to purchase and use healthy sisal planting material at affordable prices**.**

For the permanent improve of sisal production and productivity, farmers' should have access to improved disease-free planting materials. The government should support research institute with funds for establishment of disease free planting materials nearby farmers' production areas i.e. in each ward for easy access and to reduce transport costs to farmers. Moreover, capacity building to extension officers and research institution with new sisal production technologies is very important. Without forgetting provision of means of transport to extension officers for easy and frequent reaching of sisal farmers as a way to increase farmers' participation in extension programs to increase their awareness on management of the disease which will results in to reduced disease intensity in farmers' sisal farms. In addition, the capacity building to extension officers and research institutes with new sisal production technologies is very important.

4.6 Conclusion/Recommendations

Education is important to make farmers aware of sisal production practices, occurrence, prevalence and management of the disease. Muheza District extension Office should use the prepared comprehensive training module on sisal production practices and integrated management practices against the disease and introduce it to sisal farmers to raise their awareness about sisal production and management of bole rot disease. Not only that, but they should prepare campaigns and plans that will improve farmers' access to improved disease-free planting materials through effective dissemination pathways. Disease-free plant materials should be produced closely to farmers' production areas for easy access and to reduce costs. Therefore, Tanzania Agricultural Research Institute (TARI Mlingano) should open sisal seedling nurseries in each ward. Furthermore, capacity building for key farmers, extension workers and research institutes with new sisal production technologies is very important. Not forgetting the provision of transport to extension officers so that sisal farmers can be reached easily and frequently as a way to increase farmers' participation in extension programs to raise awareness. Furthermore, sisal growers should be advised to carry out sisal cultivation activities in areas where there is no waterlogging in order to minimize environments conducive for the growth of the bole rot pathogen and thus reduce the occurrence of disease.

CHAPTER FIVE

5.0 General Conclusions and Recommendations

5.1 Conclusions

It was noted that most sisal farmers rely primarily on their fellow sisal growers for information on sisal production and management of bole rot disease. The concern is that if they don't have enough knowledge, they may mislead each other or give partial information about sisal production and how to manage the disease. Also, in regardless of the benefits of producing healthy sisal planting materials at Mlingano Agricultural Research Institute (TARI) in Muheza district, most sisal farmers in Muheza district still increasingly use unhealthy plant materials. Additionally, farmers harvest their sisal during the rainy season and leave infected sisal plants in the field. All these serve as inocula for reinfection and contribute to a high incidence of the disease. The disease intensity among the studied wards was strongly influenced by the (altitude), where low altitude areas during heavy rains get wet easily causing water logging, results into rapid growth, multiplication and high infection to sisal plants. The stagnant condition in the sisal fields encourages leaching of important minerals such as calcium, exposes the sisal plants to stress, easily attacked by the bole rot pathogen and increases the intensity of the disease.

5.2 Recommendations

The study recommends further research on farmers' perception on bole rot disease and on the determination of disease intensity in all other sisal-growing regions of Tanzania. Secondly, because in Tanzania there is no research which has been done on the development of sisal varieties which are resistant to bole rot disease, a research should be carried out to come up with sisal varieties that are resistant to the disease so as to eliminate the disease in farmers' sisal fields. Together with that, the study observed that, to date sisal farmers are only using phytosanitary measures to manage the disease, no research has been done on the use of chemicals or biocontrol measures to alleviate the disease and farmers need to be exposed to a wide range of disease management options so that they can be able to identify management practices that suit their particular social-economic conditions. The use of micro-fungi have been the source of novel and pharmacologically active compounds over decades and among them, *Penicillium citrinum* has been recognized as a rich source of bioactive metabolites to combat sisal bole rot disease in other countries. Therefore, critical investigations should be done to produce different biocontrol products that can be applied in sisal plantlets at the nurseries to create a population of plantlets that are highly resistant to the disease. Furthermore, a research should be done to produce different fungicides which are environmentally friendly but manage bole rot disease.

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APPENDICES

Appendix 1: Type of information and specific data collected using the questionnaire

Type of information	Specific data collected using the questionnaire
Farmers general information	Bio-data (gender, age, education level, full time sisal farmer, occupation and respondent position in the household). Source of family income (daily activity) Contribution of sisal in farmers economy Size of land cultivated by farmers (ha) Sources of information on sisal production
Farmers awareness on occurrence, prevalence and management of sisal bole rot disease	Heard of sisal bole rot disease Symptoms of the disease to sisal crop Presence of the disease in the sisal field Cause of the disease Plant stage mostly affected by the disease Methods of infection of fungus to sisal crop Spread of bole rot disease in the sisal field Its effect on sisal yield Sanitation and management practices of sisal bole rot disease
Sisal production practices	Farmers experience (years) in sisal production Time spent by farmer at farm in a week (h) Hire labour to conduct farm work Kind of planting materials used to establish sisal field Consideration of mother plants age when selecting planting materials Times in a year for carrying weeding in sisal field Removal, destruction of the diseased plants from the field Use of fertilizers with Calcium to prevent plant stresses Application of lime in areas with acidic and water logged Disinfection of tools/machine/cloth/shoes/hands after farm work Season of harvesting sisal crop Attended training on sisal production Number of training on sisal production attended Adopted any new technology on sisal production in the last three years Number of new technology adopted in the last three years

Appendix 2: Interview questionnaire for individual respondents

The purpose of this interview was to assess farmers' awareness of the occurrence, prevalence and management of sisal bole rot disease in the Muheza district. The information collected is treated confidentially and used only for this research.

Date_________________ Ward ______________
Estate/small scale farmer _______________________

A. PERSONAL INFORMATION:

1. Code No. ___________ **Phone number** _________________________________

2. Gender (Tick √ one)
(1) Male
(2) Female
3. **Age (years)** (Tick √ one)
(1) ≤ 20
(2) 21- 30
(3) 31- 40
(4) 41- 50
(5) > 50

4. Level of Education (Tick √ one)
(1) No formal training
(2) primary education
(3) secondary education
(4) higher education

5. Are you a full time sisal farmer? (Tick √ one)
(1) Yes (2) No

6. If No, what are other occupations **(**Tick √ more than one)
(1) Farmer
(2) Livestock keeper
(3) Businessman
(4) Fisherman
(5) Government /private sector employee
(6) Other occupations Specify ……………………………………………………..

7. Position of the respondent in the household (Tick √ one)
(1) father
(2) mother
(3 children
(4) Other Specify………………………………………………………

8. Where does most of your family income come from? (Check √ one)
(1) Agriculture
(2) livestock keeper
(3) business
(4) Fishing
(5) Citing other sources …………… ………………………….

9. What is the contribution of sisal cultivation in your economy? (Tick √ more than one)
(1) Provide income
(2) Improve living standards of my family
(3) Provide self-employment
(4) Used as a field marker when planted at the farms edge

10. What is the size of your sisal farm? (Tick √ one)
(1) 1-2 ha
(2) 3-4 ha
(3) 5-6 ha
(4) > 6 ha

11. How do you get information for sisal production? (Tick √ more than one)
(1) Friends
(2) Farmers
(3) Poster
(4) Radio/TV
(5) Extension officers
(6) Village leaders
(7) School
(8) Parents/family
(9) Others sources   Specify..

B. Sisal Production Practices (Tick √ one)
1. What is your experience (years) in sisal production?
(1) ≤ 2
(2) 3-5
(3) 6-8
(4) >9

2. What time do you spend at sisal farm in a week (hours)
(1) < 1
(2) 1-2
(3) 3-4
(4) 5-6
(5) > 7

3. Do you hire labour to conduct farm work?
(1) Yes
(2) No

4. What type of tillage do you use?
(1) Zero tillage
(2) Hand hoe
(3) Oxen animals
(4) Tractor
(5) Others Specify ………………………………..

5. Which kind of planting material do you use to establish your sisal field?
(1)Bulbils   Why………………………………………………………………………....
(2) Stolons/suckers from previous mother plants   Why? ....

(3) Tissue cultures Why? ....
(4) Rhizomes Why? ....
(5) Others Specify....................................... Why? ....

6. During selection of planting materials, do you consider the age of the mother plant?
(1) Yes Why? ....
(2) No Why?..

7. Do you disinfect tools/machines/cloth/shoes/hands after farm work?
(1) Yes
(2) No

8. Do you apply lime material in your farm areas with acidic soil and water logging?
(1) Yes
(2) No

9. Do you use fertilizers enriched with Calcium to prevent plant stresses?
(1) Yes
(2) No

10. How many times in a year do you carryout weeding in your sisal field?
(1) None
(2) Once
(3) Twice
(4) Thrice
(5) Four

11. How old is your sisal in the field?
(1) <1 year
(2) 1-3 years
(3) 4-6 years old
(4) >6 years

12. Have you started harvesting your sisal?
(1) Yes
(2) No

13. If yes, how many times in a year do you harvest your sisal?
(1) Once
(2) Twice
(3) Thrice
(4) Four

14. How many m^2 of sisal leaf do you collect per hectare per crop?
(1) 1-5 m^2
(2) 6-10 m^2
(3) 11-15 m^2
(4) 16-20 m
(5) > 20 m^2

15. Which season do you harvest your sisal crop?
(1) Wet
(2) Dry
(3) Both dry and wet
(4) Not yet harvesting

16. Do you remove and destruct diseased plants from the field?
(1) Yes
(2) No

17. Have you ever attended training on sisal production?
(1) Yes
(2) No

18. How many training on sisal production have you attended?
(1) 1
(2) 2
(3) 3
(4) ≥ 4
(5) None

19. Have you adopted any new technology on sisal production in the last three years?
(1) Yes
(2) No

20. What is the number of new technology adopted in the last three years?
(1) 1
(2) 2
(3) 3
(4) >3
(5) None

C. Farmers Awareness on Occurrence, Prevalence and Management of Sisal Bole Rot Disease

1. Have you ever heard of sisal bole rot disease (Tick √ one)
(1) Yes
(2) No

2. Is there any farm previously reported of having bole rot disease by extension officers? (Tick √ one)
(1) Yes
(2) No

3. What are the symptoms of bole rot disease? (Tick √ more than one)
(1) Wilting of leaves
(2) Yellowing of leaves at the stem base
(3) Plant internal tissues become brown, with a reddish border
(4) Bole starts to rot
(5) Death of plant
(6) I don’t know

4. Is the disease present in your sisal field? (Tick √ one)
(1) Yes
(2) No

5. If yes, at what rate? (Tick √ one)
(1) Minimum
(2) Average
(3) Maximum

6. What is the cause of the sisal bole rot disease? (Tick √ one)
(1) Fungus
(2) Virus
(3) Bacteria
(4) Nematodes
(5) Others Specify...
(6) I don't know

7. Which plant stage of sisal is mostly affected by bole rot disease? (Tick √ one)
(1) Plantlets
(2) Adult plants
(3) All plantlets and adult plants
(4) I don't know

8. What are the methods of infection of a fungus with sisal plants? (Check √ more than one)
(1) Insect wounds
(2) Injuries caused by tools during plant maintenance, e.g. during harvest
(3) Natural openings in plants
(4) I don't know

9. How was sisal bole rot disease spread in your field? (Tick √ more than one)
(1) By planting affected planting materials
(2) Using contaminated tools/machines
(3) Through contaminated clothes, shoes and hands
(4) I don't know
(5) Others means Specify ………………………………………….........................

10. Did you report to an agriculture extension officer when you found your sisal plants infected with bole rot disease? (Tick √ one)
(1) Yes
(2) No
If No, Why? Give reason(s) ……………………………………………………..........................
....

11. Is there any effect in sisal yield due to bole rot disease? (Tick √ one)
(1) Yes
(2) No

12. Do you think this disease need to be managed in relation to its impact in production? (Tick √ one)
(1) Yes
(2) No

13. Is there a way to prevent sisal crop from getting bole rot disease? (Tick √ one)
(1) Yes
(2) No

14. What sanitation practices do you use to reduce bole rot disease in your sisal field? (Tick √ more than one)
(1) Wash and disinfect tools and machinery before and after farm work
(2) Disinfect shoes, clothes, hands before and after farm work
(3) Weeding the sisal farms
(4) Uproot and destroy infected plants
(5) I don't do anything

15. Which among the following way(s) do you use to manage sisal bole rot in your sisal field? (Tick √ more than one).
(1) Planting health planting materials
(2) Wash and disinfect tools, machinery, shoes, clothes, hands before and after farm work
(3) Uproot and destroy affected plants
(4) Harvest when it is dry
(5) Application of lime material in areas with acidic soil and water logging
(6) Using fertilizers enriched with Calcium
(7) Spraying chemicals (Name the chemical)..
(8) Weeding the sisal farms
(9) Other ways (Specify)..
(10) I don't do anything

THANK YOU