THE SEED INDUSTRY IN LIBERIA: A CASE STUDY OF RICE (*Oryza sativa L.*) SEED QUALITY AND SUSTAINABLE SEED HEALTH MANAGEMENT

BY

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DECLARATION

DECLARATION BY THE STUDENT

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I dedicate this work to my children; Abdullah, Ousman, Lagbeh, the whole Dorley, and Sarnor families.

ABSTRACT

Rice is the staple food in Liberia and despite being largely cultivated throughout the country imports contribute about 75% of the national requirement. Additionally, the seed industry is not well developed nor efficient. This study sought to evaluate the suitability of seed systems and sustainable disease management as a possible cure for this problem of inadequate production. Survey was carried out on 500 smallholder farmers to determine the characteristics of the Liberian farmers and their knowledge on the best agricultural practices. Further, focus group discussions were held with key informants to determine the government policies governing the seed industry and rice production in the country. The data generated from these exercises were analysed using descriptive statistics and ANOVA. Five rice varieties namely Yarka, Gizzie, LAC23-red and LAC23- white (local types) and the improved variety, NERICA L-19, were sampled from four counties that grow and produce most rice in Liberia (Montserrado, Nimba, Lofa, and Bong). The seeds were taken to the University of Eldoret seed science lab for the analysis of various seed quality aspects including vigour index, yield and seed health. Botanical extracts from chilli, garlic, ginger, neem and common bean ash were tested to assess their biocide potential against the isolated fungal seed infection. It was found that there was no significant difference in the numbers of male (49.8%) and female (50.2%) rice farmers. However, this was not true across the counties. Two counties had huge disparities between the genders; Montserrado (males 61.1%, females 38.9%) and Nimba (males 30.4%, females 69.6%). On education however, females were less educated compared to their male counterparts and the majority with no prior formal education in all the counties. Only 1.4% of the farmers obtain their seeds from certified seed dealers while the rest obtain their seeds from the various informal seed systems. NERICA-L19, had the best germination rate achieving 90% germination rate. Yarka variety recorded the least weight (19.7g) in all the counties and Nerica had the highest (26.5g). A total of six fungi were isolated from the rice seeds and this included in the order of prevalence; *Aspergillus niger, A. flavus, Penicillium* sp, *Pyricularia oryzae*, and *Fusarium* sp). The *Aspergillus* sp and *Penicillium* sp were found in all the counties. Seeds from Nimba County were the most infected and all the pathogens listed were isolated from rice seeds sampled from this county. With the exception of *Fusarium sp*., bean ash was the most efficient botanical extract, completely inhibiting all of the tested fungi. The synthetic fungicide (tebuconazole) provided the best inhibition against the most resistant fungal pathogen, *Fusarium sp*, at 56% inhibition. Liberia's seed industry has no practical governance and both formal and informal seed industry run harphazadly. There is huge gap in the farmers' knowledge on government policies governing rice production. Women should be the major targets of enlightenment regarding agricultural practices due to their huge lack of formal education. Policies should be created that strengthen the capacity of formal and informal seed systems to produce improved seeds. NERICA-L 19 appears to be the best rice variety for all the counties under study. Further research should be done to determine whether any of the botanical extracts used in the study can be used to treat disease more sustainably.

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LIST OF ABREVIATIONS AND ACRONYMS

A F	*Aspergillus flavus*
A N	*Aspergillus Niger*
AfT	Agenda for Transformation
BLS	Bacterial Leaf Streak
BL	Bacterial Blight
B C	Before Christ
BRAC	Bangladesh Rehabilitation Assistance Committee
CAADP	Comprehensive African Agricultural Development Program
CAC	County Agriculture Coordinator
CAF	College of Agriculture and Forestry
CAY	Cayman Airways
CARE	Central Agriculture Research Institute
CM	Centi Meters
DNA	Deoxyribonucleic acid
ECOWAS	Economic Community of West African States
EW	Emailable Wet
FAOSTAT	Food Agriculture Organozation Statistics
FAO	Food Agriculture Organization

FAPS	Food Agriculture Policy and Strategy
FGD	Focus Group Discussions
G	Grams
GMS	Genetically Modified seeds
GM	Genetically Modified
GENSTAT	General Statistical
HA	Hyaluronic Acid
ISSD	Integrated Seed System Development
ISTA	International Seed Testing Association
IPRS	Interim Poverty Reduction Strategy
K M	Kilo Meter
LAC	Liberia Agriculture Company
LACRA	Liberia Agriculture Commodity Regulatory Authority
L C D	Liquid Crystal Display
LASIP	Liberia Agriculture Sector Investment Program
LSDCR	Liberia Seed Development and Certification Regulations
LISGIS	Liberia Information Geo Information Services
M L	Mili liter

M M	Mili Meters
MGI	Mycelial Growth Inhibition
M T	Metri Tons
MOA	Ministry of Agriculture
NaOCl	Sodium Chloride
NGO	Non-Governmental Organizations
NERICA	New Rice in Africa
ODA	Official Development Assistance
PRS	Poverty Reduction Strategy
PAPD	Pro-Poor Agenda for Prosperity and Development
PCA	Principal Analysis
P D A	Potato Dextrose Agar
RNA	Ribonucleic Acid
RTD	Rice Tungro Disease
SSA	Sub-Saharan Africa
SADC	Southern African Development Community
SPSS	Statistical Package Social Sciences
T S W	Thousand Seed Weight

USD	United States Dollars
UN	United Nations
VNS	'Vagus Nerve Stimulation
VSN	Virtual Seismic Network

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CHAPTER ONE

INTRODUCTION

1.1 Background information

In Liberia, rice serves a variety of purposes, making it a crucial crop for the nation's food and economy. The crop is the primary preferred staple food for nearly 99% of the nation's population (Hilson and Bockstael, 2012), and in 2010 it had the highest per capita consumption in Africa at more than 140 kg. For about two million people, either directly or indirectly, the crop provides their primary source of income (Republic of Liberia, 2019). However, rice productivity has been on the decline in the country, forcing the nation to divert its budgetary allocation to importations. The latter has been a result of several factors ranging from weak policies, poor methods of production and most importantly the lack of quality rice seed and knowledge on improving or sustaining the quality of community-sourced seeds.

Globally, rice (*Oryza sativa L.*) is the most important cereal crop in terms of consumption and production, followed by corn and wheat (Cosslett and Cosslett, 2018). Currently, China is the leading rice producer with more than 200 million metric tons of rice grain (Pathak and Zaidi, 2013), while Nigeria leads in Africa followed by Egypt with 6.8 and 4.9 million metric tons of grain rice production in 2018 respectively (Pathak and Zaidi, 2013). On the other hand, Liberia only produced 257,995 tons in the same year. Because of the expanding population and the reduced availability of other cereals due to climate change, it is predicted that more people will eat rice. The rice industry is proud of its multi-sector utilization, which has produced diverse nodes within its value chain. In addition to being consumed by humans, rice is also used as a source of medicinal oil that is extracted from the grain's outer layer and as food for fish, poultry, and pigs, among other animals.

Smallholder farmers dispersed across Liberia primarily cultivate rice (Ashmun, 2020). Agronomic, technical, and post-harvest handling requirements are not met by the predominant rain fed, less intensive, and low input cultivation style resulting in a yearly decrease in the yield. For instance, Nigeria produced an average of 2.035084 tons of grain in the same year that the United States produced 257,995 tons from 238,090 hectares of land (FAOSTAT, 2020). The latter occur despite increasing land designated for rice production (Vorrath, 2018) since the end of the Liberian fourteen years (14) civil crisis. Interventions by stakeholders including government and non-governmental organizations have had negligible success because they ignore to address core problems affecting the sector. And among the challenges constraining rice farming in the country are attributable to weak seed systems.

Liberia’s seed industry is still in its infancy, the slow development is attributed to the country long years’ war which saw the destruction of the planting materials, crops, fibers, and rice seeds across the nation (SDCA, 2016). The war also destabilized the state infrastructural development and dragged enactment of policies that would advocate for the development and use of certified seeds in the country.

Farmers currently purchase their planting materials from friends, neighbors, and local markets, but they also rely on the community seed systems (MOA, 2014). Due to the genetic yield potential's decline with repeated use, the seed being circulated within the community system is of poor quality (Finch-Savage, 1995). In addition to being highly susceptible to pests and diseases, seeds and planting materials obtained through community seed systems typically have low tolerances for climatic and environmental stress (McGuire and Sperling, 2016). Specifically, plantain, cassava, millet, and most importantly rice, which is the main staple food for the Liberian population, are among the crops, fodder, and fiber that are not produced enough due to overreliance on such seeds by farmers and the absence of a formal seed system (Luther *et al.*, 2017).

Studies have shown that the quality of the seed, particularly in cereals like rice, can account for about 50% of the yield of the crops (Neergaard, 1997). The rice seed quality in Liberia seed system is generally of poor quality, which is denominated by lack of proper seed system and inappropriate handling techniques, favoring the prevalence of seed fungal and bacterial attack (ISSD-Africa, 2017).The problem is more engraved in poor smallholder farmers because of the poor seed storage structures, lack of seed handling technology and inadequate information on sustainable methods of preserving seeds (Rodenburg *et al.*, 2014).The lack of good strategies and policies to fight such challenges raises the need to develop economically feasible and practical strategies that would aid farmers in ensuring rice seed quality and sustainable productivity.

In order to help farmers ensure high-quality rice seed, this work was created to identify feasible, sustainable, and useful strategies that can be used with the resources already in the area. To achieve the latter, a study was established in the main rice-producing agro-ecological zones of Liberia to determine the existing seed systems and assess the seed quality assurance practices employed by farmers. In addition to assessing quality, the study assessed the variety of common fungal pathogens in charge of deteriorating seed quality in the main rice-producing agrological zones in Liberia.

Additionally, the study assessed how well locally available botanicals managed the fungal species limiting Liberia's rice seed production in vitro.

1.2 Statement of the problem

Limited access to quality rice seed and inadequate knowledge on sustainable management of its quality significantly constrain rice production in Liberia. The situation is worsened by the weak government policies and lack of education among the rice farmers (MOA, 2014). There have also been little efforts towards modernizing agriculture particularly the seed sector, hence leaving farmers dependent on poor community seed systems. The latter has been the major driver in continuous decline of rice yields (Kontgis *et al.*, 2019) due to poor seed quality assurance techniques adopted by farmers.

Despite rice playing pivotal role in all aspects, its production is insufficient and declining despite the favorable climate and soils of Liberia. The decline trend is underscored by poor seed systems. Countries like China and Nigeria which are ranked as the best global and African rice producers respectively (FAOSTAT, 2020), with high consumption rates have poorer climatic conditions and less fertile soils compared to Liberia but their production is supported by well-coordinated seed systems (Kim *et al.*, 2017; Mensah *et al.*, 2017).

Similarly, success in seed industry in different countries have been shown to support sustained crop production. For instance, improved maize production and cultivation in different agro-ecological zones in Kenya has been firmly supported by investment, supportive structure and policies channeled and focused on seed industry.

1.3 Justification of the study

Liberia's human population has steadily grown since the end of the civil war in 2003 (Vorrath, 2018). While this scenario has been associated with a positive impact on the national labour, giving rise to skilled, semi-skilled, and unskilled cheap local labour, the challenge intertwined in these population growths is increasing poverty. The young population is therefore, forced to depend on agriculture for both food and other basic needs. Rice, is an important crop, has been key to the achievement of these goals. Unfortunately, as reported by FAOSTAT, the trend of rice yield and the land under cultivation of rice for the year 2008-2018 has increased but rice production is at all times low due to poor quality rice seed. Its decline in yields despite an increase in cultivation area threatens the livelihood of almost all Liberians and, most notably, resource-poor farmers.

Rice forms Liberians staple food in terms of consumption and ranks first as the most consumed cereal estimated to provide more than 85% of calories in the country (MOA, 2014). The inability of the local production to sustainably supply the grain relative to its demand has made the country to direct most of its budget expenditures towards importation. Overreliance on imports accounts for more than two-thirds of consumed rice, translating to more than US$200 million annually (Republic of Liberia, 2019). These figures are too high to be sustained by the Liberian population, as the Liberian community averagely lives on less than US $1 a day (FAO, 2019). Imports have made access to the commodity delicate due to their high prices hence threatening the country's rice/food security.

In spite of these constrains, government and partners like Africa Rice are currently engaged in rice varieties trails, and the Central Agriculture Research Institution (CARI) is also involved in rice breeding and carrying out rice varieties multiplications.

However, rice seeds deteriorations, lack of multiplicity of improved and short duration rice varieties still remains a serious concern. Such challenges thus form the basis of this study. Understanding the level of farmers' indigenous knowledge on rice seed quality maintenance would highlight the weak links that the government, policymakers, and other stakeholders need to address with urgency to shift the current production trajectory. Evaluation of sustainable environmentally friendly botanicals used in checking fungi infection of rice seeds thus, increased shelf life of rice seeds would ensure that farmers access new information that would help them cheaply ensure they possess quality rice seeds. The study aims at the identification of the common fungal pathogens affecting rice seeds to provide information to steer targeted management practices. For proper understanding and sustainable management of rice seeds quality, this research work would therefore ensure writing proper documentation on the seed systems in Liberia, ranging from the major gaps and the best possible ways forward in improving the rice seed quality within the currently existing seed systems. Similarly, information on the rice seed quality parameters as well as, the identification of specific rice pathogens involved would be provided as a substantial baseline for future solutions towards enhanced seed quality. Additionally, for sustainable management of fungal pathogens involved in the seed quality *In-vitro* study of frequently isolated fungi the rice seeds would help in the identification of locally available plant extracts and different formulations, different rates of concentrations that can be locally used by resource poor farmers to ensuring rice seed quality is highly maintained.

1.4 Study objectives

1.4.1 Broad objective

To contribute towards increased rice production in Liberia.

1.4.2 Specific Objectives

1. To characterize and evaluate the Liberia rice seed industry

2. To assess seed quality, seed health status of rice seed collected from various seed systems commonly used by farmers in Liberia.

3. To evaluate efficiency of locally available plant extracts for their control on *Aspergillus falvus, Aspergillus niger, Penicullum spp. and Fusarium spp.* isolated from rice seed samples collected from major growing zones in Liberia.

1.4.3 Research questions

Specific objective one research questions

1. What is the status of Liberian seed industry, as concerns the legal framework and completeness of the seed industry components?
2. Is the quality of rice seed affected by the different seed systems?
3. How are the government policies affecting the quality of rice seed?
4. Is the farmers' level of awareness on pre- and post-harvest practices affecting Liberia rice seed?
5. What are the main factors affecting rice seed quality in Liberia in relation to current existing seed systems?

Specific objective two research questions

1. Is there variation in rice seed quality aspects like germination, purity, vigor and 1000 seed weight across different varieties of rice, collected in different agro-ecological zones of Liberia?
2. What are the fungal pathogens affecting rice grains from different varieties and agro-ecological zones?
3. How does disease seed quality aspect and weather factors influence occurrence of fungal pathogens?

Specific objective three research questions

1. To what degree do botanical extracts inhibit mycelial growth of the identified rice fungal pathogens in comparison with positive and negative controls?

2. Which botanical extract has the highest efficacy on the selected fungal pathogens?
3. Which extract has the highest inhibition on sporulation potential?
4. Which pathogen was the most sensitive to plant extracts?
5. Which pathogen expressed highest tolerance to plant extracts?
6. Was there significant difference in terms of percent inhibitory index between synthetic fungicide compared to other plant extracts?

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter addresses five major themes in the current study. First a review is done to cover the challenges facing the seed industry in the Sub-Saharan Africa. Here the seed systems in the region have also been reviewed. The section then narrows to the second theme of seed policies in the West African region. Strengths and weaknesses of these policies have been addressed and an assessment of regional compliance has been done. Liberia's own policies have also been addressed especially with respect to coordination with regional policies. A third issue deals with the pre- and post-harvest practices among the Liberian rice farmers. Effect of these practices on rice seeds is also assessed. Major pathogens affecting rice is another theme that takes center stage in this section. More insights coalesce around the post-harvest spoilage fungi. The section then wraps by addressing the issue of different control approaches and a case is built for the botanical extracts.

2.2 Components of a seed industry

The seed development program is a complex undertaking, as such national governments always have crucial roles (Spielman & Smale, 2017). Main government roles include inspection and legislation enforcement in addition to financing in the national research institutes. Indeed, in the whole chain of activities aimed at having improved plant varieties, seed production is among the last technical bit (Fung *et al*., 2017). From varietal improvement, activities that follow include multiplication and production, harvesting, conditioning and drying, processing and grading, treating, packaging, and storage and distribution (Saito *et al*., 2018). All these processes are done under strict quality control measures for which the government provides minimum guidelines.

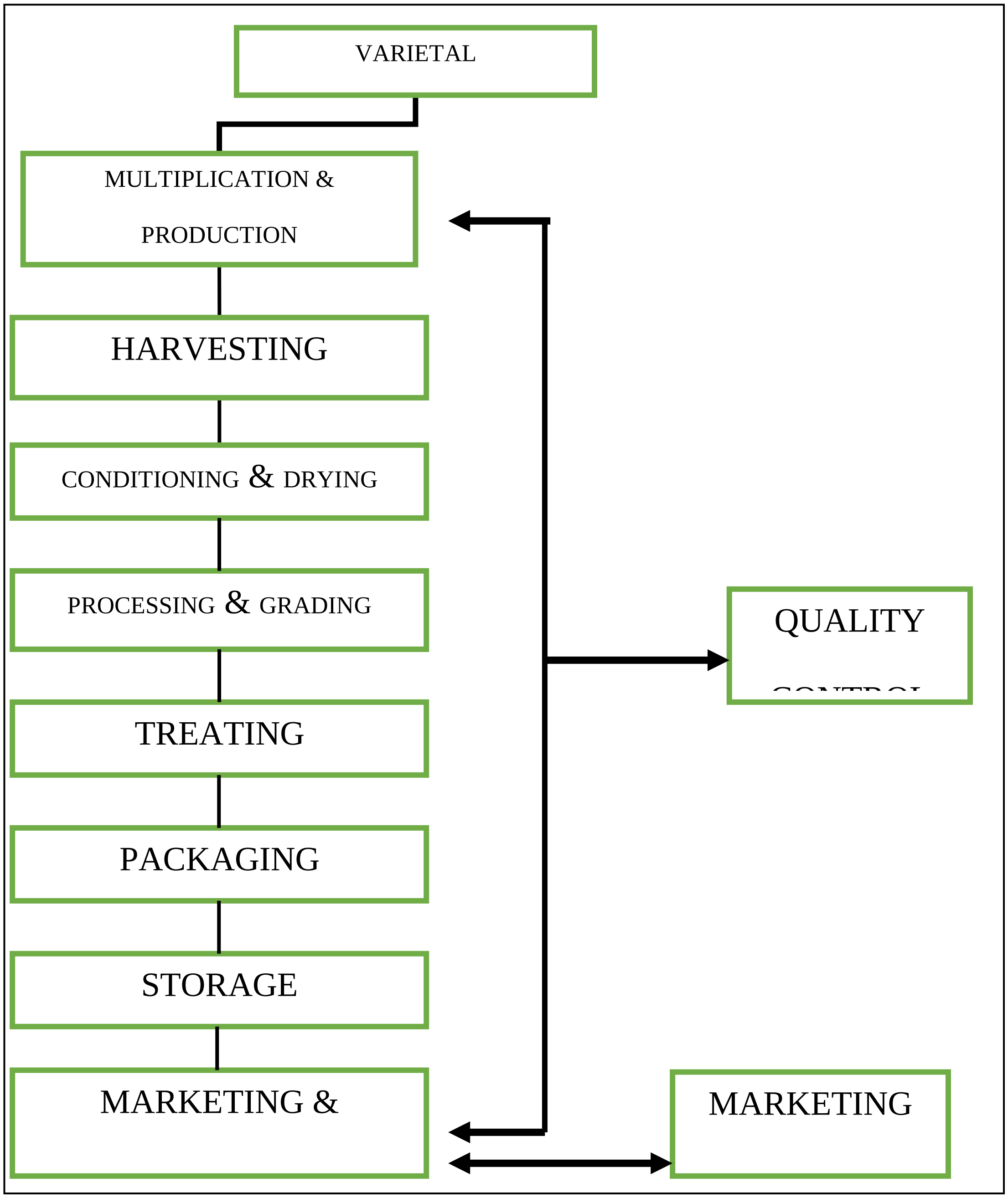


Figure 2.1: Summary diagram showing steps in development, testing and release of improved varieties (Assefa *et al.*, 2013).

2.2.1 Varietal improvement – variety development and maintenance

The main steps in the production of a variety may vary from plant species to another albeit with very little difference (Fung *et al*., 2017). At the beginning of any variety improvement is breeding and therefore genetic resources have to be available. The genetic resources are the different varieties of the crop which are mainly refereed as genotypes to distinguish them from the already released varieties (Atlin *et al*., 2017). For self-pollinating crops, the genetic resource is called lines instead of genotypes.

Breeding is a long activity for all crops. It takes six to seven years for a new variety to be recommended for the final release (Samantara *et al*., 2022). However, this also depends on the total collection of the genetic resources and whether or not the breeding aims at creating or introducing a new characteristic. Varietal improvement of a particular crop does not only depend on breeding crosses, it may also involve the introduction of newer varieties (Qi *et al*., 2020). This will however involve other procedures such as quarantine due to phytosanitary concerns.

2.2.2 Multiplication and production

Before the multiplication and production of a new variety, a comparative analysis is first done (Poku *et al*., 2018). This is normally done at the main research site and also in another field outside the research station. Main agronomic traits targeted for improvement are observed and compared with a check (Labarthe *et al*., 2021). This is the most widely grown variety for which the new variety may replace. The agronomic performance is evaluated statistically to gauge the level of improvement by the new variety. The need for different sites allows for the testing of the stability of the variety (Fung *et al*., 2017). The last stage before a variety is released to the farmers is making the trials in the farmer's field. At this stage, the breeder is not the main player but rather an agronomist and an extension officer.

The seed that is to be produced is normally referred to as breeder's seed, nucleus seed, or basic seed (Timsina *et al*., 2018). These seeds first come from a minimum of 100 or 1000 plants according to the need (Fung *et al*., 2017). This is done to maintain strict conformity to variety characteristics as this is crucial for variety homogeneity in the subsequent multiplication steps. A variety is sown in single plant progenies and each progeny carefully examined before planting the following year.

2.2.3 Harvesting, and threshing

Harvesting seeds is the most crucial step in seed production activities (Dornbos *et al*., 2020). A producer should be conscious of the moisture content of the seeds. Mostly, harvest starts once the moisture content first drops below 14.5%. Too low moisture content would render the seed vulnerable to mechanical injury during the harvesting and processing of the seeds (Fung *et al*., 2017). Further, reduced moisture as a result of hot weather during harvesting may promote weathering of seed quality and hence diminish its quality. The field should also be free from weeds. During harvesting, especially if it is aided by machinery, the harvester should periodically check on the physical integrity of the seeds (Poku *et al*., 2018). In case there is a potential breach of quality, they should take measures to rectify that. Such measures would include harvesting at a uniform speed, and adjusting cylinder speed in combined harvesters.

After the harvesting, all handling must be done gently to reduced mechanically or any other damages to the seed. Frequently, loading of the seeds is done bins via belt-veyours. The metal bins are fitted with aeration or means of drying before they are processed and packaged for sell (Delouche *et al*., 2021). The period of bulk storage of seed may last from few weeks up to about 6 months. During this period, there can be a significant reduction vigour of the seeds. If the seed moisture content is slightly above 13% during storage supplemental heating might be required for drying. However, if the moisture content is beyond 20% and supplemental heating is employed to bring down the moisture content, this may harm the seeds (Fung *et al*., 2020). Aeration of the seeds is also done to so as to equalize temperature with the seeds and hence avoid cases of moisture movement. Aeration further eliminates seed deterioration by fungal spoilage.

2.2.4 Seed Processing or Seed Conditioning – cleaning, grading, treatment, packaging and storage

After bulk storage of seeds in the bins, the seeds are processed before packaging. Processing activities involve cleaning the seeds and grading (Delouche, 2021). Air can be used to remove husks or any light debris present in the seeds depending on the type of crop. Screening is used mainly to remove weed seeds, and the seeds which are significantly smaller or larger than the recommended sizes at physiological maturity. By removing the broken pieces, the germination percentage is increased (Atlin *et al*., 2017).

Frequently, the seeds are normally packaged and marketed after basic cleaning. However, for some type of seeds, for example the soy-bean seed, the seed is passed through the seed spiral separator. It helps in removing some weed seeds and sizing of the seeds. This additional step can therefore be used additionally for grading. The entire cleaning system however can be a source of seed contamination (Jitanan & Chimlek, 2019). Therefore, thorough cleaning of the seed cleaning system is essential to maintain seed homogeneity.

2.2.5 Treatment, Packaging and Storage

Before a seed is packaged germination test is done to examine if it meets basic requirements for a particular region (Fung *et al*., 2017). Treatment of the seeds is done using fungicide and is especially beneficial if the seeds had a germination percentage of less than 80% or is infested with disease (Delouche, 2021). Once the seeds is so treated, it is solely used for planting. If it does not meet the required standard then such seeds are dumped.

The last step in seed processing is the packaging. Seeds are packaged depending on the amount. Mainly, seeds are packaged in woven plastic bags or multi-wall paper bags.

Storage of the seeds can be divided into two; storage before processing and storage after packaging. The storage before processing that is, immediately after harvesting, has already been briefly dealt with. The length of time a packaged seed would remain viable depends on a number of factors. First is the moisture content of the seed prior to packaging, the temperature of the environment where the seeds are kept, the initial quality of the seed when it was taken for storage, and the inheritance characteristics of the crop (Saito *et al*., 2018). Seeds are naturally hygroscopic and will either absorb or lose water to the immediate environment depending on the relative humidity. Many studies lay emphasis on the controlling of the relative humidity during seed storage. This is especially important if the packaging material is not vapour –roof (Solberg *et al*., 2020). Seeds with moisture content ranging from 15-18% can be stored for a year at 10 ˚ C or lower while seeds with moisture content lower than 9% can be stored for the same period at higher temperatures of 30-35 ˚ C.

2.2.6 Distribution and Marketing

After packaging, the seeds are ready to be supplied to different distributors. Many studies have shown that farmers' purchasing choice is determined by the quality of the product, price, place (distributor), and promotion (Rafdinal & Amalia, 2019). Strict quality control measures should be put in place to ensure consistency in the quality of the seed products (Suvedi *et al*., 2017). Price not only reflects affordability but also hints to the customers about the quality of the seeds. The proper selection of the place (distributor) determines the ease with which the customers access the products. Promotion helps a firm communicate the position of the seed to the farmers (Soare & Chiurciu, 2018). It is good that during the promotion the characteristics of the seed variety are well communicated to the farmers.

2.2.7 Seed quality control or Assurance

Seed quality attributes includes, genetic purity, physical purity, high germination rate (greater than 90%) and vigour (Delouche, 2021). Genetic purity is especially important when that means uniformity in maturity. Poor quality seeds is many times as a result of inexperienced producers, mostly when a breeder tips too much towards quantity over quality. Germination and vigour problems are influenced by the climatic conditions.

After physiological maturation, prolonged stay in the field should be avoided. Moisture levels of below 25% leaves the seeds vulnerable to climatic shocks which leads to deterioration in the quality (Solberg *et al*., 2020). To minimize the risks associated with climatic conditions, harvest should be done when the moisture content in the seeds are about 14-16% (Delouche, 2021). Genetic purity of seeds is generally a consequence of experience from the seed manufacturer.

2.3 Seed industry challenges in Sub-Saharan Africa

Sub-Saharan Africa (SSA) region is geographically positioned in the African continent, south of the Sahara-desert, between 15° North and 35° South. The number of countries in the region is forty-eight (48) occupying an area of land measuring roughly 21.2 million square kilometers. It comprises of 600 Mha of productive land, less than a tenth is currently cultivated. It is generally agreed that SSA has the largest underutilized land reserve in the world (Khojely *et al*., 2018). Most authors with seed science backgrounds when alluding to SSA, it is normally with the exception of South Africa.

Seeds and other planting materials can be placed into different groups (Bonny, 2017). ‘The conventional seeds are those that are produced and sold by most seed companies including parastatals. They are simply certified seeds like the hybrid corn seeds or just clean pathogen free seeds for potatoes. Genetically Modified seeds (GM seeds), have been altered genetically to give them certain unnatural characteristics. Initially these characteristics included abilities like drought and disease resistance (Brookes & Barfoot, 2017). But, these types of seed are synonymous with big seed companies these features endowed upon plants grown from GM seeds tend to be driven by profit making venture. Farmers' seed systems are seeds that are produced from farmers' own breeding knowledge and efforts (Kansiime &Mastenbroek, 2016). Closely related with farmers' seed system is farm saved seeds. Farmer first begins with purchasing conventional seeds. From the harvest, sorting can be done to preserve what would now be called farmer saved seeds. While farmers' seed system produces newly bred seeds, farmer saved seed can be perceived as "carbon copy" or "photocopy" of conventional seeds if the crop breed true to type (Croft *et al*., 2018). The other kind of seeds are seeds from public research. The end user of this type of seed is normally not the farmer as public research generally work upstream (Bonny, 2017).

These seeds are then found in different seed systems. A seed system broadly refers to the mechanisms, either economic or social mechanism or both by which the seed demand by farmers are met through numerous sources (Kansiime & Mastenbroek, 2016). In SSA seed systems are generally grouped as either as formal or informal. The formal system is more structured and institutionalized producers of seeds and companies. These institutions can be privately owned or belongs to the public (Welu, 2015). The 'conventional' seeds, GM seeds and seeds for public research belong to the formal seed sector. The formal seed systems comprise of a sequence of inter-reliant activities, clustered into three main levels. The levels are first, development of varieties, second level is the multiplication and certification of seed and lastly marketing and certification of the developed seeds (Poku *et al*., 2018). Development of new seed varieties, which is the first level of the formal seed system is pegged on many research activities predominantly breeding. The breeding and development of the new varieties is tested of the same new varieties so that it would then be released to the farmers. The process of large-scale production of the new varieties also includes a number of stages. First there is production of breeder, foundation and certified seeds and finally the commercial seeds for the end user. There are details regarding breeder and foundation seeds. The different stages of the formal seed system accompanied by quality control procedures.

On the other hand, the informal seed sector lacks governed institutions. Their main characteristics includes saving of seeds by farmers, seed exchange either as gifts or items of barter, and seed production by farmers. This informal system is vastly localized (Westengen & Brysting, 2014). The sale of seeds hardly extends further than the area of production. It is normally on this ground that those who oppose of development of village level seed enterprises cling on. It is absurd to expect development of a flourishing village-based seed industry when there cannot be enough market to sustain this kind of industry (Tripp, 2000). While farm saved seed would fit well into the informal seed sector, seeds from farmers seed system can sometimes be grouped into an intermediate sector; implying the informal one but with technical support. The informal seed system is the more dominant means by which farmers in SSA obtain planting materials and only small fraction sourced through formal market (Langyintuo *et al*., 2010; McGuire & Sperling, 2016). In fact, for some crops like rice, African indigenous vegetables, the informal sector is the only source of seeds in Kenya (Munyi & De Jonge, 2015). In spite of the major role of the informal seed sector, efforts to enable its improvement are woefully lacking or on a very nail space in Africa (Croft *et al*., 2018; McGuire & Sperling, 2016) as it is viewed as inferior to modern seed breeding (Lukonge *et al*., 2015; Westengen *et al*., 2014).

Though a semblance of support for informal seed sector can be found in the nascent intermediate seed system in some regions of Ethiopia (Sisay *et al*., 2017). The community-based seed production has technical backing from NGOs, research, and some regulatory oversight from national bureaus of agriculture (Welu, 2015). Somewhere else, such arrangements (formal-informal seed sector interactions) are referred to as integrated, seed system development (ISSD) (Louwaars *et al*., 2013). Still there are those who view development of the informal sector is detrimental and defeats the purpose of seed production. Assumption made by such groups is that, such kinds of arrangements hardly ever develop into a reliable industry in the long term. A better way is empowering the farmers to distinguish between seed varieties. That they will be better consumers who will then encourage better environment for the development of formal seed industries.

Judging from the rate of varietal release and degree of breeding, the policies that guards the regulatory bodies and environment, participation levels of the privately owned seed sector, and the supply chain efficiency, the seed industry players operating in virtually all the SSA countries is in stage 4 (growth stage) early growth or emerging stage (stage 4) (Ariga *et al*., 2019).

Farmer's access to improved seeds is still a major drawback to SSA farming despite liberalization (Poku *et al.*, 2018). Some problems encountered in SSA's seed industry as listed by (Tumsa & Negash, 2013) are existence of technical and infrastructural hiatus in the more dominant informal system, unclear certification system for the informal seed system, absence of mechanization, fluctuating market prices for the farm products and inadequate quality seeds by variety. Notwithstanding, the continual dependence of SSA's farmers on informal seed system, it is still viewed as both part and symptom of seed problem afflicting the region. As part of the problem because it directly contributes to the problems mentioned supra. The lack of certification for the informal seed sector for example, may mean that farmers would not have the means to distinguish between quality and fake seed. Its resilience which has not yielded to the past formalization attempts hints to some underlying inefficiencies in the part of formal seed system (Westengen *et al*., 2014). Therefore, this very resilience is the symptom of hidden problem in the formal sector.

There are three key aspects when aiming to boost food security through seed system and they include, seeds availability; it must be within reach by farmers, and they should possess qualities that are acceptable (Sperling *et al*., 2008). There is a consistent failure by the current formal seed system to satisfy farmers' seed demand (Sisay *et al*., 2017). The non-achieving nature portrayed by the formal seed system has informed others while suggesting combination of both these main seed systems so as to maximize on the positive attributes offered by both (Okry, 2011). Such is the intermediary system in Ethiopia (Sisay *et al*., 2017), Local Seed Businesses (LSBs) in Uganda (Kansiime & Mastenbroek, 2016) and integrated, seed system development (ISSD) in Tanzania (Lukonge *et al*., 2015).

The factors that hinder development of SSA's seed system are discussed in greater details. Funding by the official development assistance (ODA) for agriculturally based activities jumped from $8 billion dollars in 1984 to $3.4 billion in 2004 (Low *et al*., 2017). This is the context with which we find SSA agriculture. Such developments seem to have affected seed development of crops differently but mainly rice. The plummeting of support for example between 1984 and 2004 affected efforts to breed for new sweet potato varieties in the SSA (Low *et al*., 2017).

2.4 National government policies affecting rice production in Liberia

The government of Liberia has not carved realistic and robust policies to address the rice production sector of the country. Ranging from the importation of high yielding and short duration rice seeds and other agricultural inputs that withstand all stresses. Seed Development and Certification Regulations (LSDCR) is not a holistic regulation, taking into consideration all or most aspects of agricultural linkages ranging from seed, plant, insect pest infestations, fertilizers, chemical, tissue culture and other things (LSDCR, 2021).

It's very expedient for the document to be tremendously clear and specific about which two universities deans that would serve on the seed development board. There are two leading government universities that are agriculture related deans should be part. Additionally, one government university and one private university agriculture colleges deans would be very necessary to be part of (Mabaya and M., 2021) the seed development board (LSDCR, 2021).

As it stands, the country does not have any well-equipped and established seed science laboratory throughout the country. No seed pathology, crop physiology, seed processing, plant pathology and others essential agricultural laboratories in the country. There is no or proper auditing mechanisms enshrined in the Liberian Seed Development and Certification Regulations.

Storage as an essential component of seed science and seed technology as the document fall-short of indicated lack of linkages, packing seeds per variety, crop tags, packing of seeds in rows. The storage does not suggestion about structure as per best international practices as called for by ISTA. The seed laws of Liberia are centered around or build upon the ECOWAS seed regulations. Which may invite unspecific counterfeits seeds in Liberia since, the country does not have well facilities to determined sound seeds (LSDCR, 2021).

In the seed law regulations document, there exist no single identified plants or seed-borne pathogens as a dangerous for the country agricultural sector. There are no aspects of the document that is indicated therein nowhere that, farmers can sue and can be sued for bad seed transactions.

80% of rural households grow rice as a subsistence crop in a variety of environments, including upland, rain-fed lowlands, and irrigated lowlands. At 500,000 MT annually, cassava is a larger crop by volume than rice. Farmers in some regions only grow cassava. However, rice is the most significant rice crop in terms of value (Zeller *et al*., 2012). The 2016 rice harvest, at 189,000 MT, was about 5% higher than the five-year average and roughly equal to the previous record, set in 2012 (188,000 MT) (Pathak and Zaidi, 2013). Despite the disruptions brought on by the Ebola crisis that started in late 2014, production has quickly recovered. The average yield of paddy rice in Liberia, which is among the lowest in West Africa and the world at 1 MT/ha (Pathak and Zaidi, 2013), is low due to the use of traditional varieties that produce little and little fertilizer. In 2008, the average yield increased to 1.5 MT/ha before declining once more. Comparatively, neighboring Côte d'Ivoire's average yield rose from 2 MT/ha in 2009 to more than 5 MT/ha in 2015. Only in some rural areas does domestic rice production completely meet consumer demand. A sizable portion of the rural population also consumes imported rice during the lean months prior to harvest.

2.4.1 Liberian seeds policy

The Liberian government arm of agricultural activities, the Ministry of Agriculture (MOA) was task with other players for the carving blue print plans and policies in order to revamp the agricultural sector of the country. Many policies has come and gone for instance, "Lift Liberia" Interim Poverty Reduction Strategy (IPRS) 2006, Poverty Reduction Strategy (PRS) 2006, Food and Agriculture Policy and Strategy (FAPS) 2009, National Food Security and Nutrition Strategy (FSNS) 2008, and the Liberia Agriculture Sector Investment Program (LASIP) (Phase I: 2010 – 2015; and Phase II: 2018 – 2022) Comprehensive African Agricultural Development Program (CAADP) pact penned 2009, Agenda for Transformation (AfT) (2012 – 2017) and the Pro-Poor Agenda for Prosperity and Development (PAPD) (2018 – 2023).

Henceforth, as mentioned above, all of those legal instruments failed to address the aspects of short duration varieties or plant materials when in fact, Liberia had lost all essentials germplasms, stocks and seed pedigrees due to the country fourteen (14) years of civil carnage which had seriously undermined the development of the seed sector thus, poor sustainable agricultural production in the country (LSDCR, 2021).

The ministry responsible for agricultural issues in Liberia drafted the first proposed Seed Policy and Regulatory in 2012 and it was prepared 2015. as well as ECOWAS Regulations C/REG.4/05/2008 and related. Liberian government since foundation not had any seed laws on the book until these years above, policies and regulations, until seed legislation ECOWAS was adoption of the ECOWAS Regulations C/REG.4/05/2008, and given rise to the Liberia seed act that was make into law by the Fifty Fourth (54th) National Legislature of Liberia and penned into by head state of Liberia, 2019.

Since the end of the country's civil war (2003), the government has strived to stabilize rice production by targeting the high potential areas using the most preferred rice varieties. Crops such as cassava and plantain have recorded tremendous success compared to rice. This is because rice is a sensitive grain crop whose optimal production can only be achieved by optimizing best agronomic practices alongside conducive climatic factors. Notwithstanding the country's less depleted soils and the right amount of rainfall, the poor rice yield is embedded on the farmers' use and reuse of poor-quality seeds and stagnated awareness on economically feasible means of ensuring seed quality.

Climatic characteristics facilitate rice seed quality deterioration in tropical regions. Research indicates an annual loss of a third of the produced to post-harvest handling globally (Hiama *et al.*, 2019). Liberia being the wettest country in Africa, is not spared of the spoilage, and according to (Hiama *et al.*, 2019), the country losses about half of its total production to waste while more than half of national rice production spoils through handling.

Fungal pathogens, bacterial and virus invasion of rice seeds, especially *Aspergillus flavus, Rhizopus stolonifera, Fusarium culmoreum, Penicillium spp,* Bacterial Leaf Streak (BLS), Bacterial Blight (BL), and Rice Tungro Disease (RTD) are among significant biotic factors constraining rice production in tropical regions especially Liberia, by pre-harvest effects on crop vigor and reduction of the quality of seed grains (Oyetunji *et al.*, 2012). Due to a lack of knowledge about the severity and prevention of the fungi, particularly given the climatic and environmental conditions in Liberia, management of such fungi has failed there (Yacouba Séré *et al.*, 2013). Affected seeds rice, when used as propagating materials easily, recycles the fungal into the subsequent crop generations, which impacts both productivity and human health negatively. National government and business gurus used millions of United States Dollars every year for the importation of rice.

2.4.2 Strengths of the seeds policy of Liberia

The positives of the regulations, it's the first of its kind for the country, in regards to protection and develop the seed sector of Liberia. As the seed regulations it covers some of the essential aspects (types of seeds for importation, seed quality, purity, germination) of the seed laws and policies. The legislation was crafted in accordance with ECOWAS Seed Laws and Policies, which control seed importation and exportation (LSDCR, 2021).

Henceforth, this document when roll out and appropriately implemented it would enhance agricultural development drive of the country. The documents captured all registered varieties as it's indicated therein of the regulations of ECOWAS seed laws regulations.

2.5 Pre-and post-harvest practices influencing rice seed quality

In addition to causing yield and quality losses, pre- and post-harvest losses are a problem that affects labor, water, seeds, time, and fertilizers in addition to causing a loss of food (Zeller *et al*., 2012). The post-harvest waste and rice seed losses are estimated to account for 30 to 40% of the total production. Because of insects and rodents that get into storage containers, losses during harvest and processing, and other factors, between 10 and 40 percent of the food that is grown never makes it to the market or a consumer's plate. These losses not only weaken global food security but also drive up production costs. In other words, post-harvest food loss causes enormous environmental waste in addition to human hunger and financial losses for farmers (Pathak and Zaidi, 2013). In production of next generation propagation materials like rice seeds pre- and post-harvest factors have been found to have significant influence on the quality and quantity of the yields.

2.5.1 Pre harvest factors influencing the quality of rice seeds in Liberia

2.5.1.1 Fertilizer application of rice

Large portion of crop growing zones are depleted of plant nutrients especially in sub-Saharan Africa where nutrient replenishment is minimal and farms are rarely managed to conserve and limit erosion. One of the major soil nutrients deficient in rice farms is nitrogen; however, poor management of the fertilizer might have two opposite pronged consequence to the quality of the grains (Dordas, 2008). For instance, inadequate supply of nitrogen fertilizer would impede root and leaves development and that would reduce the amount of photosynthates produced by the plant resulting to poor quality grains. On the other hand, indiscriminate application would reduce uptake of other minerals like calcium alongside making the plants extremely succulent to paste and disease attack which might lead to devastating loss of grains yields. Field crop attacks by pathogens has a residual impact in susceptibility of the stored grains to fungal attacks (Dordas, 2008). Mismanagement of other plant nutrients and inadequate supply of fertilizer to plants as is case in Liberia rice plantations may lead to unforeseen and unprecedented consequences to next generation farming particularly in a country that highly depends on the community seed system like Liberia (Dordas, 2008).

2.5.1.2 Irrigation regimes of rice in Liberia

Rice growth is significantly depended on water, however, availing water and draining it at the right time can hugely determine the yield, plant susceptibility to pathogens and the quality of resultant grains. Few rice farmers have a reliable irrigation systems and majority use swamp water supply which is not reliable but also are the sink and source of many devastating pathogens. Use of such water has been found to reduce the rice yield by 30% (Lawler, 2001). Delays in draining water when rice is physiological mature induces increases the grains moisture content which makes them susceptible to diseases (Davatgar *et al.*, 2009). Inadequate water supply increases the grains dry matter content however, compromises the yields. Proper water scheduling and appropriate amount is key to achievement of good quality rice grains that can be utilized as subsequent season propagation materials (Balasubramanian *et al.*, 2007).

2.5.1.3 Weed control in rice production

Weeds cause stunted growth and a decrease in the yield of grain and fodder by competing with the crop for all vital nutrients. Their prompt control can boost yields (Pathak and Zaidi, 2013), recorded an increase in fresh and dry weight of sorghum by timely controlling the weeds using chemical application. At 15, 30, and 45 days after sowing, hand weeding of rice plantations was found to have a higher control efficiency (82%) than pre-emergence and post-emergence herbicide application. Increased plant height, the number of green leaves per plant, stem diameter, leaf area per plant, and the leaf-to-stem ratio at anthesis were all improved by manual weed control (Pathak and Zaidi, 2013). Thus, weeds management is crucial in rice cropping systems and the methods of control and time can have impact on both quality and quantity of grains.

2.5.2 Post-harvest factors influencing the quality of the rice seeds

Post-harvest handling and storage techniques have one main goal, to maintain the grain quality and retain its viability as a seed. Despite the viability of the stored rice grains reducing exponential with storage time, good conditions might push the limit to longer times which is favorable to farmers (Pathak and Zaidi, 2013).

2.6 Synthetic fungicides used on rice

Fungi is the main cause of disease pressure in crops and as such use of chemical fungicides for rice or crops protection is inevitable (Zubrod *et al.*, 2019). The changing climatic conditions may in some cases particularly favour the proliferation of these pathogens and therefore, calling for an increase in fungicide application best in morning and evening hours in the absent of solar radiation (Boxall *et al.*, 2009). They have been dubbed "indispensable to global food security" in some circles (Strange and Scott, 2005). Fungicide resistance with invasive fungal species (a change in the dominant pest) are two additional factors contributing to an increase in the usage of synthetic pesticides (Hakala *et al*., 2011). 2019 (Yang *et al*.). The continuous and expanded use of these compounds is a fact we must deal with, it is clear from the analysis of the literature. Despite this, synthetic chemicals have a history of harming both the environment and biodiversity. Aquatic ecosystems are the most significantly impacted, and it has been demonstrated that they exist extensively in the environment (Bereswill *et al*., 2013). They are highly poisonous to a wide spectrum of creatures in the habitats where they have been demonstrated to exist in addition to the main target. As a result, issues regarding their long-term viability are raised by such worries. The use of these compounds has a tendency to rise, as already mentioned, as a result of increased pathogen chemical resistance and a shift in the dominant pathogen species (Nesheim *et al*., 2015). Additionally, this would have an adverse effect on the environment by raising the cost of crop cultivation, leading to increased rice prices.

Due to these issues, switching to biological products (extracts, oils, cake, and powders) (Barratt *et al*., 2018) instead of synthetic chemicals has generally been seen as a sustainable strategy. (Ons *et al*., 2020). These could also cause issues because some biofungicides have been demonstrated to be entomopathogenic and to have a particularly detrimental effect on bee populations' worldwide (Yaremenko *et al*., 2020). The issues created by synthetic chemicals and biological control agents have both been addressed using integrated strategies (Majeed *et al.*, 2017). For instance, it has been demonstrated that *lipopeptides* produced by *Bacillus amyloliquefaciens* make *Fusarium graminearum* more susceptible to synthetic fungicides (Kim *et al*., 2017). Benefits from this would include a decrease in the need for chemicals and a lower risk of resistance.

2.7 Major cultivated rice varieties and diseases of rice in Liberia

According to Hiama *et al*. (2019), the majority of Liberians consume imported parboiled rice; locally produced rice is not parboiled. Prior to 2011, China and the United States were the main sources of non-parboiled medium grain "butter rice" and long grain uncle Ben rice imports (Hiama *et al*., 2019). The new, better yielding NERICA types, created particularly for West Africa, are gradually replacing one classic variety, LAC 23, with red and white bran layers. Imported rice is available in three primary grades: 100% broken, 25% broken, and 5% broken. Due to their cheaper cost, 100% broken kernels are in high demand. India's 5% broken long grain rice is less popular with middle-class customers. According to a 2015 UN Comtrade assessment, 90% of the imported rice was fully or semi-milled, while the remaining 10% was broken rice.

African rice, also known as *Oryza glaberrima*, is a kind of cultivated rice. According to Linares (2012), the domestication of African rice is thought to have occurred in the Upper Niger River’s inland delta, in what is now Mali, between 2,000 and 3,000 years ago. Its progenitor, *Oryza barthii*, still grows naturally in Africa. West Africa is where this species is raised. *O. glaberrima* differs from *O. sativa* in a number of ways that make it less appropriate for cultivation, including brittle grains and subpar milling quality (Sarla & Swamy, 2005). African rice produces less than *O. sativa* does, but it is frequently more resilient to environmental stresses such changing water depths, iron toxicity, barren soils, harsh climatee conditions, and human neglect. Additionally, it demonstrates stronger resistance to a variety of illnesses and pests, including viruses, nematodes, midges, and the parasitic plant Striga. NERICA, an abbreviation for "New Rice in Africa," is a rice variety that was created by scientists from the Africa Rice Center by crossing African rice with Asian rice species (Jones *et al*., 1997).

Diseases are the major biotic factors affecting rice production particularly in tropical regions. Some of the common diseases include; blast (*Pyricularia oryzea*), sheath blight (*Rhizoctonia solani*), brown spot (*Helminthosporium oryaza*), foot rot (*Fusarium moniliforme*), glume discoloration and many others. Some diseases affect the crop in the field such as blast. Such diseases are detrimental and can cause the loss of more than 90% field crops. For instance, because of its widespread distribution and destructiveness under favorable conditions, which result in crop loss and outbreaks, blast is regarded as the main disease of rice. Under ideal circumstances, the pandemic potential is quite great. However, some of the diseases affect the stored rice grains. The fungal pathogens are among the major pathogens responsible for both on field rice and stored grains diseases. (Pathak and Zaidi, 2013) reported that more than 80 fungal strains can be detected on the stored. A bigger percentage of the fungal strains are beneficial; they help control the population of other pathogens. However, *Aspergillus flavus*, *Aspergillus nomius* and *Aspergillus parasiticus*.) Dominate the population of pathogenic fungal strains especially in tropical and sub-tropical regions.

2.8 Diversity of major common pathogen affecting rice seed quality in Liberia

Rice (*Oryza sativa L.*) is Liberia staple food accounting for the country’s 50% adult caloric intake (Hiama *et al.*, 2019). The crop is cultivated in most parts of the country with the country's food basket being Lofa County (Hiama *et al.*, 2019). Due to this extent of dependence on rice, any impairment of this sector would result in far reaching consequences as far as nutrition is concerned. The ever-present threat to many crop are diseases majorly caused by fungal pathogens (Zeller *et al.*, 2012). Liberia being a tropical and a humid country would particularly face huge disease burden in its crops. Tropical climates favour proliferation of most plant pathogens, both in the field and spoilage during storage (Benkerroum, 2020; Hiama *et al.*, 2019). There are not many sources of information on this aspect and therefore information from other similar rice growing regions will be used to infer on pathogen diversity in Liberia.

Rice pathogen that is dominant in tropical regions such as Liberia is *Magnaporthe oryzae* B.C Couch (Anamorph *Pyricularia oryzae* (Cav)), destructive pathogen causing rice blast (Pathak and Zaidi, 2013). This pathogen is however found in all the rice growing regions of the world (Benkerroum, 2020). Lifecycle begins when conidia released from lesions in highly humid conditions lands on the surface of a susceptible rice variety (Hiama *et al.*, 2019). This is followed by leaf adherence and subsequent germination of the spore. This process also requires moisture facilitation. *M. oryzae* is majorly a foliar pathogen, but in very favourable environments it might be severe enough to infect the seed. In fact, seed has been touted as one of the vectors of the pathogen from one planting season to another (Benkerroum, 2020). The fungus has been shown to have diversity on virulence as well as morphology (Benkerroum, 2020). The morphological aspects differ with the type of culture media used. Other field fungi of importance belong to the genus *Fusarium*. This fungus infects the seed in rice and occurs in many geographical regions and is also associated with mycotoxin production in stored rice (Hiama *et al.*, 2019). The diversity of this genus mainly comes from its spore shapes and sizes intraspecific diversity has been shown in terms of virulence.

Others and mainly spoilage fungi belong to the genus *Aspergillus* and *Penicillium* and are the main sources of mycotoxins in rice (Hiama *et al.*, 2019). *Aspergillus* spp are the main contaminants in warm subtropical climates like Liberia (Benkerroum, 2020). *Aspergillus flavus* dominates as the spoilage fungi followed by *A. niger* and *Penicillium* spp. As such, aflatoxin is the main toxin of concern in rice.

2.8.1 Effects of fungal infection on rice seed quality

There have been numerous studies on the fungal invasion of stored rice grains in several varieties and the common strains identified with severe impact include; *Aspergillus flavus, Penicillium citrinum, A. niger, Alternaria padwickii* and *Rhizopus oryzae***.** The five strains have different magnitude of impact in different agro-ecological zones. When rodents and insects are managed, (Pathak and Zaidi, 2013) claim that fungal pathogens are the main factor causing the quality of stored rice to decline. Rice grains that have been stored are vulnerable to fungus, particularly in environments with moderate temperatures and high humidity. Storage fungus, which are frequently introduced during the post-harvest handling phase, are blamed for the spoilage of stored rice (Pathak and Zaidi, 2013). In some studies, *Aspergillus niger* has been isolated from rice varieties inappropriately stored in market places. The storage conditions in such area that of warm and high humidity hence favoring growth of the pathogenic fungi. This demonstrates that unmilled rice grain and storage are frequently affected by fungal invasion, which can lead to degradation in the form of discoloration and unpleasant aromas as well as a decrease in milling yield owing to the growth of mold and other microorganisms. *Aspergillus* spp., especially *A. niger* and *A. flavus* have been found to be the common fungi strains on rice seeds. Their higher presence has been directly association with poor germination of rice seeds. Such findings confirm that the species of *Aspergillus* though occur as saprophytes may be the major cause of low germination in rice seeds particularly in tropical environments.

2.8.2 Effects of fungal contamination of rice grains on consumers

Mycotoxins, which are bad for human health, are known to be produced by a number of fungi that have been identified from rice grains. A person who consumes the contaminated grains might suffer serious harm to their liver, kidneys, and nervous system from mycotoxins (Pathak and Zaidi, 2013). *Aspergillus* spp. are common fungal contaminants of cereals and also produces mycotoxins (Pathak and Zaidi, 2013). *Aspergillus flavus* produces aflatoxins which are carcinogenic associated with liver cancer (Pathak and Zaidi, 2013; **Khan *et al*., 2021**).

Aflatoxins are associated with both toxicity and carcinogenicity in human and animals feeding on affected food commodities (Chebon *et al.,* 2016). Severe aflatoxicosis results in death, while chronic aflatoxicosis leads to extended pathologic changes, including cancer and immunosuppression (London *et al.*, 2013). Provided that liver plays role of breaking down toxins, it becomes the first organ to face the effects of B1 aflatoxins (Abdallah *et al.*, 2016). Research has indicated, liver damage in test animals few seconds after ingestions while in human it is manifested as severe hepatitis. Pediatric aflatoxicosis also takes the form of illnesses like kwashiorkor, a severe malnutrition condition, and Reye syndrome, which is characterized by encephalopathy and visceral fatty degeneration. Long term ingestion of small quantities of aflatoxins have been found to correlate with risks of Hepatocellular carcinoma (Abdallah *et al.*, 2016) .

Carcinogenesis emanating from aflatoxins is thought to stimulate tumor development and growth (HouMiao and BoShou, 2013; Khan *et al*., 2021). Scientific evidences show that aflatoxin is directly involved in activation of proto-oncogenes and mutations in the tumor suppressor gene p53. Exposure to aflatoxins and subsequent p53 mutations has been correlated to p53 mutations where G to T trans-version occurs at codon 249 (London *et al.*, 2013; Asser *et al*., 2021). The biomarker provides evidence of hepatitis cancer link with aflatoxins. Scientists suggest that ingestion of aflatoxins may induce chromosomal aberrations, unscheduled DNA synthesis and chromosomal strand breaks in human cells. Production of mutagenic substance as byproducts of aflatoxins metabolization by hepatic cytochrome p450 is another postulation of aflatoxin induced carcinogenesis (Sankaranarayanan and Boffetta, 2010; Asser *et al*., 2021).

2.9 Management of fungal pathogens in rice seeds

2.9.1 Botanical Extracts as bio-fungicides

The development of bio-fungicides is fueled by the need to replace synthetic chemicals which have been labeled as harmful majorly due to their wide range targets (Al-Samarrai *et al*., 2012; Wong *et al*., 2020). Bio-fungicides are derived from two main sources, microorganisms and plants. Though these are touted as environmentally safe as compared to synthetic chemicals, some bio-fungicides have been shown to be entomopathogens and hence endangering bee population in areas where they are used (Yaremenko *et al*., 2020).

In both the plants and microorganisms, the active ingredients are the mainly the secondary metabolites. Others could be enzymes that degrade essential parts of the organism it is being directed against (Jiang *et al*., 2015). In both microbe and plant sourced bio pesticides, it is paramount that the active ingredients are able to maintain their biological activity in a cell-free state (Contreras-Cornejo *et al*., 2016). Only then, can they be applied to different environments with varying conditions that can impede the growth of the producing organism. This particularly true for microbes.

Plants have unique advantage as bio-fungicides; some of them are in-fact edible and can therefore be used as food preservatives (Johnson *et al.*, 2013). The essential oils in plants are the major active ingredients (Bernardos *et al.*, 2015). In garlic for example, the volatile essential oils are able to penetrate and disrupt fungal cell walls facilitating its destruction (Arbach *et al.*, 2019). The biological activity of the extracts may differ depending on the source of the extracts within a plant. Apart from shrubs, trees such as the neem is popular as a source of biologically active compounds important in agriculture (Liu *et al.*, 2014). Yet despite the proven efficacy of botanical extracts, the number of actual commercial products are hard to come by. They are more popular in pharmacological fronts.

Perhaps this is due to the sheer quantity needed to apply in the fields. Commercial products from microorganisms on the other hand are now available due to their convenience of growth. Most of the bio-fungicides that could be defined as of plant origin are derived from algae (Abdel-Raouf *et al*., 2012). Algae are easier to culture for the production of these bioactive compounds.

2.9.1.1 Efficacy of neem extracts in disease management

Neem *(Azadirachta indica)* is a multipurpose tree, with roles including; timber and medicinal among others. Medicinal capacity of neem is well recognized in scientific community as extracts of different parts of the tree have been used against crop pests and diseases with no environmental repercussions (Abbasi *et al.*, 2003; Rajput *et al.*, 2011). According to Subapriya and Nagini (2005) 140 medicinal chemical compounds have been isolated from different parts of neem tree, however, leaves contain the majority of key compounds like nimonolattributed to antibacterial and antifungal properties(Mahmoud *et al.*, 2011). The mode of actions of the neem extracts are not well understood (Asif, 2012), however, inhibitory and deleterious are the main suggested mode (Alzohairy, 2016). Neem chemicals have been shown to have growth-regulating, anti-feedant, anti-oviposition, and repelling effects (Pathak and Zaidi, 2013). Neem also possesses systemic characteristics that often improve selectivity for non-phytophagous species (Pathak and Zaidi, 2013). Farmers in India have used neem for many years as a traditional medicine because it possesses pesticidal, fungicidal, and anti-feedant effects without endangering animals (Pathak and Zaidi, 2013). Neem cake has been shown to offer more than 80% inhibition of *Bipolaris oryzae* which cause brown spot disease in rice(Harish *et al.*, 2008), neem also offered 88% inhibition of *Colletotrichum capsici* which causes anthracnose of chilli as tested through poisoned food technique (Sattar *et al.*, 2018).

2.9.1.2 Efficacy of ginger in disease management

Asia is home to large populations of the tropical herb ginger (Zingiber officinale Roscoe). It is a member of the Zingiberaceae family. It is frequently used in traditional and contemporary cookery as a spice and botanical. According to biochemistry, the three primary active ingredients in ginger are gingerol, shogaol, and zingiberene, with 6-Shogaol having the most anti-inflammatory and antioxidant capabilities (Mao *et al.*, 2019). The components inhibit bacteria, fungi and mycelial growth with suppression range of 50%-100% (Abdullahi *et al.*, 2020). They have been tested and found effective on *Fusarium oxysporum, Xanthomonas oryzae* pv. *oryzae*- strain A, and *Bacillus*sp among others(Abdullahi *et al.*, 2020).

2.9.1.3 Efficacy of garlic in disease management

Garlic (*Allium sativum*) is a common culinary ingredient but historically has been used for medicinal purpose. It contains allaicin which has been shown to be the major anti-microbial component (Cavallito and Bailey, 1944). When cloves of garlic are cut or crushed, alliin lyase enzyme and Alliin mixes producing Allicin (diallylthiosulphinate), the compound is readily membrane-permeable and undergoes thiol-disulphide exchange reactions with free thiol groups in proteins. The property forms the main mode of action underwhich the substance either destroys or inhibits the pathogens. Garlic has been used effectively to control tuber blight of potato, seed-borne *Alternaria spp*. in carrot, Magnaporthe on rice, and Phytophthora leaf blight of tomato(Slusarenko *et al.*, 2008). Garlic allellopathic effect has been shown to reduce effect of *Fusarium oxysporum* sp. sesami (Zap.) of succeeding crops like sesame in a relay cropping system as found by (Hassan *et al.*, 2021)

2.9.1.4. Efficacy of pepper in disease management

Similar to many other plants, Capsicum spp. contains bioactive phytochemicals with both biological and antibacterial action. According to Fieira *et al*. (2013), capsaicin extract has a protective effect in vivo against Penicillium expansumin fruits. In the first two weeks of testing, it may slow the fungus' development (Daz *et al*., 2011). By reducing spore germination in vitro, extracts from C. chinense, C. annuum, and C. fructescens restrict the development of Botrytis cinerea (Jiménez-Reyes *et al*., 2019). Aspergillus fumigatus has been proven to be resistant to the antifungal effects of the triterpene saponin CAY-1, which was isolated from cayenne pepper (Dorley, 2015). These demonstrate the Capsicum spp extracts' ability for both treatment and prevention.

Pepper has been limited research on the use of *Chili frutescens* in regard to control of fungal pathogens disease of plant and it’s environmentally friendly. However, the research by Soumya and Nair (2012) on its use in groundnut revealed that the antifungal potential of aqueous capsicum frutescens leaf and fruit extracts against four major fungal strains associated with stored groundnut, including *Aspergillus flavus*, *A. niger*, *Penicillium sp*., and Rhizopus sp., is active and has the potential to be used as anti-fungi. Despite the fact that the results showed that the inhibitory qualities varied according on the plant portion employed, for example, aqueous fruit extract was shown to block 83% of antifungal growth while leaf extract only inhibited only 16%. Active antifungal ingredients 8-methyl-N-vanillyl-6-nonenamide and aggravate creatures with their burning in tissue once in contact and has repellent aroma of 2-methoxy-3-isobutylpyrazine.

2.9.1.5 Efficacy of bean ash in management of diseases

Phaseolus vulgaris, a common bean, has been demonstrated to have antibacterial and antiviral properties (Natabirwa *et al*., 2018). Vulgarinin, an antifungal peptide derived from common beans, displays broad-spectrum antifungal activity (Wong and Ng, 2005). Fusarium oxysporum, Botrytis cinerea, and Mycosphaerella arachidicola were three phto-pathogenic fungi that were negatively impacted by its antifungal effect. Reduced mycelial development is a hallmark of the antifungal action of legume antifungal proteins against these phyto-pathogens (Ng and Ye, 2003). A defensin known as PvD1 has also been identified from common beans as an antifungal ingredient (Games *et al.*, 2008). Additionally, it was suppressive to several Rhizoctonia solani and *Fusarium sp*ecies as well as other phyto-pathogenic fungi. Defensin-like compound with suppressive effects against M. arachidicola and F. oxysporum was also discovered from common beans (Wu *et al*., 2011). Many antifungal proteins have cell-free translation inhibition as one of their established mechanisms of action (Ng and Ye, 2003). Protein synthesis and growth would be compromised by slowed mRNA translation.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Evaluation of the status of the seed industry in Liberia

A two-methodology approaches comprising of interviews and focus group discussions were adopted to achieve objective one. Ministry of agriculture personnel responsible for the Liberian seed unit, Centre for Agricultural Research Institute (CARI), agriculture and seeds policies, seed companies' non-governmental organisations (NGOs) were interviewed in the focus group discussions (FGDs) **(Appendix I).** The focus group discussion mainly dealt with policies in general agriculture and seeds.

3.1.1 Focus group discussion

Other active players in the seed sector such as agro-input suppliers and non-governmental organizations were engaged in focus group discussions. The focus group discussion is envisaged to provide qualitative primary data that were complement interview data. The FGDs were led by semi-structured questions. The discussions were comprised of 12-15 participants domiciled in each selected county.

Focus Group discussions were held to supplement the material from the interviews and to gather professional viewpoints on the rice seed industry to fill in the gaps in the literature on the institutional structure and trends. Each county hosted two FGDs aimed at active rice farmers, including women and men between the ages of 18 and 75. The facilitator made sure that a third gender participated in each FGD as required by Liberia's gender policy requirement from 2009 and section 27 (8) of the Kenyan (2010) Constitution. Twelve to fifteen people, a facilitator, a translator, and a cameraperson participated in each FGD. Pictures and videos were exclusively taken with everyone's permission. Expert FGDs were also held with six organizations, including the Liberia Agriculture Commodity Regulatory Authority (LACRA), the College of Agriculture and Forestry (CAF), the Center Agricultural Research Institute (CARI), the Bangladesh Rehabilitation Assistance Committee (BRAC), and the Ministry of Agriculture (MOA). Due to the lack of seed specialists in all the organizations, the expert discussion had fewer participation than the farmer FGDs and did not follow the gender standards. However, the debate procedure adhered to a similar format to farmers' FGDs.

The talks were focused on five key topics, including the nation's rice output, the characteristics of rice seed systems, Research institutes' involvement in the creation of seed systems, Participants adopt the Liberian rice system and quality control of seeds delivered through the official system **(Appendix II)**. The designated lead farmers (in the case of farmer FGDs) and senior most officer (in the case of expert FGDs) were asked to offer an overview of the trends in rice production in Liberia prior to the commencement of the general discussion, and from him the conversation spread to the other participants. By interjecting with leading questions, the facilitator just regulated and made sure that the talks did not veer off topic. Prior to the FGDs, guide questions were created with the intention of expanding the debate along the highlighted themes. Examples of questions asked were "What is your opinion on the current trend in rice production?" and "What sources do farmers use to obtain their planting supplies?" and "Who are the main players in distributing community-sourced seeds?" for themes one and two, respectively (a complete list of the guiding questions can be found in **(Appendix V)**. The FGDs lasted a maximum of 2.5 hours. The content of recorded videos was transcribed and narratively evaluated.

3.2 Description of the study area

The study was conducted in the rice-growing agro-ecological zones of Bong, Lofa, Montserrado, and Nimba in four of Liberia's fifteen (15) counties. The Western, Central, Southeastern, and Northern Regions of Liberia are where these counties are situated.

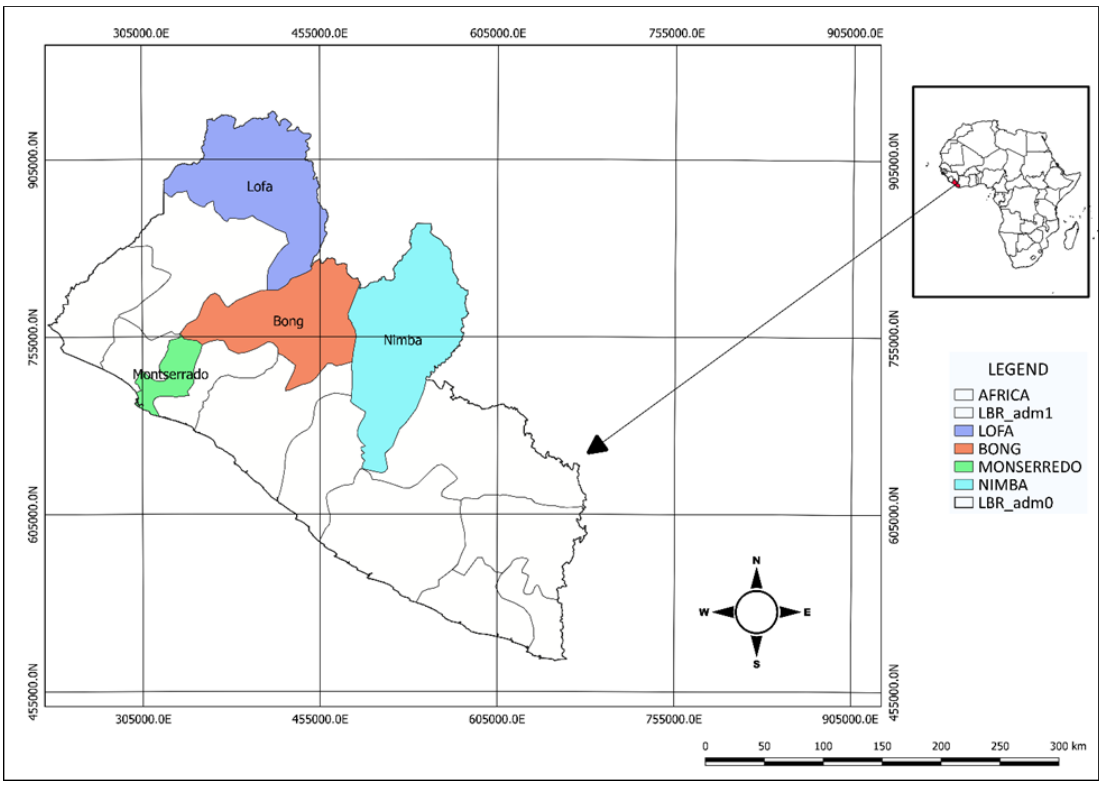


Figure 3.1. The four major rice producing counties of Liberia,

(Source: Author, 2023).

3.2.1 Bong County

A coastal county located between 8 and 75 meters above sea level is called Bong. The county is situated between latitudes 10° 28' 34" and 9° 5' 38" west and longitudes 6° 24' 7" and 7° 25' 48" north. The county covers an area of 11846.931 Km^2. The county is categorized under upper highland tropical forest agro-ecological zone, receiving an average annual rainfall of 1265 mm. The county is predominantly occupied by Ferrasols, with some parts occupied by plinthisols (Pathak and Zaidi, 2013)

3.2.2 Lofa County

Lofa County is divided between the Upper highland tropical forest and Northern savanna agro-ecological zones. It has bimodal seasons for rainfall, with an annual range of 2900-700 mm. Rice, plantains, and cocoyams are among the products grown in the county's plains, while coffee and cocoa are produced in its highlands. The county is dominated by Ferrasols which are well developed deep, friable and reddish soils (Pathak and Zaidi, 2013). They are characterized by a high content of Iron oxides, Aluminum oxides, and manganese. They are generally low in fertility and possess low cation exchange capacity.

3.2.3 Montserrado County

The smallest county in Liberia, Montserrado, with an area of 1,912.7 square kilometers. It is between latitudes 10° 48' 48" and 10° 12' 0" west and between longitudes 6° 12' 56" and 6° 49' 57" north (LISGIS, 2008). The Harmattan winds produce a tropical climate in the county. The climate constitutes an alternating wet season (May-November) and dry season (December-April) and experiences an average of 21°C in the wet season and 36°C during the dry season. Alluvial clayey soils dominate the county, making it one of the best rice-producing counties (Pathak and Zaidi, 2013).

3.2.4. Nimba County

Nimba County is located in latitudes 9° 11' 43" and 8° 16' 24" W and longitudes 5° 49' 26" and 7° 41' 46" N. It is at an altitude between 63 and 1730 meters above sea level. Inter-tropical convergence zoning is what causes the county's tropical climate, which is characterized by alternating rainy and dry seasons. November is the county's wettest month while March is the driest month. Amount of rainfall greatly varies with slight variation in altitude and distance from the sea, resulting in an average range of 4100-700 mm. Similar variations are observed in temperature regimes with a range of 23°C-27.5°C annually (Pathak and Zaidi, 2013). The interactive effect of soils characteristics, topography and climatic factors has led to the categorization of the county into two major agro-environmental zones; northern savanna and lower tropical forest. The soils of this county are dominated by iron-rich gleysols originating from weathering processes of sedimentary parent rocks (itabirite, and quartzites). Leptosols occupies few patches of the county. The soils are inherently low infertility, but the humus from the forests and silt from rivers enrich it making it suitable for rice cultivation (Pathak and Zaidi, 2013).

3.3 Field survey in Liberia

Direct interviews were conducted among the rice farmers and the extension officers. To determine farmers' awareness of their role in the improvement and degeneration of rice seeds, direct interviews were employed. The questionnaires were entailed aspects that help the study establish the farmers' awareness of their seed quality status, source of rice seeds, seed fungal contamination, storage condition stored, and perception towards the indigenous knowledge of seed preservation **(Appendix II, Appendix XIII)**. The survey was engaged the agricultural extension personnel in each of the study county. The aim of engaging extension officers is to establish the actualization process of government policies towards improving agricultural sector. Provided that extension officers frequently interact with farmers; this study aims to capitalize on their experience to understand the challenges and production patterns in the counties of study. Sample rice grain seeds were sampled from each participating farmer for subsequent a characterization of the rice seed quality. The survey was employed a mixed-structured questionnaires which were administered to purposefully sampled rice farmers and extension officers in the selected counties.

3.3.1 Survey sample size determination

The population of farmers growing rice in each count was acquired from the agricultural offices in respective counties. Systematic random sampling was used to select participants per county. Microsoft Excel 2019 was used for the randomization process.The sample size was calculated as by per equation 1, by (Pathak and Zaidi, 2013)

$\eta = \frac{p}{\mu}\theta$ Eqn 1

Where;

n = sample population per location

μ = Average households in the Location rice

p = population of the households in the Location growing rice

θ = 10% of total households in each Location growing rice

3.3.3 Sample collection and seed quality assessments

Five hundred grams (500g) of the rice samples were obtained from each participating farmer. The samples collection was involved a single slotted tube, which were pierced diagonally through the storage bags (Pathak and Zaidi, 2013). The samples from all sides were mixed thoroughly on a polythene bag and composite and working samples were taken for subsequent analysis.

3.3.4 Data collection

Qualitative and quantitative data on farmers' demographic characteristics (Farmer age, level of education, land ownership status, land acreages under rice by each farmer), practices in rice production (major seed sources by farmers, level of awareness of seed policies by farmers, farmer perception on efficiency of existing seed systems, accessibility of rice seeds through the existing seed systems and reasons for underutilization), types of rice seed systems existing in the study region, level of development of the existing seed systems, government and other agricultural role in the seed systems, county's farmers' perception on rice production among many others. Meteorological data for the past 10 years were also collected from meteorological stations within the selected counties.

3.3.5 Data analysis

Qualitative data obtained from focus group discussions, by evaluating participants' contribution to the subject matter were subjected to content analysis where the data was grouped, summarized and tabulated. On the other hand, interview data were cleaned, converted to percentage and subjected to descriptive and inferential statistics. The associations among all the variables assessed were subjected to multivariance analysis with focused on principal analysis, (PCA) on GENSTAT statistical software version 16.0 VNS Intentional at 5% level of significance.

3.4. Seed quality assessment for rice seed obtained from Liberian seed system

3.4.1 Physical quality

Sample rice seed lot quality from each county was tested by evaluating quality factors such as; moisture content, purity analysis, Thousand Seed Weight (TSW).

3.4.2 Seed moisture content

The seeds in each variety were mixed thoroughly and a sample was put in automated moisture meter (Draminski Twist Grain Pro moisture meter) for grains moisture determination.

3.4.3 Seed purity analysis

According to (Pathak and Zaidi, 2013) purity analysis refers to the ratio of pure seed variety under test to the seeds of different varieties and crops and inert debris like stones. To conduct this test 250g of sample rice seeds were weighed and pure seed variety was separated from debris and other varietal seeds by handpicking. The two fractions were then be compared and correlated to working sample weight. If discrepancies of less than 5% was found the percentage pure seeds were calculated as per Equation 3.

$$percentage\ Pure\ seed = \frac{Fraction\ weight\ of\ pure\ seed}{weight\ of\ working\ sample} \times 100 \qquad \textbf{(Eqn 3)}$$

3.4.4 Thousand Seed Weight (TSW)

Thousand (1000) seed weight (TSW) test was provided as an estimate of the weight of seed rice grain weight for every variety from different counties. The test was conducted using theseed samples obtained from the four counties of Liberia Ten replicates of 100 rice grains of pure sample seeds were weighed using electronic weighing machine (LCD series, TP-B200 model). The average weights of the 10 replicates were used to calculate the estimated1000 seed weight.

3.4.5 Physiological seed quality aspects

Sampled rice seed lot quality from each county was tested by evaluating physiology aspects such as germination and vigor.

3.4.5.1 Germination and vigor test

Germination test aims to evaluate germination potential of the seed rice samples acquired from the four selected counties. (Pathak and Zaidi, 2013) recommends germination test was conducted at specific controlled conditions. To conduct a seed germination test, 100 seeds of each sample obtained and uniformly distributed on a bloating paper. The seeds were incubated in a germination chamber at 28± 2^{o}C under the 12 hours of alternating cycles of near-ultraviolet (NUV) light provided by Philips black tube and darkness for 14 days. Germination and vigor index were calculated using equation **2** and **3.**

Percent Seed Germination = $\frac{Number\ of\ seeds\ germinated}{Total\ Number\ of\ seeds\ plated} \times 100$ **Eqn 2**

Speed or rate of germination /Vigor index = % Seed Germination × (Mean Root Length + Mean Shoot Length) **Eqn 3**

Further, the germination rate index was calculated following the Timson germination index,

(TGI) = E G/T **Eqn 4**

where G is the percentage of seed germinated on a particular day while T is time.

3.4.5.2 Seed health tests for pathogenic fungi

3.4.7.1 Isolation and purification of pathogenic fungi affecting seed quality in Liberia

Each county's sample rice seed lot quality was put through a health test by separating the fungal strains that cause mold and discolored rice grains. 200 seeds from the samples of each type were chosen at random, and they were steeped in 1% NaOCl for five minutes before being washed three times in distilled, sterile water. Clean seeds were put in a petri dish and dried using sterile tissue paper before being placed on wet sterilized blotter paper. For seven days, the dish and its contents were kept in a temperature-controlled growth room at 20°C with 12 alternate cycles of ultraviolet radiation. At the end of eight days, the seeds were physically examined for the growth of fungi. Plates with fungal growth were further examined daily under light microscope for growth of fungal hypha.

With the help of a cork borer, 5 mm mycelium was transferred to fresh medium. The mycelium was obtained from the edge of a growing colony. After the fungal growth on PDA, a purification process was undertaken by transferring a small block of agar containing a single hypha to another plate of agar medium.

The appearance of fruiting bodies and the features of fungal colonies were examined under a microscope to identify the fungi that caused the disease. Additionally, using a light microscope, several properties like size, color, quantity of spores, form of sporophores, and many others were evaluated. This way the fungus can only be identified to the genus level.

3.5 In-vitro assessment of botanicals in management of selected fungal pathogens

3.5.1 Extracts preparations

The botanical leaves of neem (*Azadirachta indica*), common bean, pepper (*Capsicum annuum*), garlic (*Allium Sativum*), and ginger (*Zingiber Officinalis*) were gathered. 100g of their samples were completely washed with HCl and left to dry at room temperature. The botanicals were sieved into extracts using an electronic blender, then put in separate airtight containers for protection. After being further dried and burnt, the common bean leaves were sieved into a fine powder and placed in an airtight container.

3.5.2 Evaluation of botanical extracts inhibition on fungi isolates

Aqueous of the botanicals, common bean ash and synthetic fungicide (Tebuconazole) used as positive control, were evaluated for their toxicity to isolated fungi; *Aspergillus flavus*, *Aspergillus niger* and *Penicillium citinum* under *in vitro* conditions at different concentrations (0ml, 3ml, 5ml, and 7ml (v/v)) for aqueous extracts and (0g, 0.3g, 0.5 and 0.7g all in 15ml PDA) for common bean ash, using poisoned food technique (Grover and Singh, 2013). A stock solution for the fungicide was made by combining the necessary quantity with a small amount of distilled water, then diluting it further to the necessary concentrations. On sanitized petri plates (9.0 mm), 15 ml of PDA was combined with the extract quantities of the botanicals and fungicides, agitated, and allowed to cool and coagulate for 15 minutes. After the medium had solidified, the plates were fully randomized, set up in an incubator at a temperature of 27 1 oC, and injected with active cultures of Aspergillus flavus, Aspergillus niger, and Penicillium citinum on PDA. Mycelia development was monitored every 24 hours until the negative control petri plates were covered by measuring their radial expansion (change in diameter). Using equation 4, the mycelial growth inhibition (MGI) was computed.

$$\text{MGI (\%)} = \frac{\text{Growth in negative control plate} - \text{Growth in extract treatment}}{\text{Growth in negative control plate}} \times 100 \qquad \textbf{Eqn 4}$$

Each treatment's duplicates underwent microscopy examination to determine the size, color, shape, and sporulation of the spores. The sample of mycelia that had been treated with various extracts was scooped onto a slide using a sterile needle, stained with lactophenol cotton blue solution, and examined under a 10 X light microscope.

3.6 Morphological diversity of *Aspergillus flavus, Aspergillus niger, Penicillum spp*. and *Fusarium spp.*isolates on seed rice

3.6.1 Collection of seed rice

The fifteen (15) counties of Liberia were divided into four (4) counties: Bong, Lofa, Montserrado, and Nimba. During the dry season, samples were randomly selected from rice growers in the research locations. Seed rice was brought to the university's lab in Eldoret, Kenya **(Appendices X, XI).**

3.6.2 Sorting of diseased seed rice samples

Samples collected from the four (4) counties were sorted thoroughly by sorting seed rice showing diseases symptoms.

Plate 3.1: Infested rice seeds collected from the main farming counties of Liberia. They were obtained from Bong (A), Lofa (B), Montserrado (C) and Nimba (D) Counties. Notice the discoloration of seeds from (a) and (b), and different seed sizes, small sizes in (c).

The isolation and Culture purification for each isolate was done in line with (Hiama *et al.*, 2019), and of the infested seed rice samples were sterilized with 5% sodium hypochlorite for the period of three (3) minutes and raised well in a distilled water three (3) times just for a minute for all the seeds. Seeds rice were plated on a fresh prepared half strength of Potato Dextrose Agar (PDA), incubated under persistent white fluorescent light at the 25 ^{0} C for the seven (7) periods in order to stimulate sporulation of the fungi. The total of thirty-six (36) isolates were obtained and the pure cultures of the pathogens were grown from a single pore of all isolates.

3.7 Morphological diversity and growth rates of *Aspergillus flavus***,** *Aspergillus niger***,** *Penicillum spp.* and *Fusarium spp.* infesting seed rice

The morphological was done as prescribed by manual of (Pathak and Zaidi, 2013). The mycelia disc, which was about four (4) mm in diameter, was aseptically collected at the growing edge of the purified cultures that had been aged for five (5) days. It was then incubated on a half strength of PDA at 250 C under persistent white fluorescent light (20%) for seven (7) days in an incubator chamber made by Gallenkamp. After seven (7) days, the features of the colony growth, such as the color of the mycelia, the color of the media's surfaces, the shape, texture, and color of the pores in the conidia, as well as the size and description of the spores, were noted. Every day during the following seven (7) days, the mycelia's growth rates were assessed, and the diameter of the pure cultures was measured.

3.7.1 Morphological assessments on isolates from seed rice

Morphology of the thirty-six (36) Isolates were recorded and observed on the half strength of the PDA glass plates and also microscope at the eyepiece lens, at the magnification of X 10 and the objective lens was at the magnification of X 40 or ($mg_{=}$ X 40). The isolates growth rates were calculated by averaging the daily mean growth in centimeter (cm per day).

3.8 Statistical data analysis

Descriptive analysis was used for data collected on morphological chrematistics, microscopic on mycelia deformity of shape of mycelia, spore colour, spore shape and spore size. Tables were created and given with information on growth and colony features. The mean of common bean ash, chili, garlic, ginger, fungicide, and pepper correlation analysis was done to determine the significance relationships between and among the treatments. The radius growth was analyzed using GENSTAT statistical software, version 16.0 (VSN) International at 5% level of significance.

CHAPTER FOUR

RESULTS

4.1 Focus group discussion

Farmers and experts who participated in Focus Group Discussions (FGDs) shared information on certain topics in agreement, while they offered conflicting opinions on other topics. Both sides agreed that the civil war had an influence on the whole agricultural industry and had slowed the growth of the seed industry, especially for non-horticultural crops like rice. The following points were created by combining the discussions:

In the FGD, the key informants were aware of several seed policies by the government of Liberia. For some, they participated in the curving of those policies and regulation. However, the policies implementation is poor due to inadequate budgeting as well as lack of appropriate structures. Establishment of seed companies have suffered due to this. This is captured by the verbatim from chief of the seed unit at the Liberia's ministry of Agriculture;

"*The first thing one should know, if you want something to be active they have to go through legislature. First we need to have a structure, when you have a structure then those instruments can come in. But we do not have a structure. Had we a seed structure then people would talk about seed companies, seed industries all of that and setting a seed certification agencies, all of that. But we are still forging ahead. As I told you, we developed a seed policy. It was carried to cabinet, they approved the seed policy, it has also been legislated. But in terms of structure, putting the technicians, budgeting the structure that has not happened yet*."

Despite being the nation of Liberia's major crop and having been in decline since the end of the civil war, the government does not appear to have strategies in place to reverse the situation. Lofa and Nimba are the main producers of rice among the major producing counties. All the FGDs concurred that Liberia's rice output is deemed to be highly subpar when compared to its neighboring nations like Nigeria. This was well reflected by the response given by head of seed unit at the Center Agricultural Research Institute (CARI) on the frameworks in place to guide the informal seed system. This was her response;

"*For Liberia there is none (framework to guide the informal seed system). Farmers just do their own things randomly in Liberia. But other countries, they have system put in place*"

Farmers denied the existence of research organizations and had little knowledge of their responsibilities in rice production. Only a few non-governmental groups were known to them. Expert FGDs, on the other hand, recognised the presence of research institutes and their role in germplasm banking and the pursuit of various advances. Among the organizations mentioned were Africa Rice and CARI.

Because there is no official seed system in existence, it is hard to establish a monitoring agency to evaluate and guarantee seed quality.

4.2 Characterization of rice farmers in Liberia

4.2.1 Farmer Age-group and Gender Distribution

Based on the gender ratio among the farmers in the study area, they were generally in fairly equal proportions. However, the number of males were slightly more than females at 50.2% and 49.8 respectively. However, this parity in farmers between the genders is not replicated in all the counties.

In particular, with respect to counties, only Lofa county recorded gender parity in the number of rice farmers (Male = 50.4%, Female = 50.6%) (Fig 4.1). Montserrado had the lowest number of females (38.9%) engaged in rice farming compared to their male (61.1%) counterparts. This was the opposite in Nimba where females (69.6%) far outnumbered males (30.4%).

The number of males were also higher than females in Bong but not with a big margin compared to Montserrado. Therefore, the number of males was generally higher in the two counties of Montserrado and Bong and significantly low in Nimba. In Lofa, both sexes are in the same number. Without the great female number of farmers in Nimba, it would be evident that the agricultural activities of the sampled area in dominated by men.

Looking at the ages, the prime age for farming appears to be between 30-60 years (Fig. 4.1). However, there are some disparities among the counties. Except for Bong County, the 15-25 age group seems not to engage in agricultural activities in the sampled counties of Liberia. In Nimba, there were no males in the 15-25 years' category. Further, in Nimba, the 45-60 years' category had a significantly higher number of farmers than the other age groups. The number of males in the above 65 years group was consistently higher than those of females with Bong not recording any females in this category.

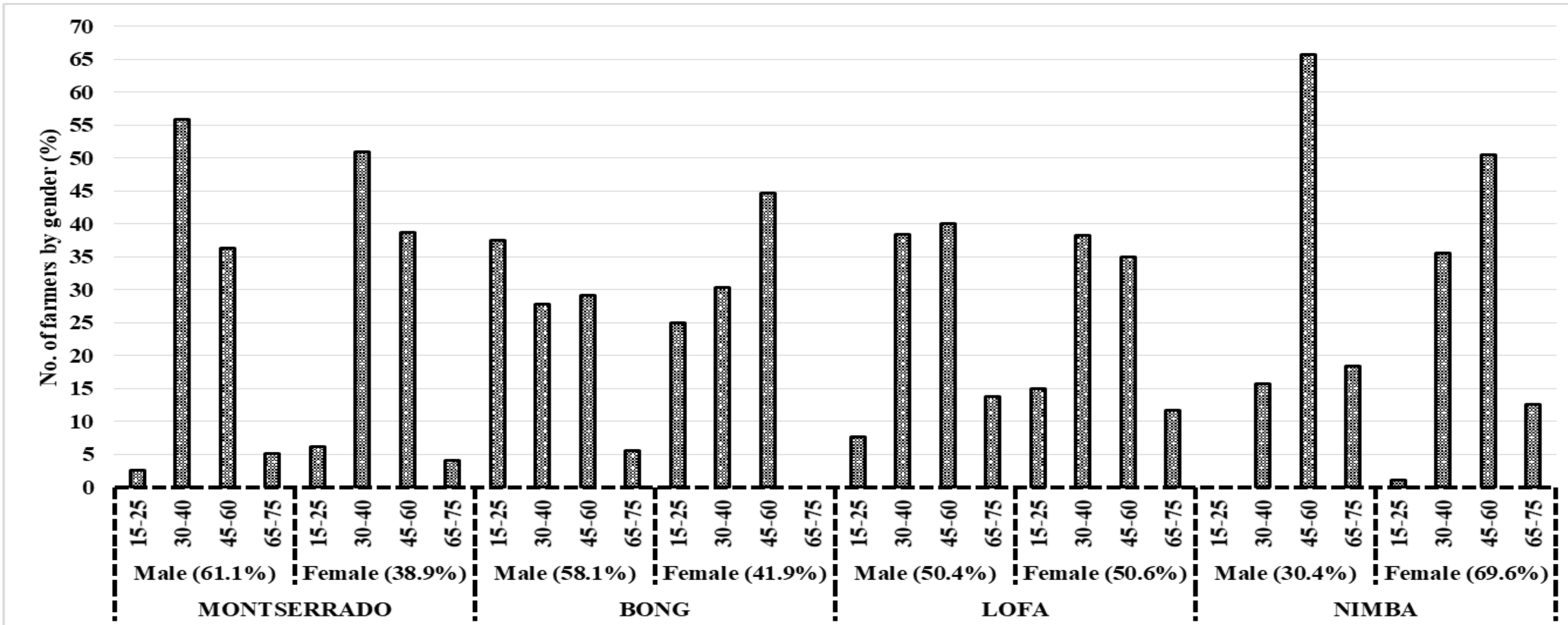
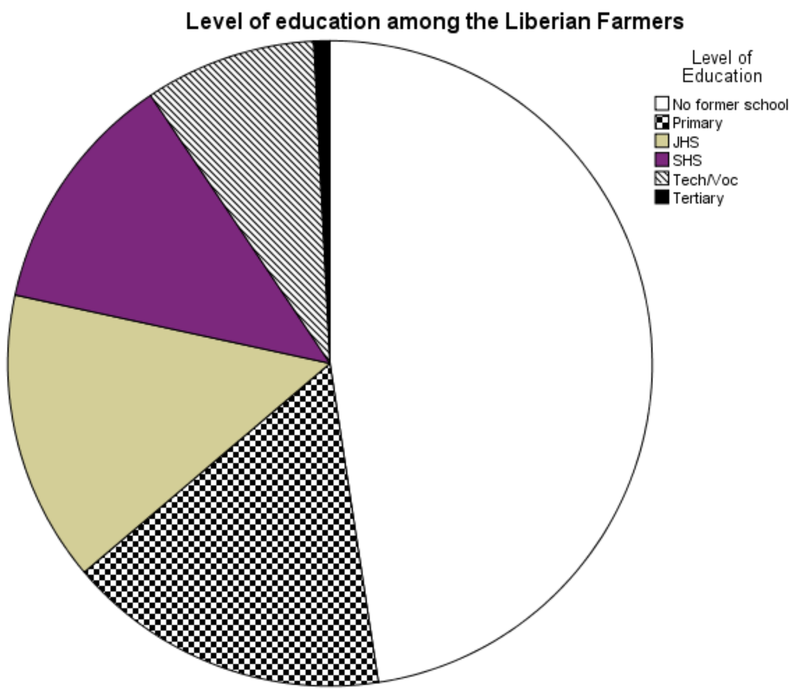


Figure 4.1. The gender ratio among the Liberian farmers in the four sampled counties of Montserrado, Bong, Lofa and Nimba.

4.2.2 Level of Education among the Rice farmers in Liberia

Generally, an overwhelming majority of the farmers sampled have no formal education (48%) (Fig 4.2). The numbers further decrease as the level of education increases. Of the farmers with formal education, those with primary, junior high school (JHS), senior high school (SHS), and technical and vocational education qualifications were 16%, 15%,12% and 9% respectively. Only 0.8% of the farmers had a tertiary level of education. This is a general picture of the four counties, but this can still be assessed in the individual counties and gender-wise.



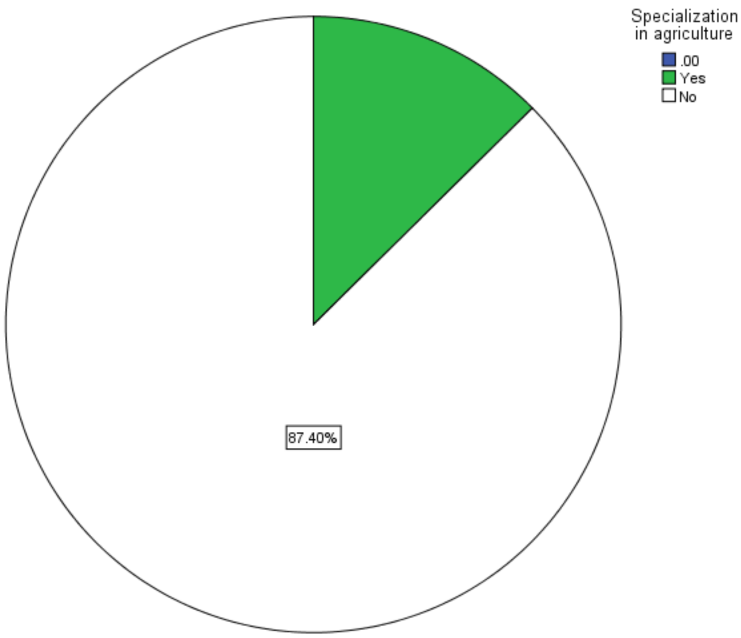


Figure 4.2. The level of education among the sampled rice farmers in the four sampled counties in Liberia; the different levels of education and whether or not the farmer has agricultural academic background.

Fig 4.2a shows the majority of the farmers have not received any formal education. Generally, the number decreases with a higher level of education. Fig 4.2b shows that of the educated only 12% have any specialty in agriculture**.**

Considering different counties and gender distribution in terms of education, Montserrado appears to be the most educated county as the farmers with a tertiary level of education are only found in this county. Another observation is the fact that the majority of the women have no formal education. The leading figures of people with no formal education in all the counties come from female farmers. That number is highest in Nimba (72%) and closely followed by Montserrado (68%) (Fig 4.3). Compared with the males, the county that recorded the highest number of males with no formal education was Lofa and Nimba both at very slightly above 30%. The ratio of the genders with primary education is almost equal. With the males, however, the numbers keep on increasing up to the vocational education level. For the females, the number reduces from the number recorded with primary education. The only exception for the females is in Bong County where the Majority (28%) of the sampled female farmers had a junior high school education level.

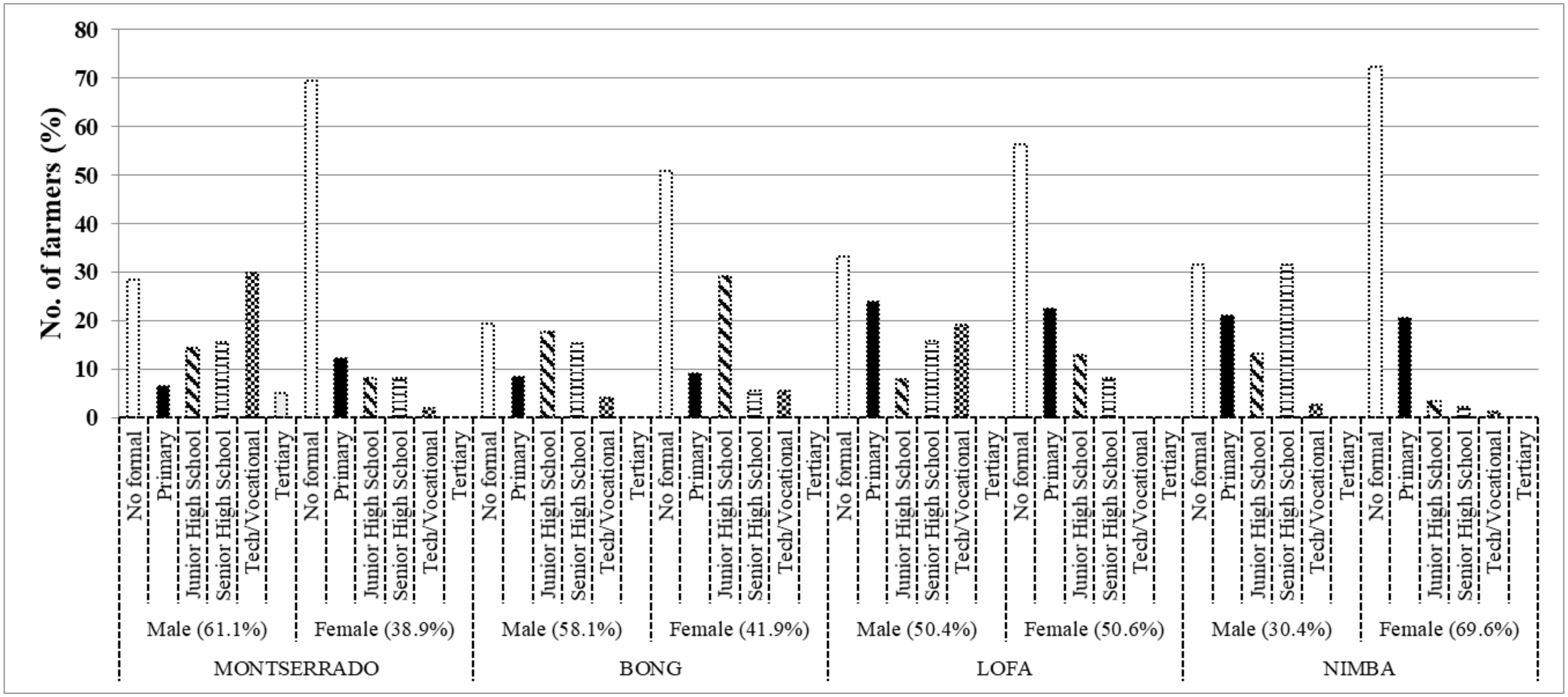


Figure 4.3. The education level as per gender in the four rice growing counties of Liberia. Generally, more women lack education as compared to their male counterparts.

4.2.3 Major Rice seed sources in Liberia

The study revealed that the major sources of rice seeds by farmers in Liberia were open markets, friends and relatives, non-governmental organizations (NGOs), agro-shops, Farmer saved seed and research institutions. Specifically, 37% of farmers obtained their rice seeds from friends and relatives which was the highest across all counties. This was closely followed by own saved seeds at 33% while open market was 9% (Fig 4.4).

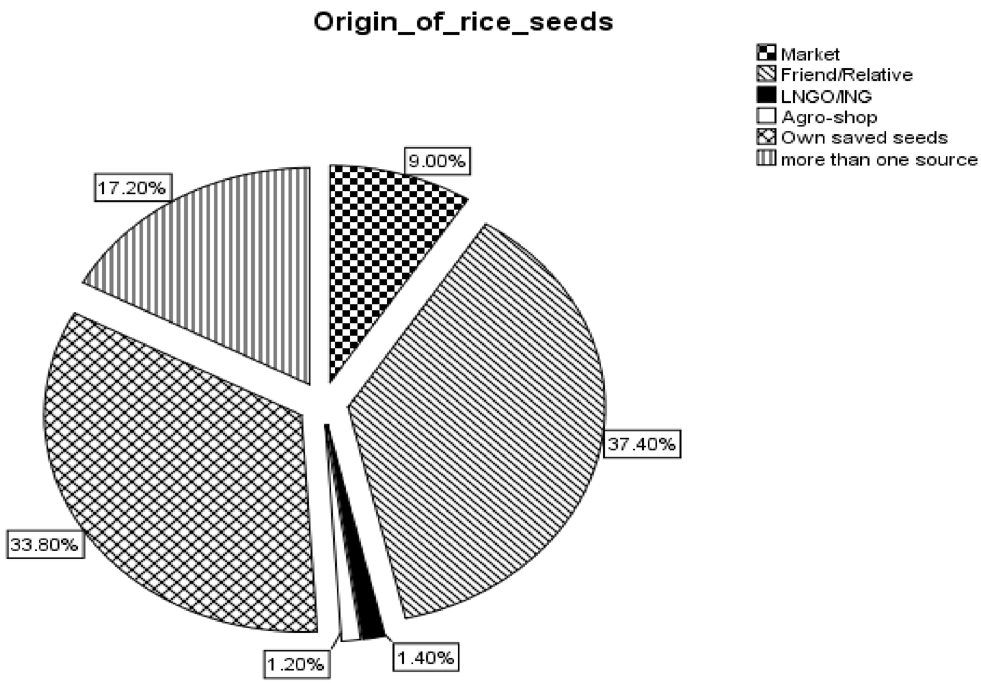


Figure 4.4. The sources of rice seeds used by the farmers in the four counties sampled in Liberia – Bong, Montserrado, Lofa and Nimba.

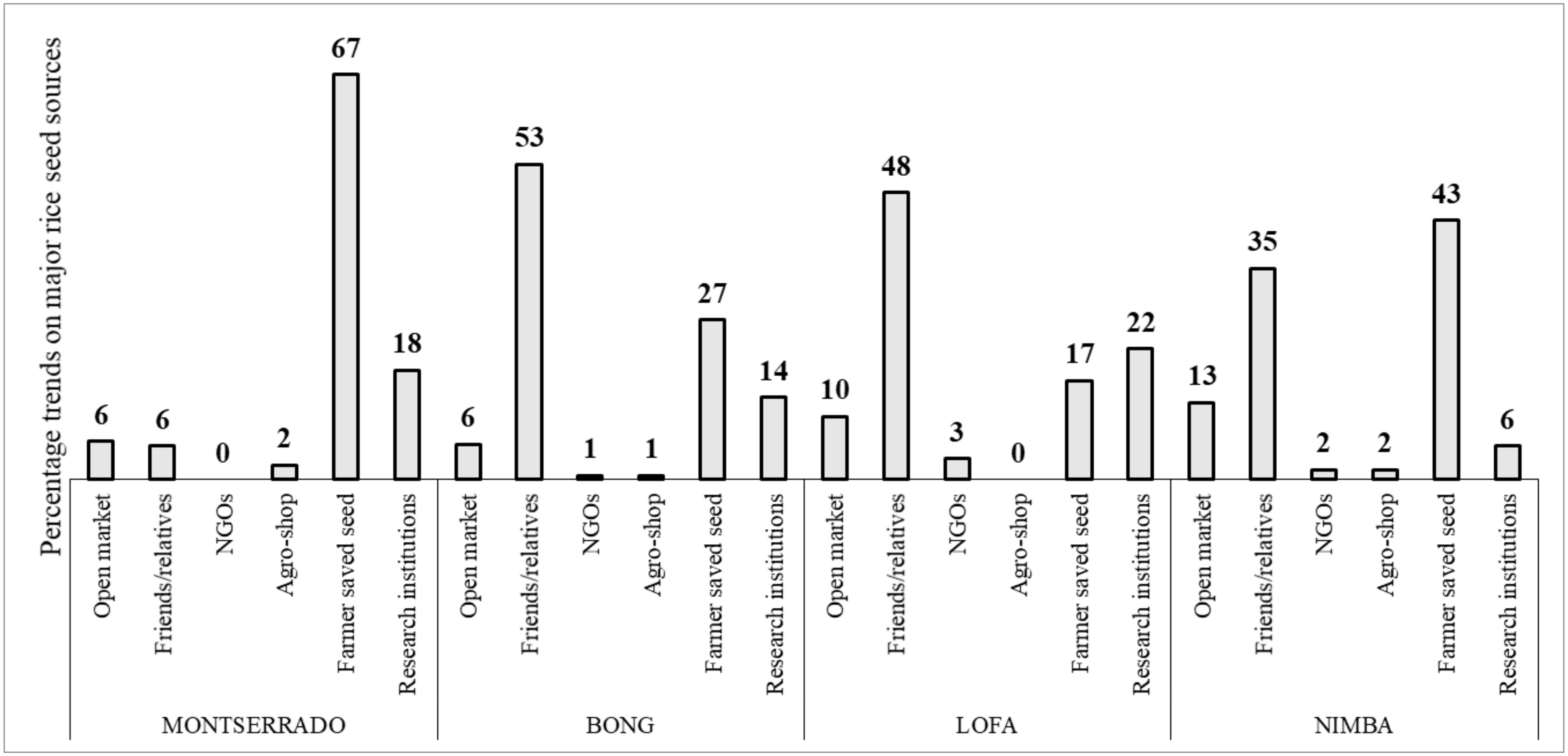


Figure 4.5. Sources of rice seed as per the four counties sampled in Liberia. Generally, various forms of the informal seed system dominate in every county.

However, among the counties under the study, there were no consistency in preferences in terms of seed sources and most farmers sourced their seeds from diverse sources depending on the county location. For instance, in Montserrado, 67% of the farmers plated saved seeds from previous season while 18% and 6% obtained their seeds from research institutions and friends/relatives respectively. However, NGOs and Agro-shops were the least preferred by most farmers as the source of rice seed by recording 0% and 2% respectively. Similarly, in, Bong County, majority of farmers preferred informal seed sectors for their rice seed. For example, Bong, in descending order, friends and relatives, own saved seeds, and research institutions, were the commonly utilized sources of seed at 53%, 27% and 14% respectively. In Lofa County, friends and relatives was the most preferred source of seed at 48% and this was closely followed by research institution with 22% and contrary to Montserrado, only 17% sourced their seed from previous season, In comparison to Montserrado, Nimba County had most farmers using own saved seeds at 43%, followed by friends and relatives at 35% and open markets at 13%. In all the counties where rice is grown as one of the main sources of income, agro-shop which should be the source of quality seed was underutilized by farmers with a score below 2% and sometimes 0% in some of the counties in Liberia.

4.2.4 Duration of Storage for the Farmer saved seeds

Many of the farmers used either 6 months or 1-year-old stored seeds (Fig. 4.7). In Montserrado and Bong majority of the farmers at 63% and 58% use 1-year-old stored seeds. In Nimba and Lofa, 65% and 51% of the interviewed farmers use 6-month-old seeds respectively.

It is only in Montserrado where 2-years-old rice seeds are used by over 25% of the interviewed farmers. In the rest of the three counties, it was the least used seeds barely reaching 20% of the use.

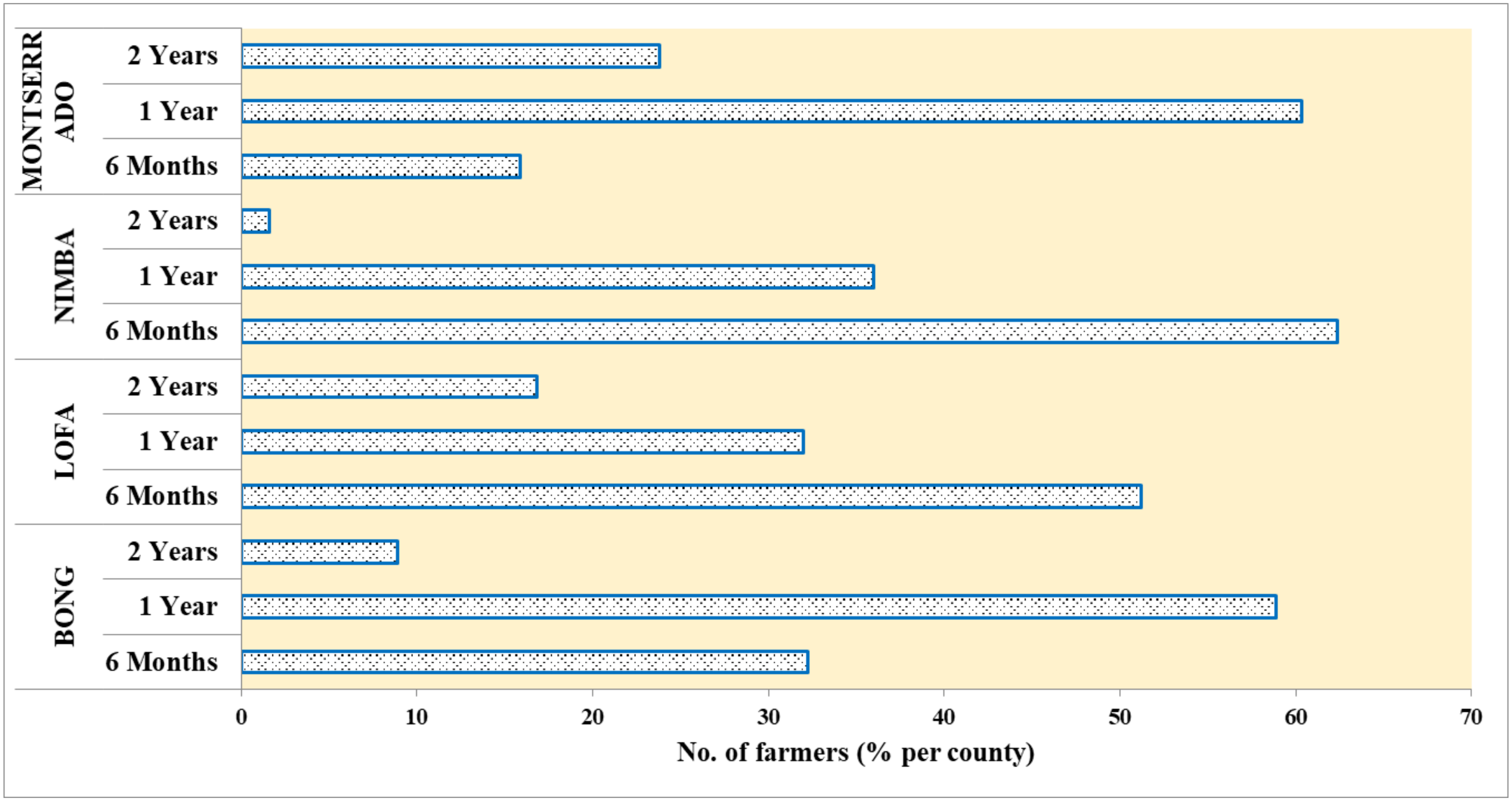


Figure 4.6. The storage duration of the own-saved-seeds by the Liberian Rice Farmers.

4.2.5 Rice Farmers' Perceptions on the Quality of seeds

Generally, less than half of the farmers in Lofa, Nimba and Montserrado used certified seeds. Montserrado is the county with the lowest adoption of certified seeds with only 35% of the farmers using it. Bong had the highest number of farmers using certified seeds at 53% (Fig 4.7). Conversely, in Bong, fewest number (16%) of farmers reported experiencing seasonal increase in the yields. Highest seasonal increases appear to be in Nimba and Lofa each scoring 38% and 36% in the number of farmers who said that they experienced seasonal increase in the yields. In Montserrado, 23% of the farmers said that they have had any yield increase every season. Seed health problems were greatly experienced by the farmers sampled. Bong also ranked very highly with 91% of the farmers saying that they have experienced some form of seed health problems. Bong was followed by Lofa (86%), Nimba (83%), and finally Montserrado at 62%.

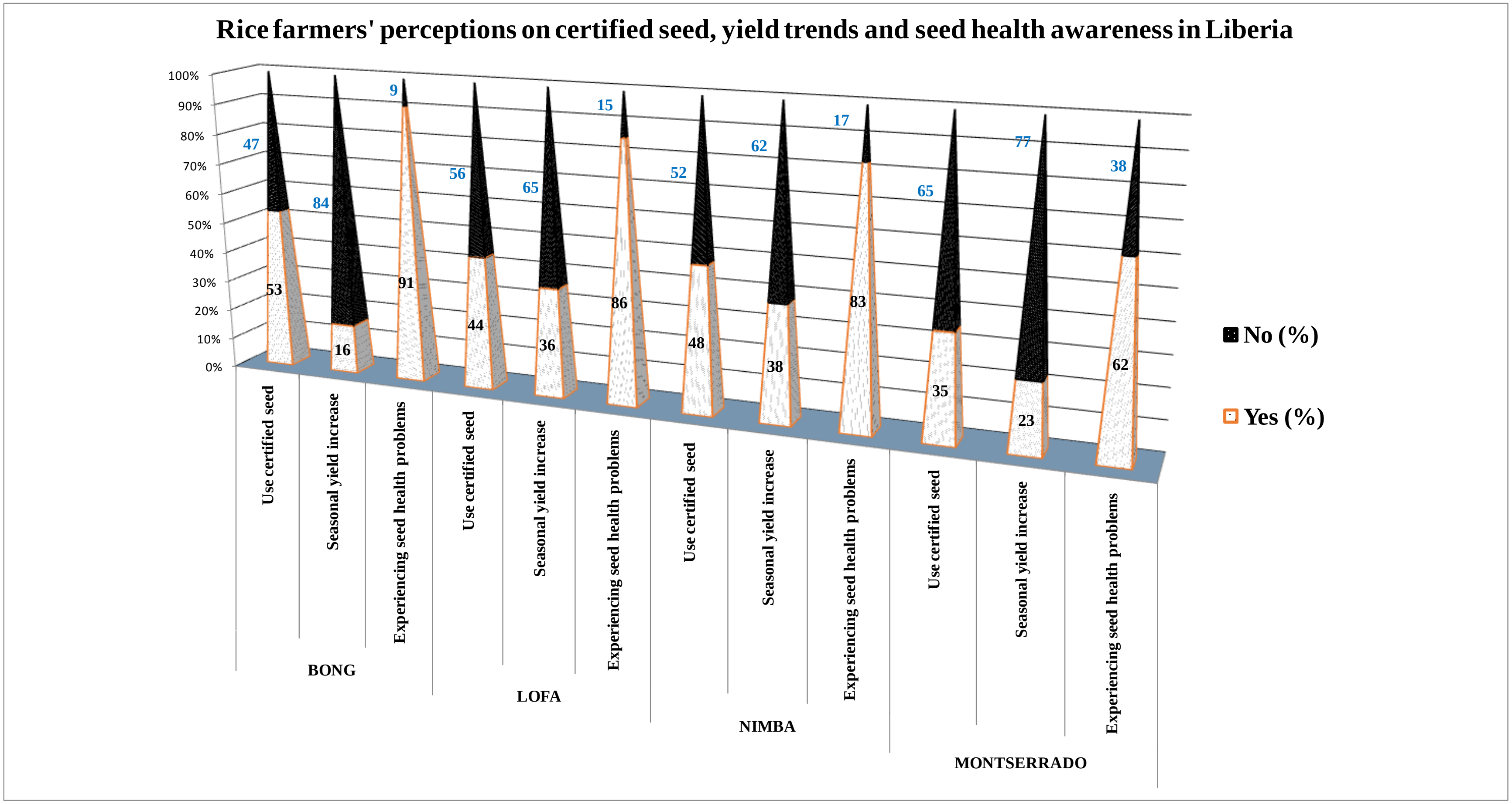


Figure 4.7. Farmers' perceptions on the use of quality seeds.

4.2.6 Governmental Policy

Governmental policies were largely unknown by most farmers in all the counties. Montserrado had the highest number of farmers aware of government policies at 10%. In Lofa there was no single farmer aware of any government policy (Fig 4.8). Only a few were aware of the policies in Bong and Nimba. Only the key informants are mainly aware of the government policies affecting rice production.

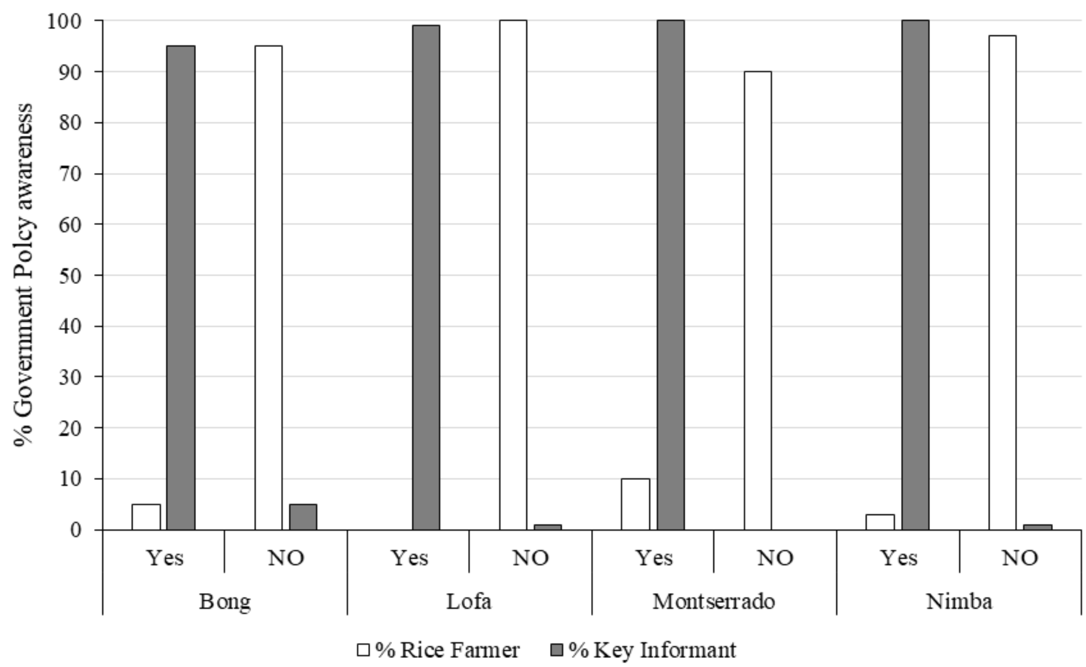


Figure 4.8 Level of awareness of government policies affecting rice farmers.

It is only the key informants in Bong County where some were not well versed with government policies. Although that numbers were very low about 5% key informants in Montserrado, were aware of the government policies.

4.2.7 Pre and Post-harvest Practices

Fertilizer application is not a common practice among the Liberian farmers (fig 4.9). Around 88% of all the farmers reported not using any fertilizer during rice production while 63% of the farmers harvest their crops manually.

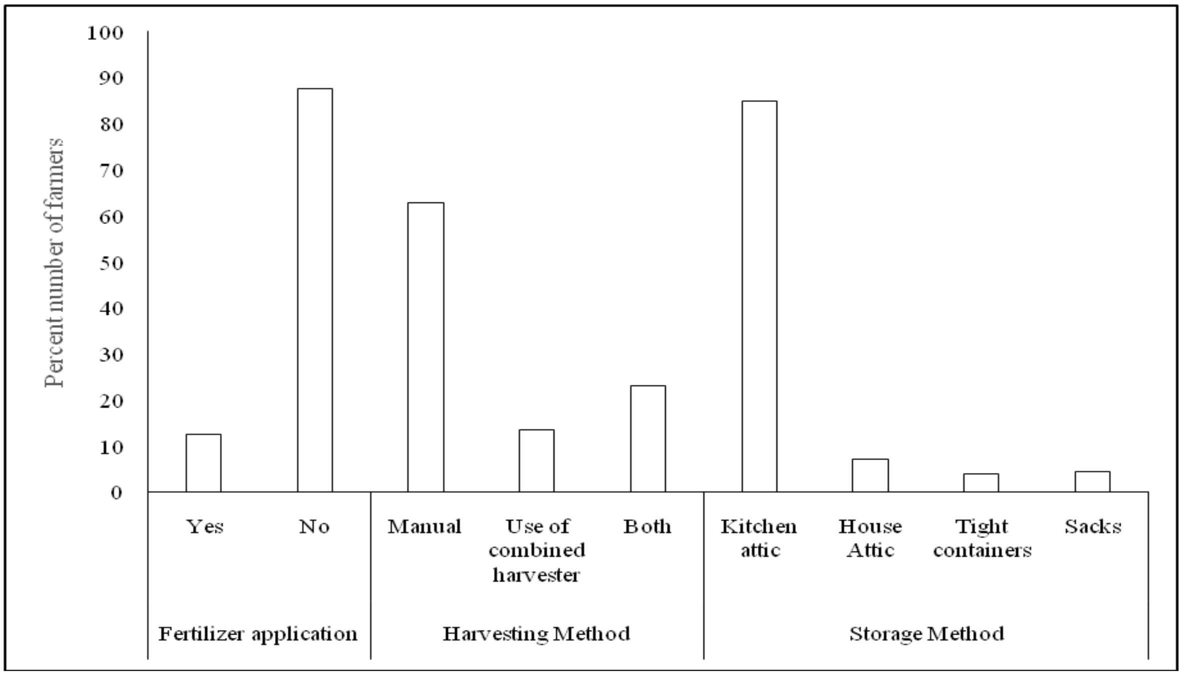


Figure 4.9. Pre- and postharvest practices among the Liberian rice farmers.

Looking at the fertilizer applications per county, the general picture is reflected for every county (Fig 4.10). As shown the county with the highest number of farmers not using fertilizer is Montserrado while Lofa had the highest number of fertilizer users. These numbers were however not significantly different among the counties.

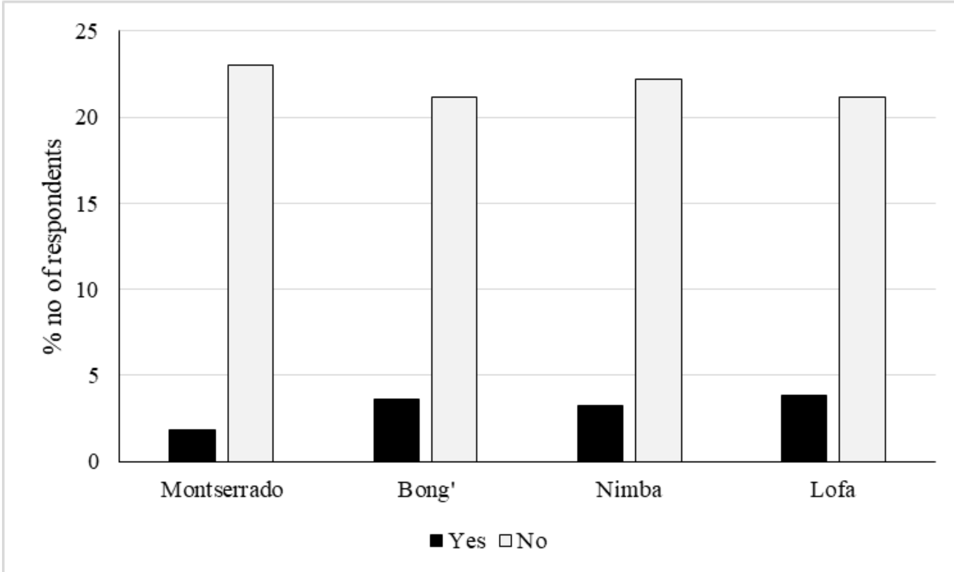


Figure 4.10. Fertilizer application per county.

4.3 Seed quality and health status

4.3.1 Physiological quality parameters

4.3.1.1 Germination Percentage and Moisture Content

NERICA L-19 proved to have superior germination qualities with the top germination percentage in all the counties with a 99.75 % in Bong County (Fig 4.11). No other rice variety had such a consistent performance in all the counties **(Appendix IV)**. Gizzie variety had the poorest germination in all the counties except for Nimba County where it just outperformed LAC-23RED.

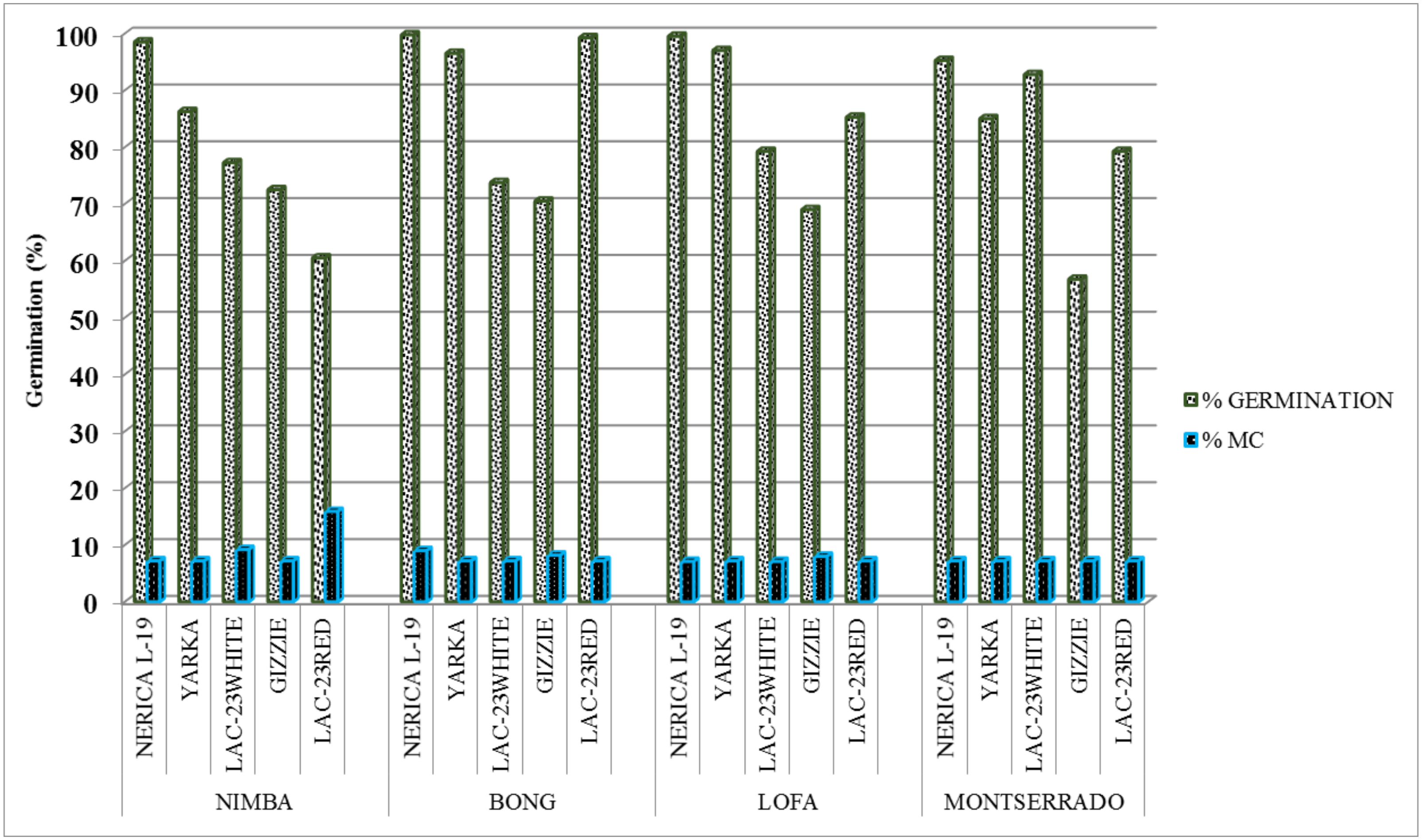


Figure 4.11. Graph showing germination of rice seeds from four counties. Rice varieties were differently affected as per the county.

Each rice variety had the best performance in Bong County except for LAC-23WHITE. Rice from Montserrado had the poorest germination. It is only the LAC23WHITE variety that seem to have been favoured by conditions in Montserrado. In terms of moisture content, LAC-23RED from Nimba had the highest content at 15.9%. For the rest of the seeds in all the counties, not much variation can be observed in the content of moisture.

4.3.1.2 Thousand seed weight

For the measures of a thousand seed weight, it was clearly apparent that the Yarka variety had the least weight (Fig 4.12). The lowest weight was obtained from the Yarka variety in Nimba County (19.80g). Further, the rice obtained from Bong County had an average weight ranging from 20-22g except for NERICA L-19 (26g). The weight from NERICA L-19 was the highest overall weight as this rice variety proved to be good for all the counties.

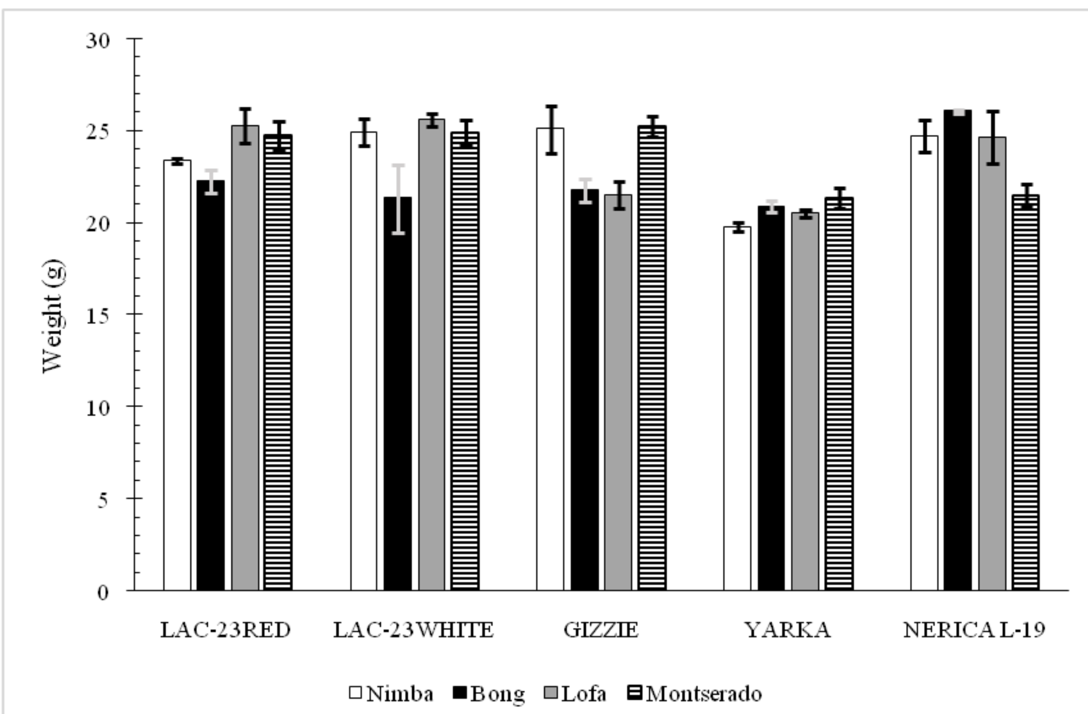
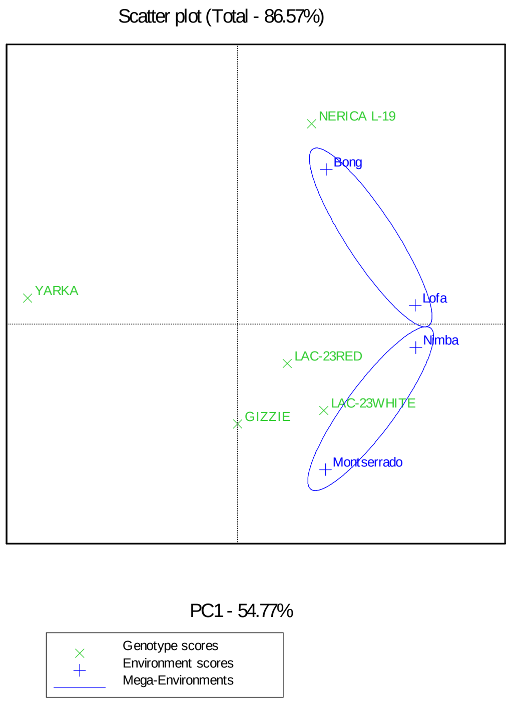


Figure 4.12. Thousand Seed Weight (TSW) of the rice seed varieties obtained from the four counties.

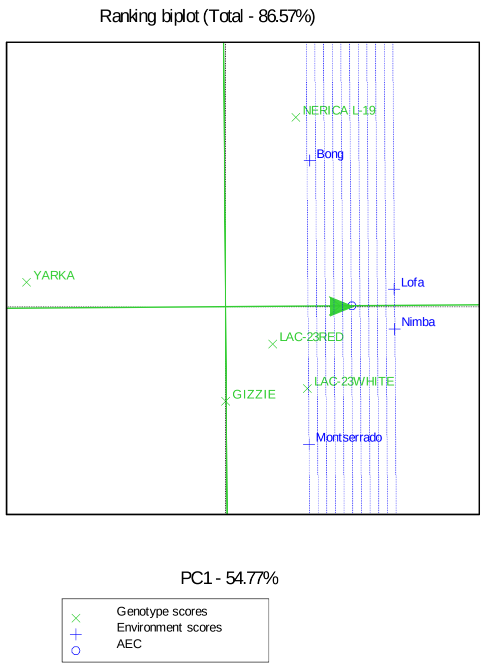
Montserrado appears to be favourable for the growth of all the rice varieties except NERICA L-19. Lofa County also favours LAC-23RED, LAC23-WHITE and NERICA L-19. Overall, at least one rice variety shows poor performance in at least one specific county.

The scatter plot, ranking and comparison biplot below show the influence of environment on the weights of the rice seeds. For the different rice varieties, (Fig 4.13, a) the first interaction principle component sum of squares (54.77%) was greater than the second sum of squares (31.79%) reflecting significant differences in a thousand seed weight due to environmental (county) differences. Total variability recorded was 86.57%.

The ranking biplot (Fig 4.13, b), shows where particular rice varieties are best adapted. NERICA L-19 is the only rice variety well adapted to Bong and Lofa based on the dry weights experiment. Nimba and Montserrado are best environments for LAC-23 red and white varieties and to a lesser extent Gizzie variety. The Yarka variety has been plotted farthest from all the rice varieties. This means that Yarka had an inferior performance in terms of seed weights regardless of the environment.

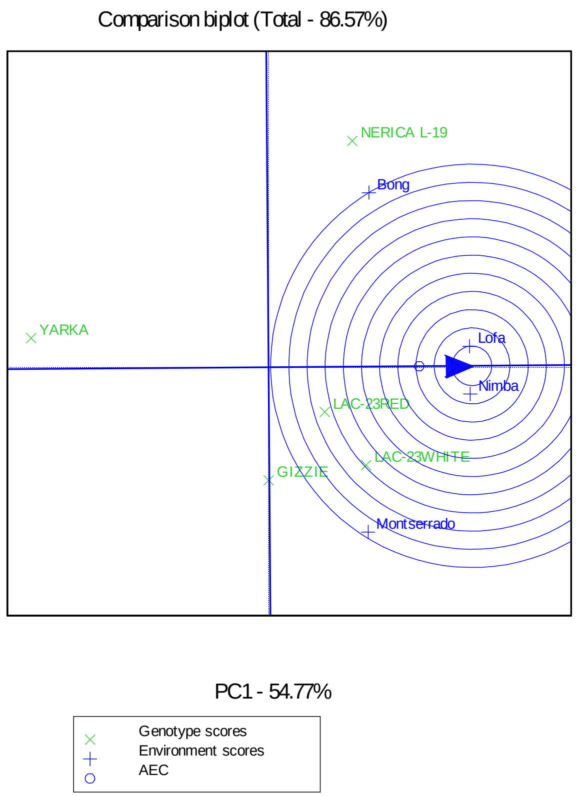


(a). Scatter plot

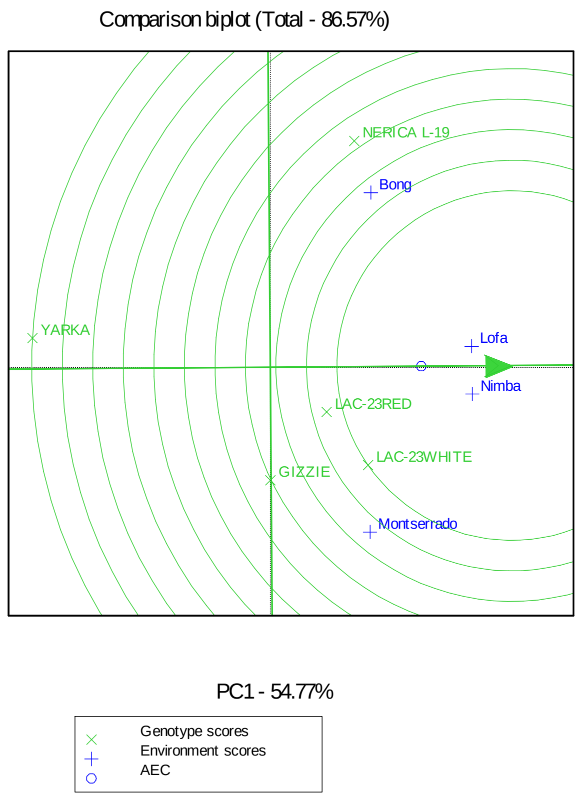


(b). Ranking biplot

Figure 4.13a: The influence of environment on TSW of the rice in the four sampled regions.



(c). Comparison biplot



(d). Comparison biplot

Figure 4.13b: The influence of environment on TSW of the rice in the four sampled regions.

The comparison biplot in figure c, shows concentric circle that gives insights of the best seed varieties. LAC-2RED and LAC-2WHITE are the best rice varieties as they are nearest to the centre of the concentric circles. Yarka is least performing variety in terms of yields and is plotted the farthest. This is well reflected in the bar graph shown earlier. The information here mirrors that shown by ranking biplot in Fig b.

Comparison biplot in Fig d shows the best environments for rice production. Lofa and Nimba rank as the best environments for rice production due to their proximity to the centre of the concentric circle. Bong seems to be the least desirable environment for rice production closely followed by Montserrado **(Appendix XI)**..

4.3.1.3 Seed vigour analysis

a) The speed of Germination analysis

Germination test was also carried out to determine the differences in the rate of germination among the seed varieties **(Appendix IV)**. In a seven-day period, most of the seeds had already germinated. Differences can be however seen in the daily growth rates. A reflection of the daily growth rates is provided by germination rate index in figure 4.14. Yarka and NERICA L-19 varieties from the counties under study all had the best germination rates. Their peak growth rate occurred on the second day after inoculation. For NERICA L-19 especially, at least two seeds germinated by the second day. It was the only rice variety having some signs of germination second day after sowing. For NERICA-19 and Yarka seed varieties most them had already germinated by the fourth.

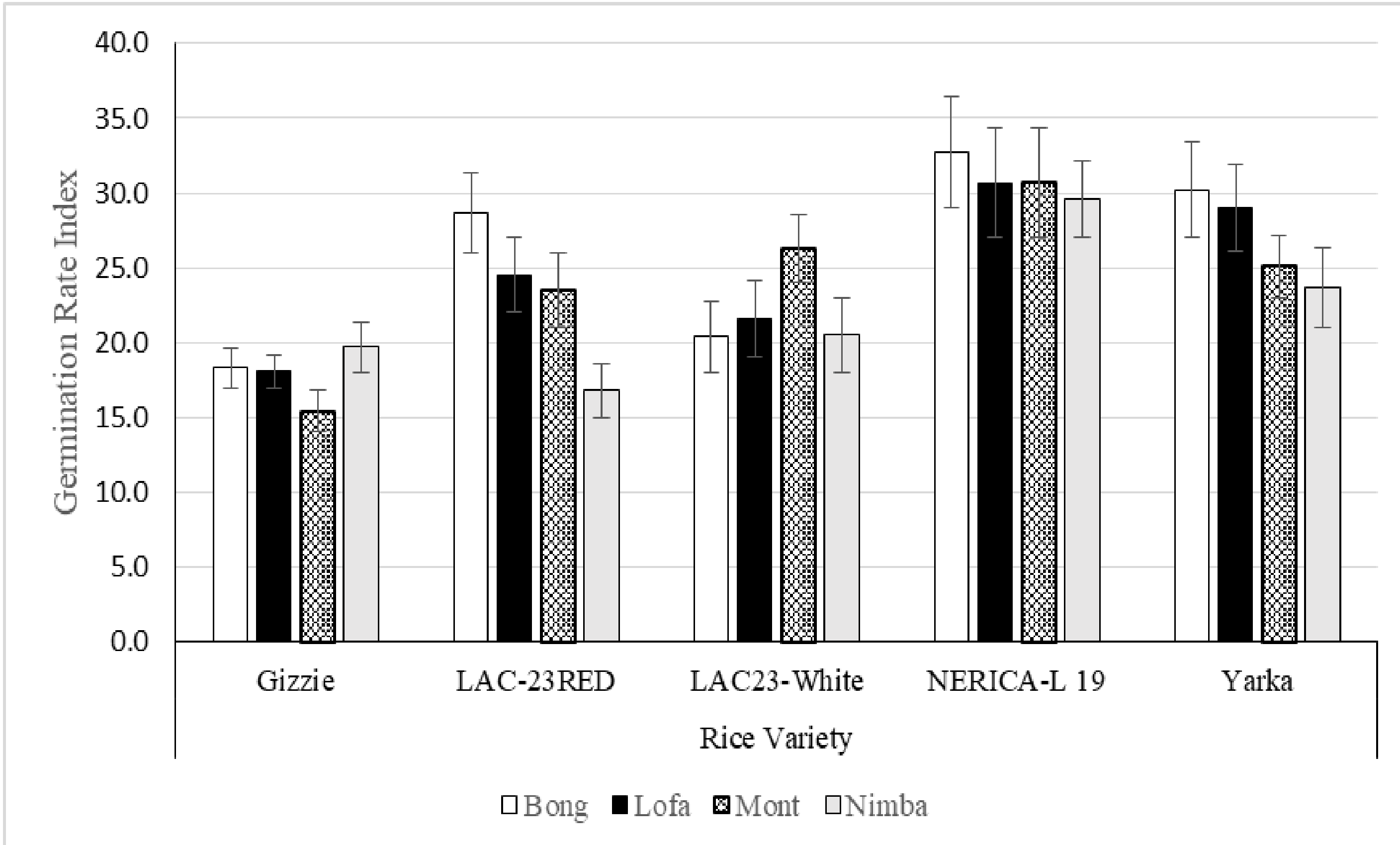


Figure 4.14. The germination index for the seed varieties tested. The bars represent mean germination index while the error bars represent the standard deviation.

Judging from the days of germination, bulk of the seeds germinated on the third and fourth day after sowing (DAS). Majority however germinated on the 2nd day with a total of 44 counts. However, as earlier indicated only Yarka and NERICA-L 19 were most dominant in the early days after sowing. Tukey's test separated the germination days into three categories. The third and the fourth days are in different groups indicating different growth rates. The second, fifth, sixth and seventh days are in the same categories. On the second day, too few seeds had germinated while on the fifth day onwards, few seeds were still left un-germinated.

Apart from the number of days to germination, germination percentage was also determined. This is the proportion of the germinated seeds at the end of seven days for each seed type. Gizzie rice variety had the lowest germination percentage in all the counties while NERICA L-19 had the highest (Fig 4.15).

Germination percentage for Gizzie variety per county were as follows; Nimba 72.50%, Bong 70.50%, Lofa 68.00%, Montserrado 56.75%. That for NERICA L-19 were, Nimba 98.50%, Bong 99.75%, Lofa 99.50%, and Montserrado 95.50%. For the rest of the seed varieties differed considerably depending with the county of origin of the seed varieties. The rice seed variety LAC-23 Red for example had a germination percentage of 60.50% when it was obtained from Nimba and 99.25% when it obtained from Bong.

b) Vigour index

Index of the Farmers' saved seeds

The vigour index of the farmers' saved seeds was determined as shown in the graph below. The variety which showed the highest vigour index was the LAC-23White variety grown in Bong County. The least vigour index was displayed by Gizzie variety in Montserrado County. NERICA-L19 in Montserrado showed great variation in its vigour index.

In Bong County, the seed varieties have been grouped into three based on the vigour index. NERICA-L19 and Yarka can be grouped together based on the overlap of the boxes between these two varieties. They are intermediate in vigour between LAC23-Red which is the highest and Gizzie and LAC 23 white ranking highly in vigour.

In Lofa, there are only two categories of the seeds in terms of vigour. Gizzie and LAC 23 White have a lower vigour index compared to NERICA L-19 and Yarka. Between NERICA- L 19 and Yarka however, the interaction occurs between the box and whisker. The mean vigour for Yarka is below that of NERICA L-19. However, Gizzie and LAC 23 white rank very closely based on the interactions of their boxes and whiskers.

From Montserrado, Gizzie had the lowest vigour. Its box and whisker ranked so low compared with the rest of the varieties. Vigour recorded from NERICA L-19 varied greatly spanning from around 600 to 1400. This feature made have considerable interaction with the other seed varieties except Gizzie. However, the vigour indexes of Yarka and LAC 23 Red interacted only that some replications scored highly as shown by a very long whisker. LAC 23 White ranked the highest here.

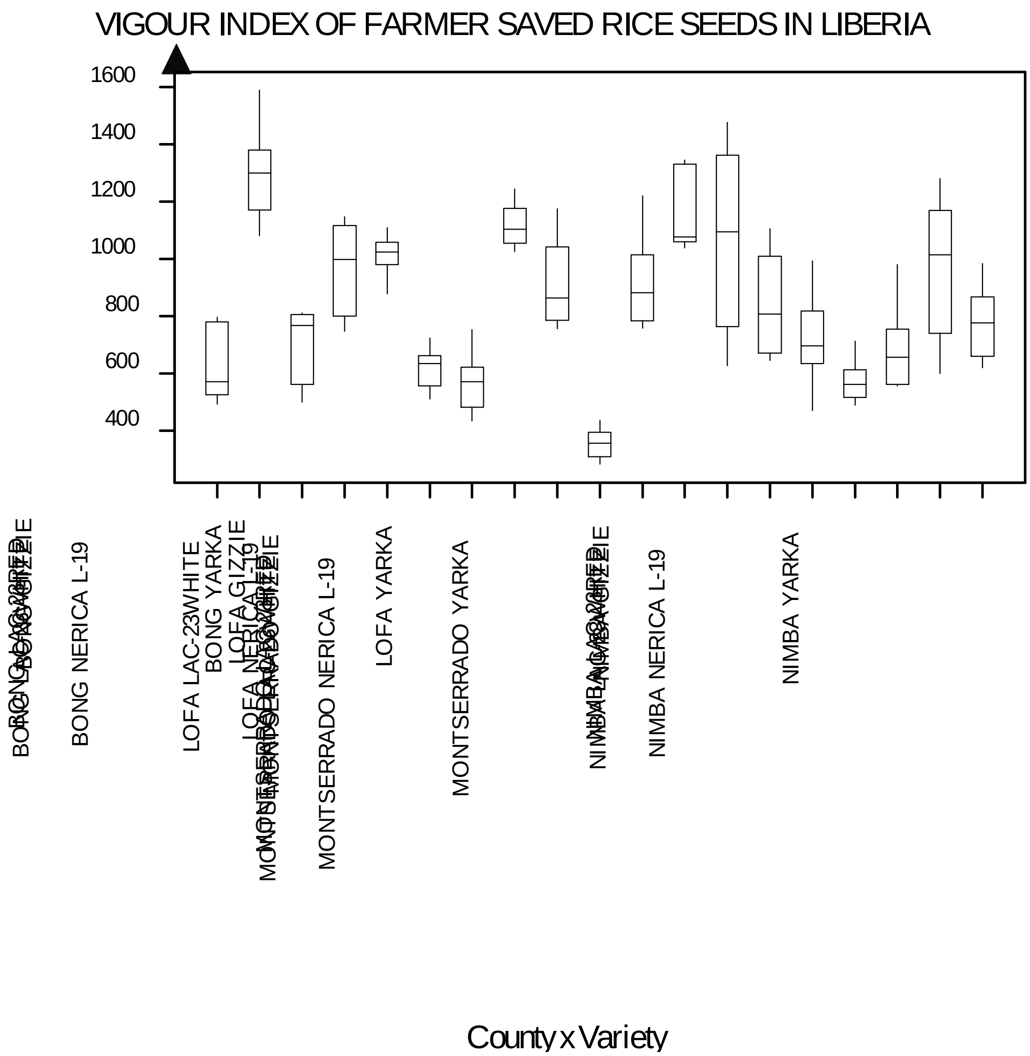


Figure 4.15: Plot Boxes showing the vigour index of the rice varieties in the four counties.

4.3.2. Seed Health Management

Incidences and frequencies of seed- borne Fungal Pathogens in Liberia

A total of six different fungal isolates were obtained from the seeds in the four counties in Liberia (Fig 4.14). *A. niger, A. flavus* and *Penicillium* spp were found in all the counties making them the most prevalent fungal pathogens. *Aspergillus niger* was undoubtedly the most abundant fungal isolate. Slight differences in these fungi only manifest in the density of and texture of the conidiospores. In Bong County spores from *A. niger* were black and more dense. Further, the *A. niger* spherical spores had a diameter of 2µm. The spore colours reflected the colony and rear colour. Sporulation of the *Aspergillus niger* from Lofa County appeared slightly denser than that from Bong County. Further the conidia were both in chains and clusters. *A. niger* isolated from Montserrado County had conidia with rough surface. The conidia were dense with evidence of organization into chains and bunches. The size of the conidia matched those of the other previous *Aspegillus niger* isolates in other counties.

A. flavus was also found in all the counties. The colony and the conidia of *A. flavus* were green in colour. Just as *A. niger* the edge of the growing colony was cream white before the characteristic colony colour dominates. The conidia were smaller (0.8µm) than those of *A. niger*. Further, from the micrographs in table 2 it is clearly evident that the conidia from *A. flavus* were less dense. The rear colour of *A. flavus* were cream. The culture only greatly differed in the form of the colonies. The colonies isolated from seed samples obtained from Bong and Nimba Counties, the colonies showed concentric rings. This difference however was not reflected in microscopic images no major variation could be seen in aspects like sporulation potential.

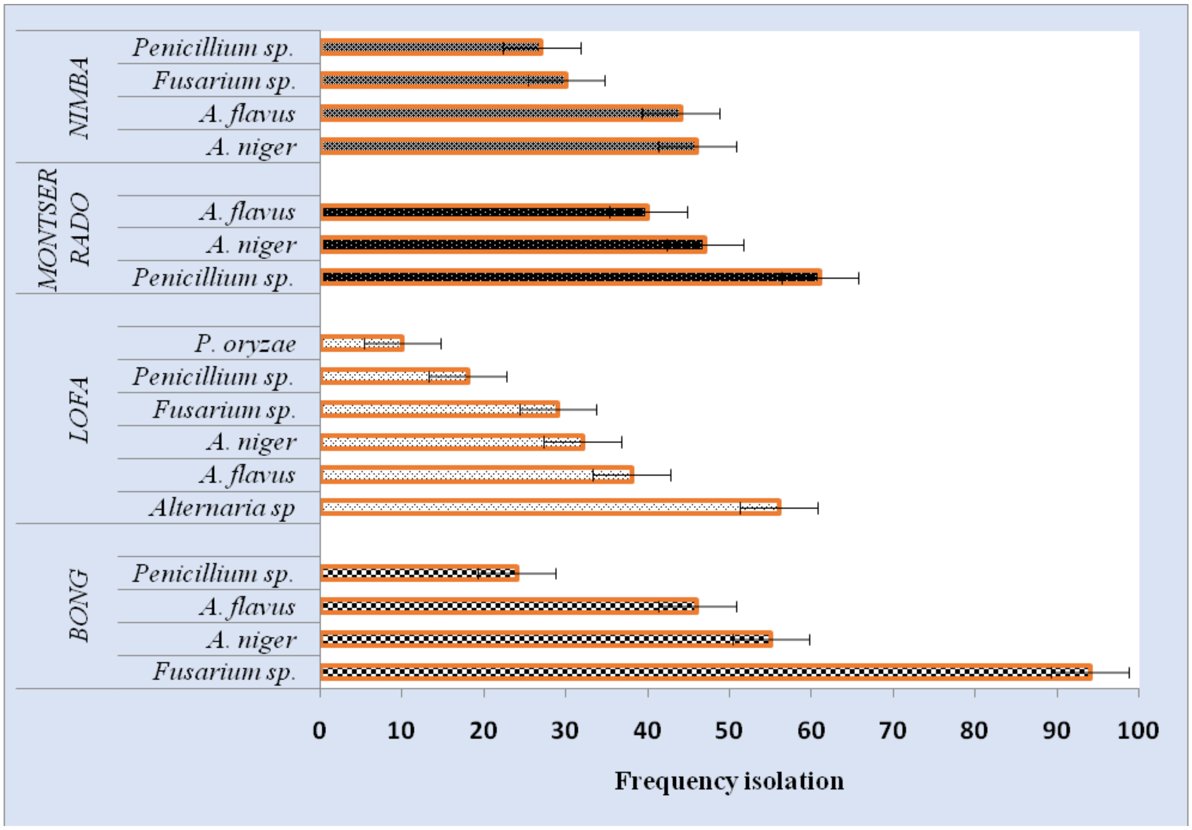


Figure 4.16: The % incidence of Major Fungal Pathogens Affecting rice seed quality in Liberia.

Penicillium sp was also secluded from the seed samples sourced from all the counties. There was greater variation among the isolates in different dimensions. However, they all had greenish colonies with whitish-cream rear. Differences in the form of the colonies was clearly evident. The spores also appeared in groups and varied solely in size. In many ways, the *Penicillium sp*. isolated from the rice grains in Bong and Lofa Counties were comparable. Conidia were the same size in both areas (2 m), but the Lofa samples had less aggregate numbers.

Perhaps an indication if inferior sporulation. The colony morphology of *Penicillium spp*. isolated from Montserrado and Bong Counties was comparable and markedly different from that of the other two counties. They had concentric rings which was lacking from the previous two isolates.

Seeds from Lofa County were the most pathogen infested with a total of six pathogens isolated from this region. Two pathogens were unique to this county, *Pyricularia oryzae* isolated from 10 different rice samples and *Alternaria* spp isolated from 56 rice samples. Montserrado had only three fungal pathogens making it the least infested. *Fusarium* spp from Bong County was the most frequently (94 times) isolated pathogen. *A. niger* was the most frequently isolated pathogen in Nimba (46), *Penicillium* sp in Montserrado (61), *Alternaria* spp in Lofa (56) and *Fusarium* spp in Bong (94). On the other hand, the least frequently isolated fungi in Nimba was *Penicillium* spp (27), *A. flavus* in Montserrado (40), *P. oryzae*in Lofa (10), and *Penicillium* spp in Bong (24).

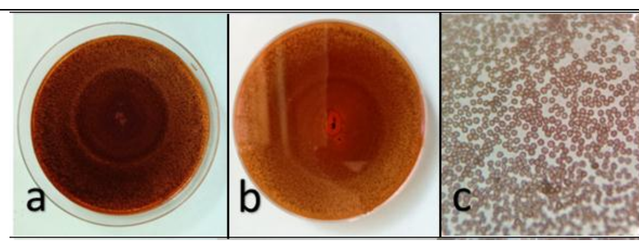
A. niger	

Plate 4.1 a: ***Aspergillus niger***

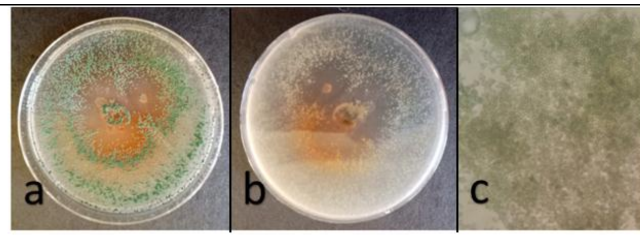
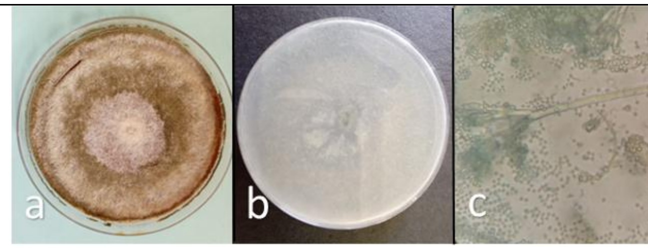
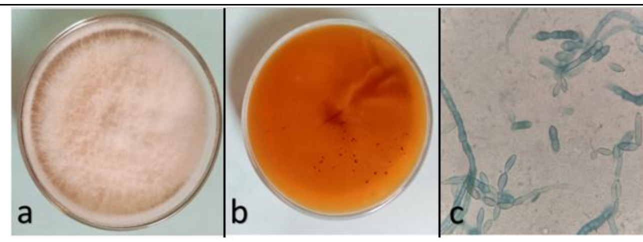
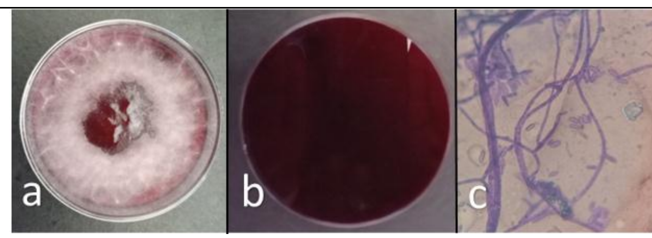
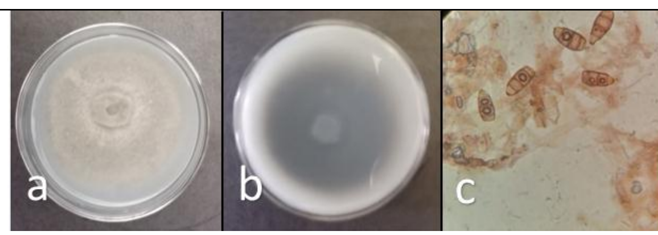
A. flavus	
Penicillium spp.	
Fusarium sp	
Fusarium sp	
Pyricularia oryzae	

Plate 4.1b: *Aspergillus flavus, Penicillium* sp, *Fusarium* spp and *Pyricularia oryzae*

Fusarium sp was not found in Montserrado but was present in all of the counties. Compared to *Aspergillus* spp and *Penicillium* spp, sporulation was greatly diminished.

Conidia were all long and slender. Major differences were observed in the colony morphology. Isolates from Bong and Nimba resembled culturally but the conidia of the colonies from Nimba were slightly longer. Colonies were of white mycelia with an orange rear. There were two different isolates from Lofa. One of the isolates resembled those from Bong and Nimba but differed greatly in the shape of spores. Here, instead of long and slender spores, they appeared short and bulged. The other isolate from Lofa was cotton white with a pink rear. The conidia were also shorter and slender.

Another pathogen isolated from the rice grains from Lofa County was *Pyricularia oryzae*. This county has the only instance of this fungus (Plate 4.2). The colony's color is grey and white, while the rear is dark in older neighborhoods and white in newer ones. The spores had three septa and were cylindrical, measuring (35) m. The color of the spores was brown. However, sporulation was weak since there were few conidia visible in the microscope field. The septa of the mycelia.

4.4 Efficacy of botanical plant extracts

The botanical extracts for this study were obtained from bean ash, garlic, neem, chilli, and ginger. Aqueous extracts were used for all the plants. The extracts were applied in three different concentrations; 0.3ml, 0.5ml, and 0.7ml in every 20ml of the plated media. For the bean ash, the equivalent was 0.3g, 0.5g and 0.7g in every 20ml of the dispensed media. Bean ash was generally the strongest botanical extract (fig 4.17). Ginger on the other hand, was the weakest although it also had inhibition towards the pathogens under study. All the botanical extracts showed dose dependent antifungal activity. The fungal pathogen *Fusarium sp*. was the most resistant to all of the plant extracts.

As soon as the fungi on the negative control plate had occupied the whole plate, antifungal activity was determined by measuring the fungal colony diameter on a regular basis **(Appendices V and VI).** Therefore, the strength of the botanical extract decreases with increasing diameter. The *A. niger* fungus responded to all treatments the best. Nine times, there was complete inhibition since no diameter could be measured. The second most vulnerable pathogen was *Penicillium sp*. Although 100% inhibition was only seen once, the greatest colony diameter for this fungus was barely 18mm. When compared to *Penicillium sp*., *A. niger* seems to be more vulnerable. Six of the occurrences showed absolute inhibition; nevertheless, greater diameters were noted when there was partial inhibition **(Appendix VII)**. *Fusarium sp*. wasn't completely inhibited. In the pages before, an extensive description of the antifungal activity is covered.

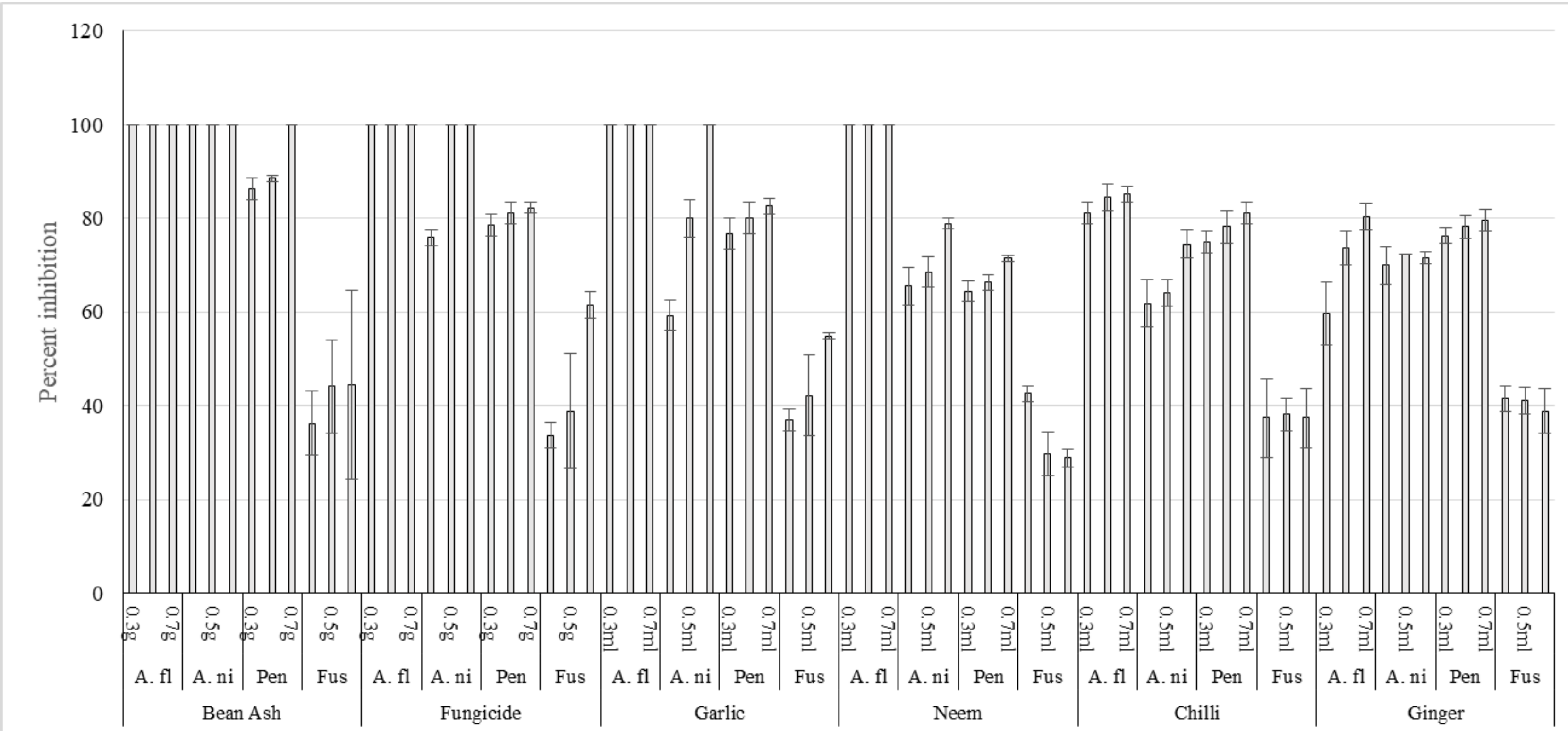


Figure 4.17. Percent inhibition of different extracts against the isolated pathogens. The bars represent mean percent inhibition. The error bars represent Standard Errors (SE). *A. fl; A. flavus, A. ni; A. niger*, Pen*; Penicillium* sp, and Fus*; Fusarium sp*. Bars lacking the error bars represents those extracts that had 100% inhibition.

4.4.1 Inhibition on *Aspergillus flavus*

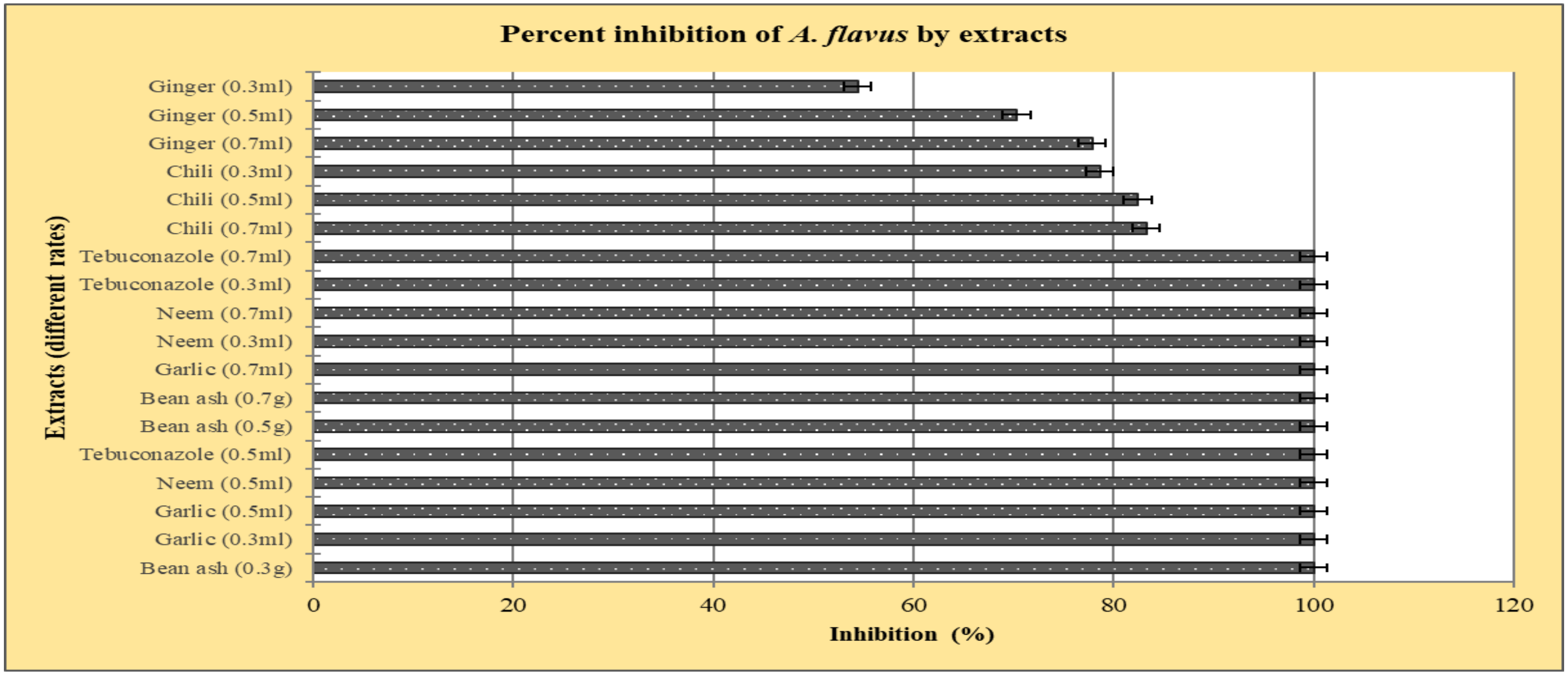


Figure 4.18. Inhibition of *A. flavus* the various plant extracts after day 4.

All plant extracts, with the exception of ginger and chilli, completely inhibited the development of the *A. flavus* colonies (Fig. 4.16). However, even with ginger and chilli, some inhibition was seen since the pace of the colonies' development was slowed down at different concentration levels (Plate 4.2). The lowest amount of ginger (0.3ml) has a 57% concentration. This number showed the *A. flavus*'s least inhibition percentage.

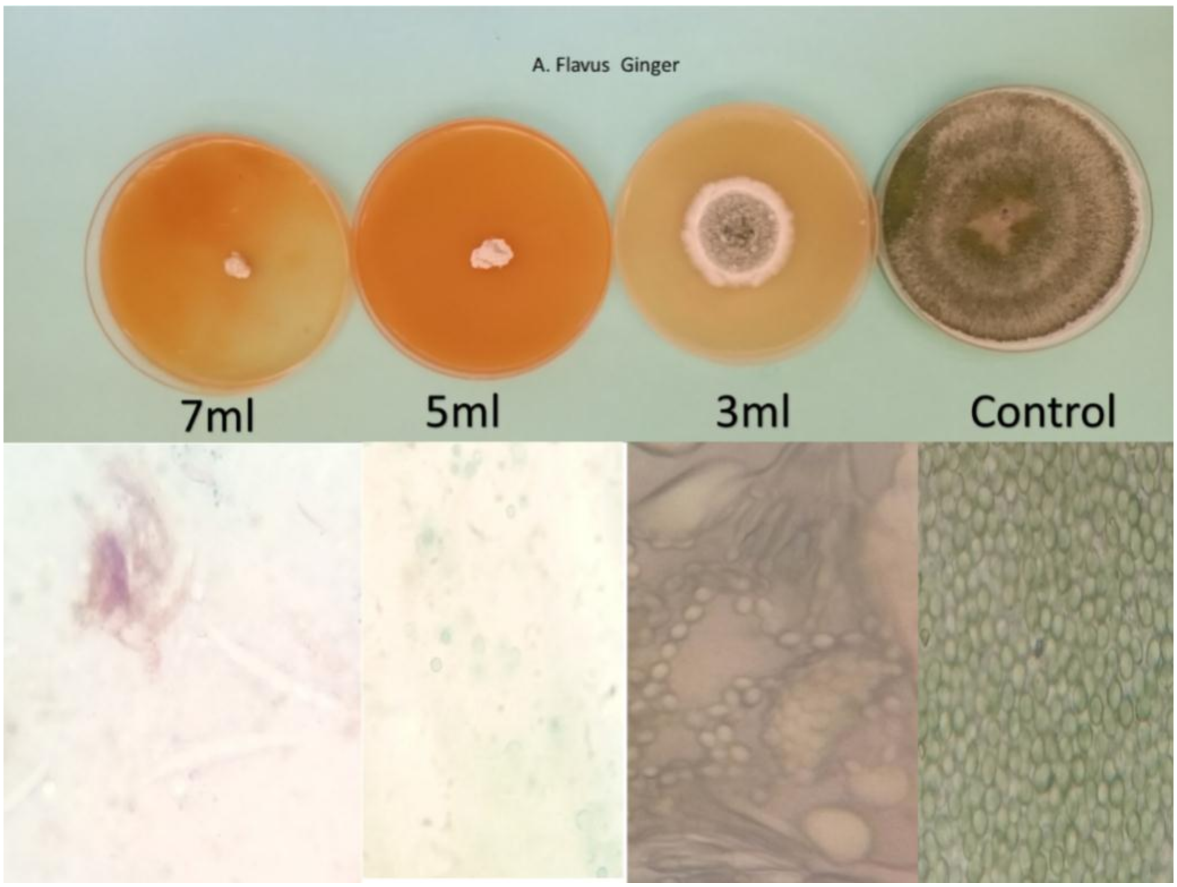


Plate 4.2. *A. flavus* growing on medium amended with ginger extracts at different concentrations. Below each concentration is micrograph showing sporulation characteristics as affected by the ginger extracts.

In every tested concentration, the other botanicals were all efficient against the fungus **(Appendix VIII).** The fungus colony did not spread from the injection site in any of these. Increased extract concentration hampered the development of ginger and chilies.

The fungicide served as the test subject. The *A. flavus* colonies were completely inhibited, just like with the other treatments. Conidia completely disintegrated at every fungicide concentration employed as well. Therefore, from this angle, fungicide seems to be the most effective in stopping *A. flavus* i*n vitro*.

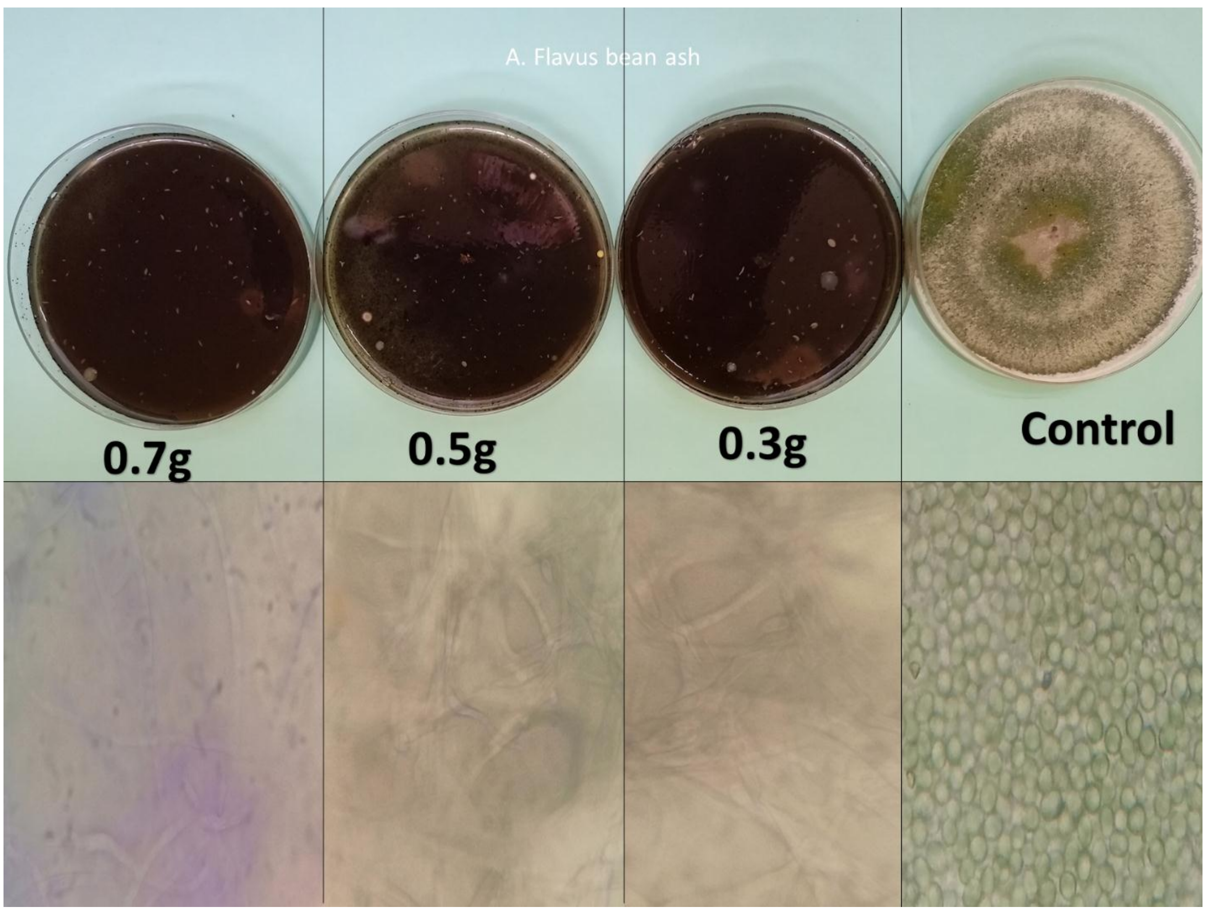


Plate 4.3. *A. flavus* inoculated onto PDA amended with different quantities of common bean ash (black media).

4.4.2 Inhibition on *Aspergillus niger*

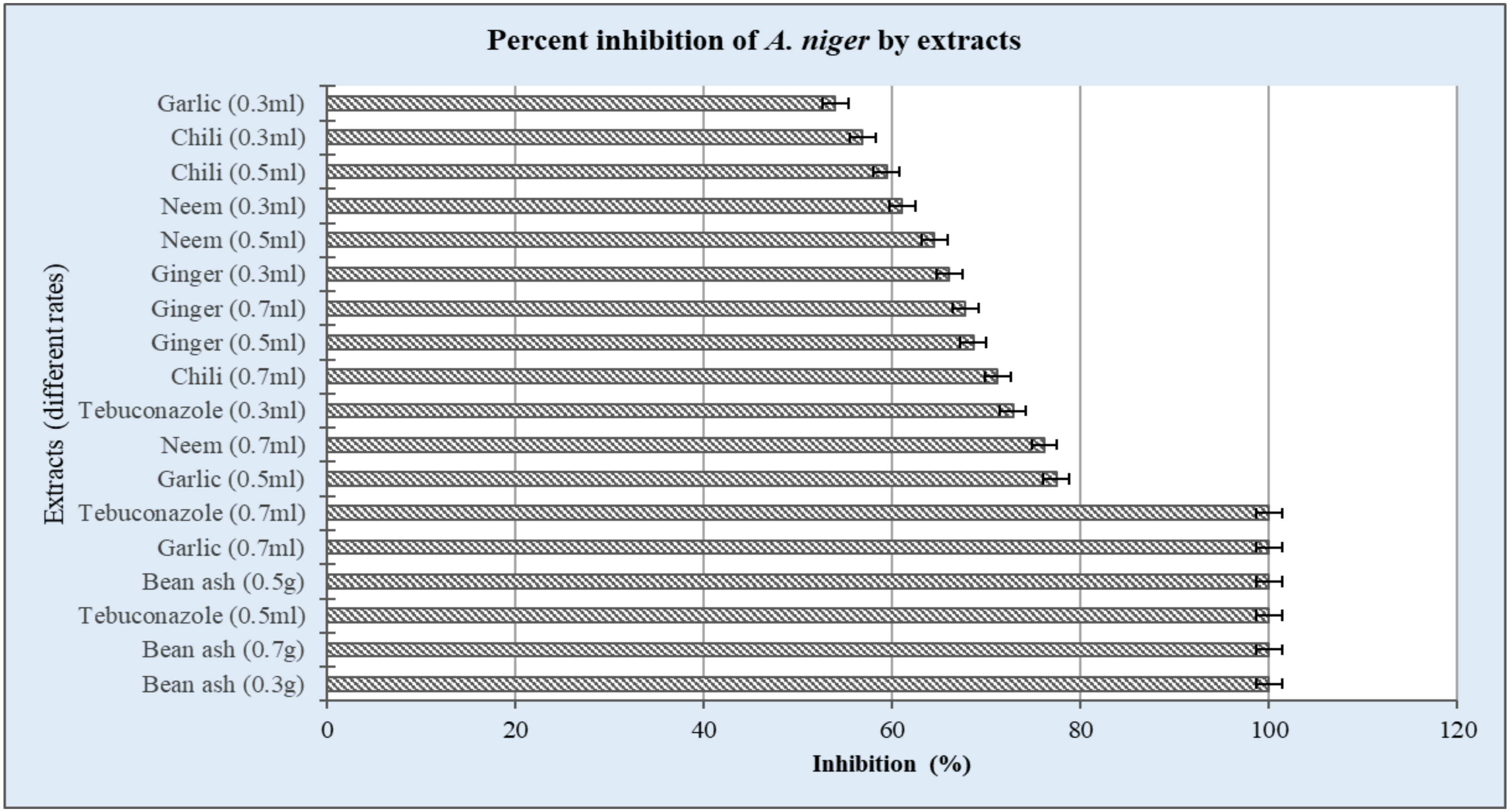


Figure 4.19: Inhibition of *A. niger* by the various plant extracts.

A. niger was only entirely suppressed by all amounts of common bean ash, in contrast to *A. flavus*. Tebuconazole, the positive control utilized, only completely inhibited *A. flavus* at concentrations of 0.5 ml and 0.7 ml (Plate 4.5). The only amount of garlic extract that completely controlled the fungal growth was the maximum dosage (0.7ml).

The other extracts (ginger, neem, and chilli) displayed varying levels of control that were noticeably distinct from the negative control **(Appendix VIII)**. In this group, the concentration of garlic in 0.5 ml had the highest concentration of about 78%, while the concentration of garlic extract in 0.3 ml had the lowest concentration of about 57% inhibition (Plate 4.4).

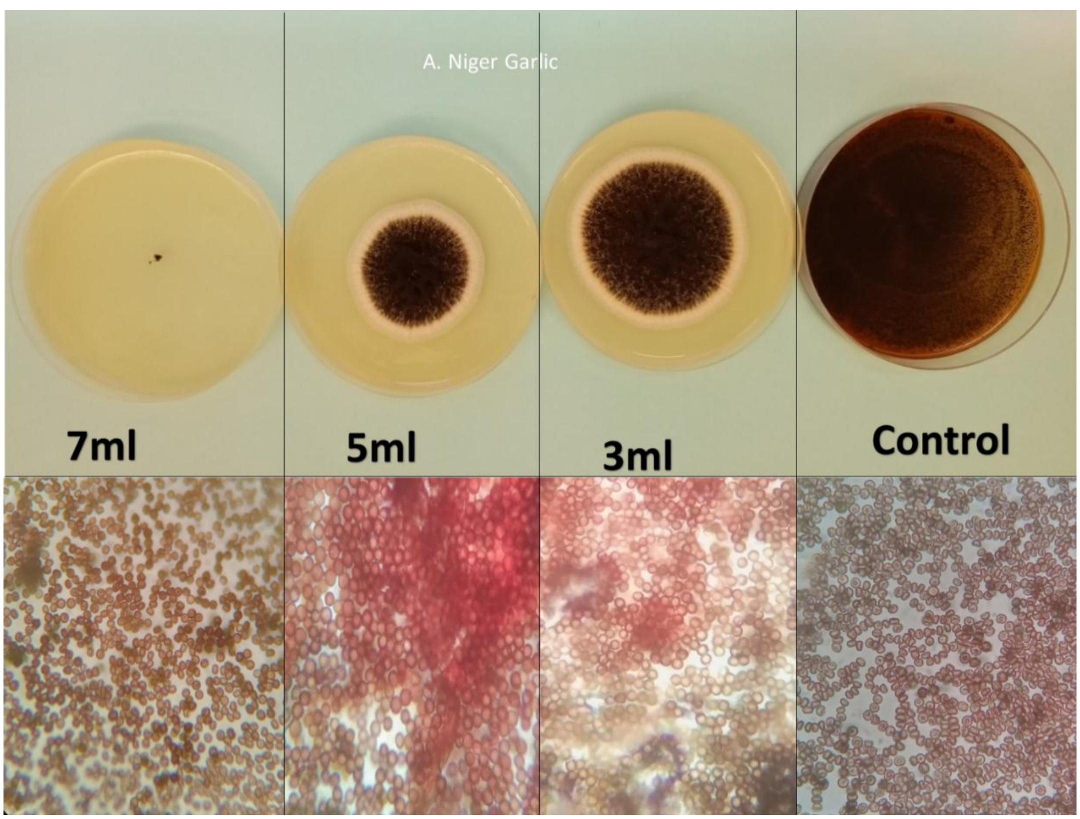


Plate 4.4. The effect of garlic on *A. niger.* Concentration dependent suppression of the fungal colonies is clearly evident.

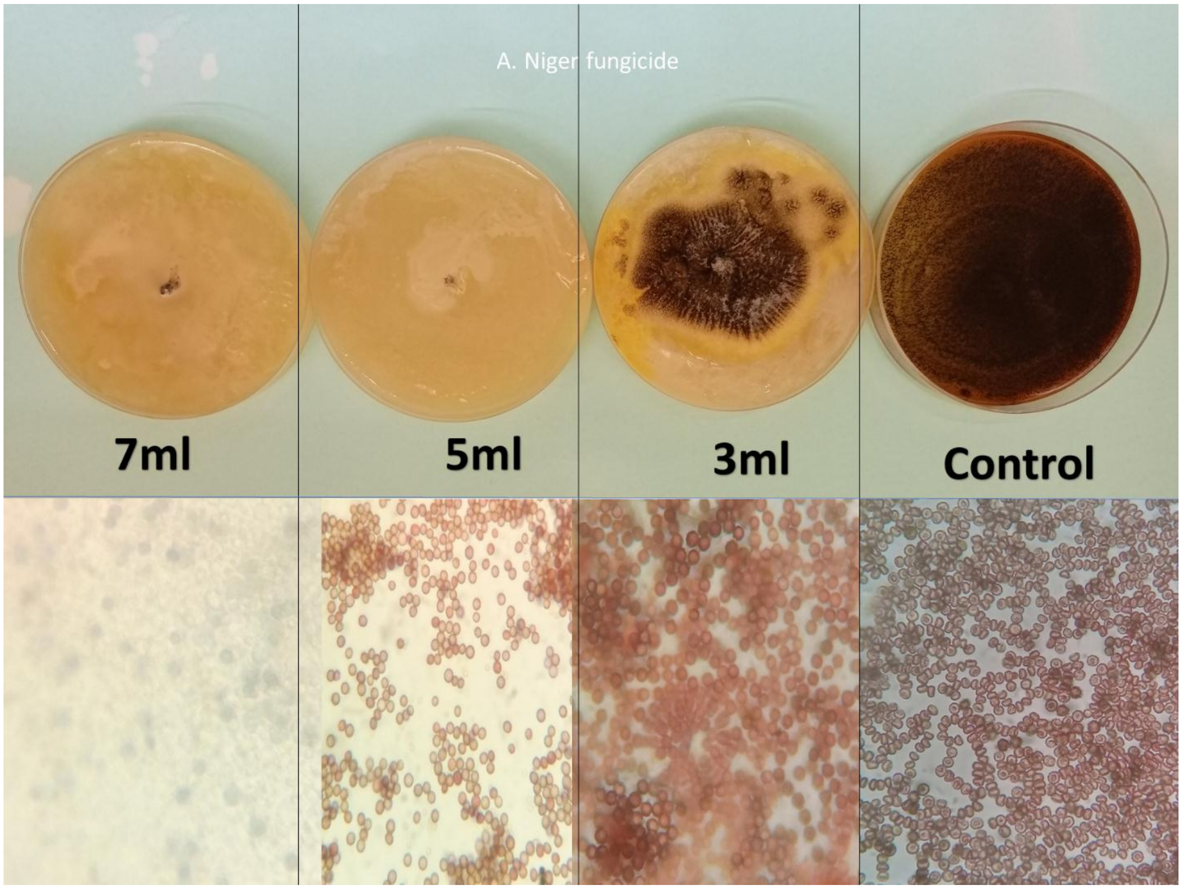


Plate 4.5. *A. niger* growing in media with different concentrations of fungicide. Growth appeared only in the lowest concentration.

4.4.3 Inhibition on *Penicillium specie*

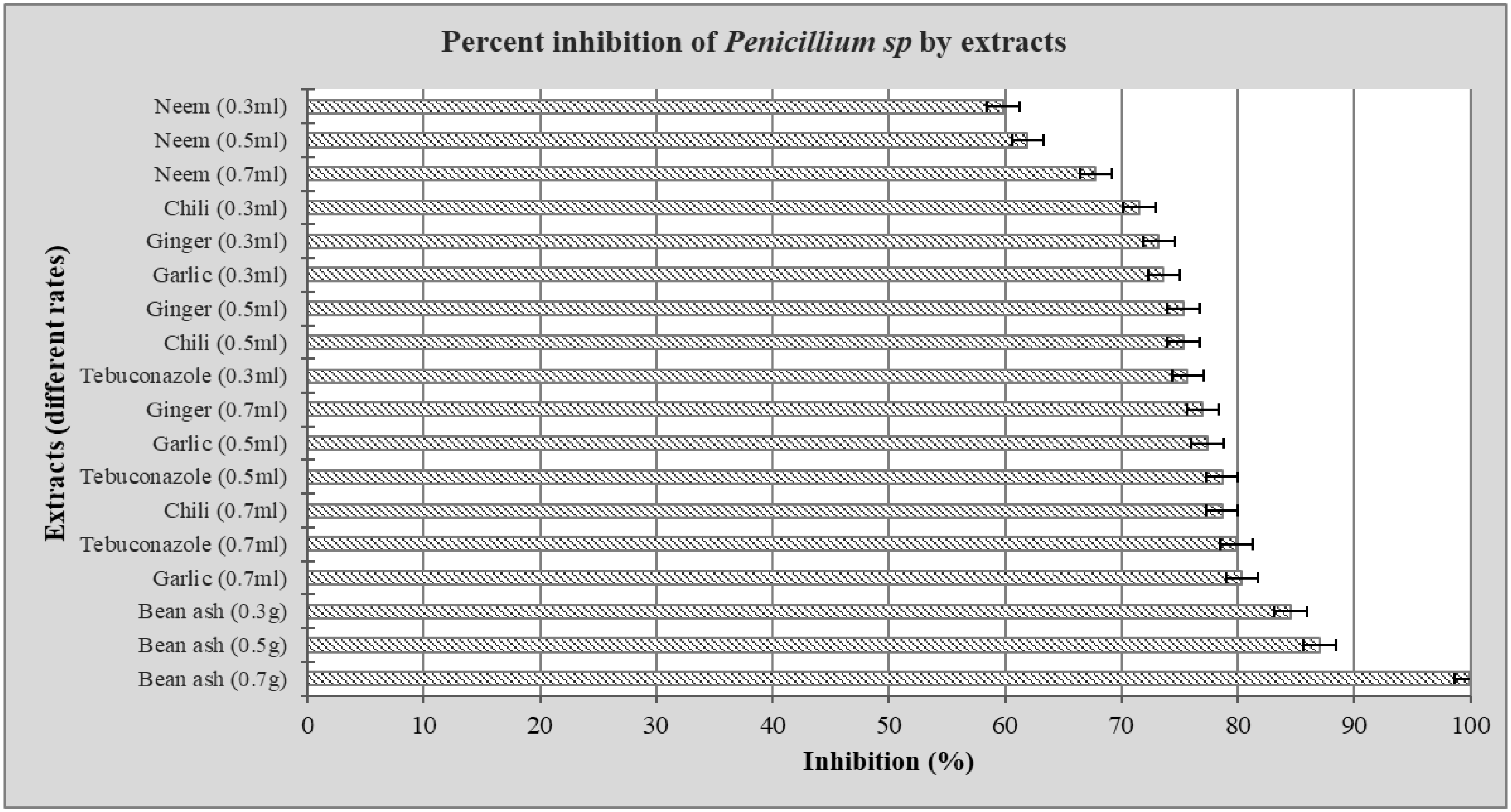


Figure 4.20: Inhibition of *Penicillium* sp by the various plant extracts.

Penicillium sp. was more resistant to the botanical extracts utilized in this investigation compared to both *A. flavus* and *A. niger*. The Penicillium colony was completely eradicated by only one treatment (highest concentration of common bean ash) (Plate 4.6).

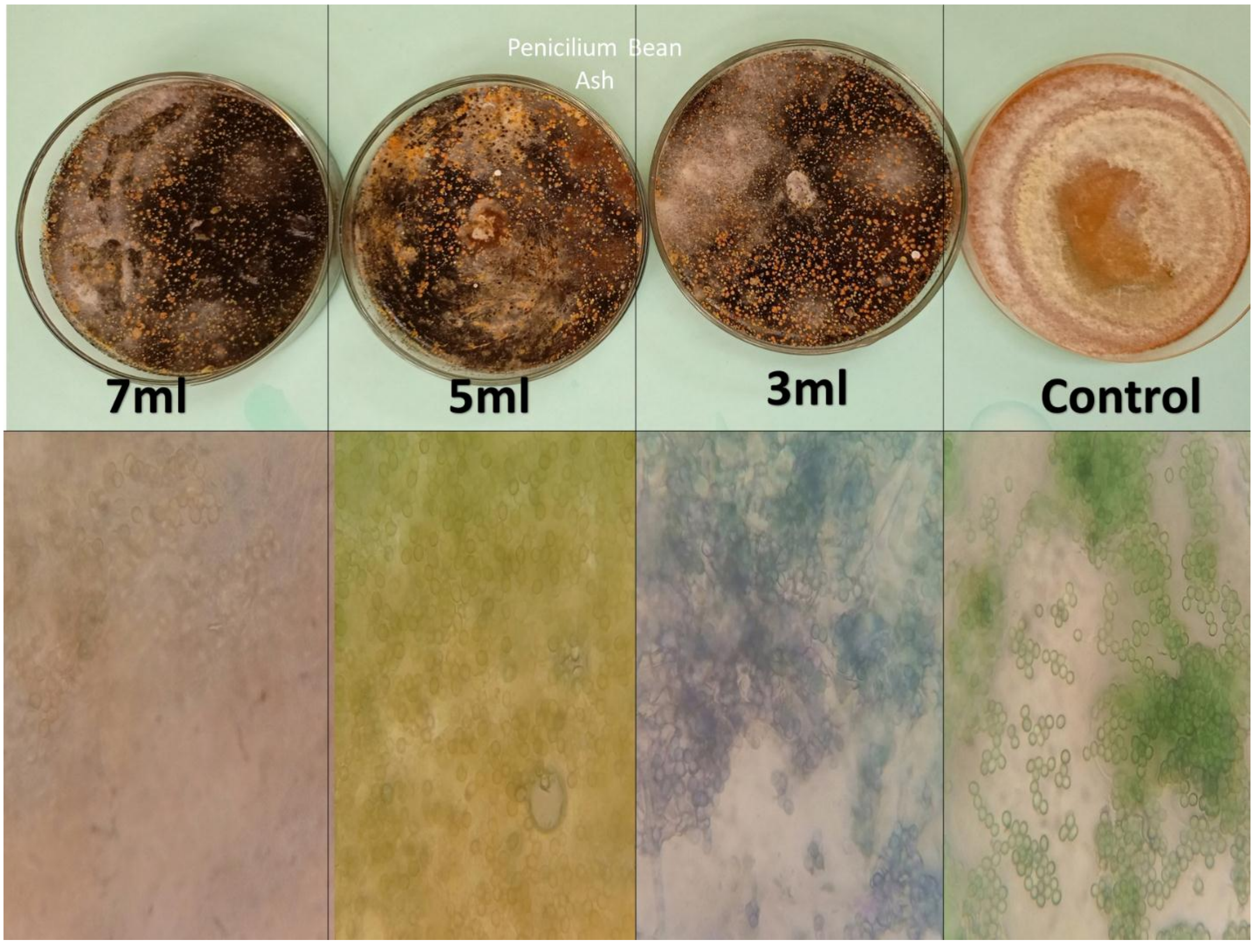


Plate 4.6. Small *Penicillium* sp colonies can be seen in the 0.5g and 0.3g concentrations.

However, in this instance, the most effective antifungal agents were bean ash extracts. The two lower doses of 0.3g and 0.5g of the bean ash extracts were similarly potent, limiting the fungal growth by 85% and 87%, respectively, in addition to the maximum concentration.

Neem, on the other hand, has the least performance of all *Penicillium* *sp*p. inhibitors, making it the mildest. Higher extract doses demonstrated increasing levels of control while being the least effective extract (Plate 4.7). The bean ash and 0.7 ml of garlic concentration similarly beat the commercial fungicide **(Appendix VIII)**. Tebuconazole was used at the greatest possible concentration, but only achieved a maximum inhibition of 80%.

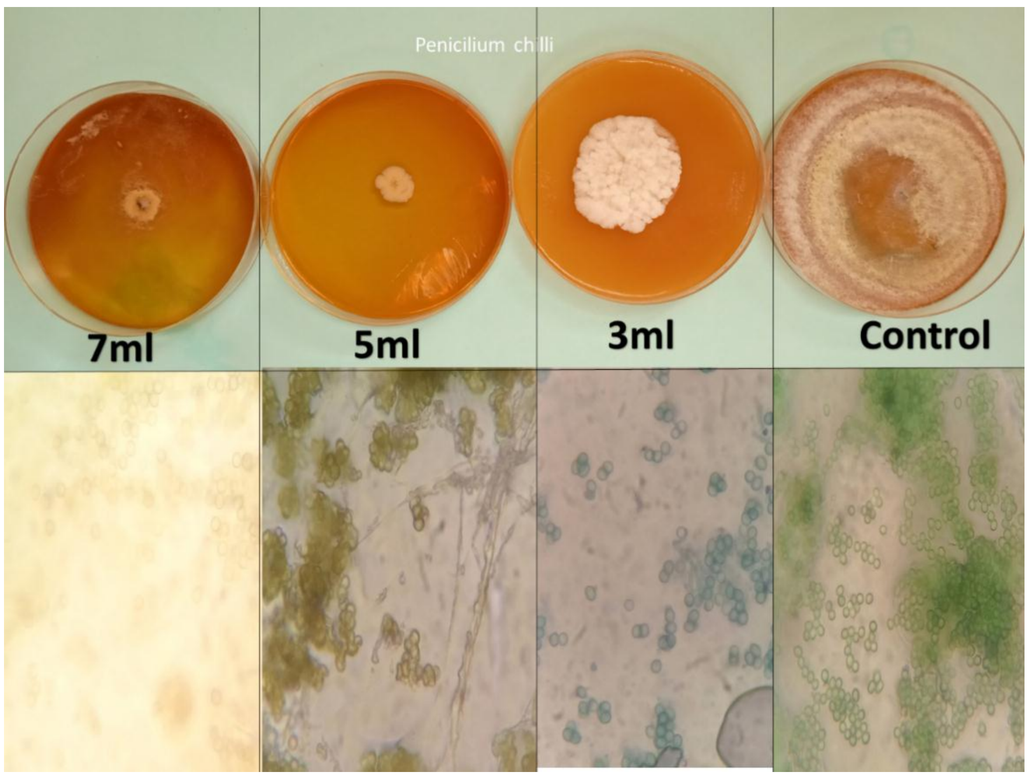


Plate 4.7 Biological control of *Penicillium* sp using different concentrations of chili extracts. Potency of the extracts is concentration dependent.

The rest of the extracts ranged from around 73-80% inhibition, with the exception of the bean ash at the top and neem at the bottom. From this vantage point, it is evident that although though many extracts could not achieve 100% colony suppression, most extracts outperformed the previous two pathogens (both Aspergilli) on Penicillium. The lowest observed inhibition, at 60%, is still a fairly strong performance in comparison.

4.4.4 Inhibition on *Fusarium* sp

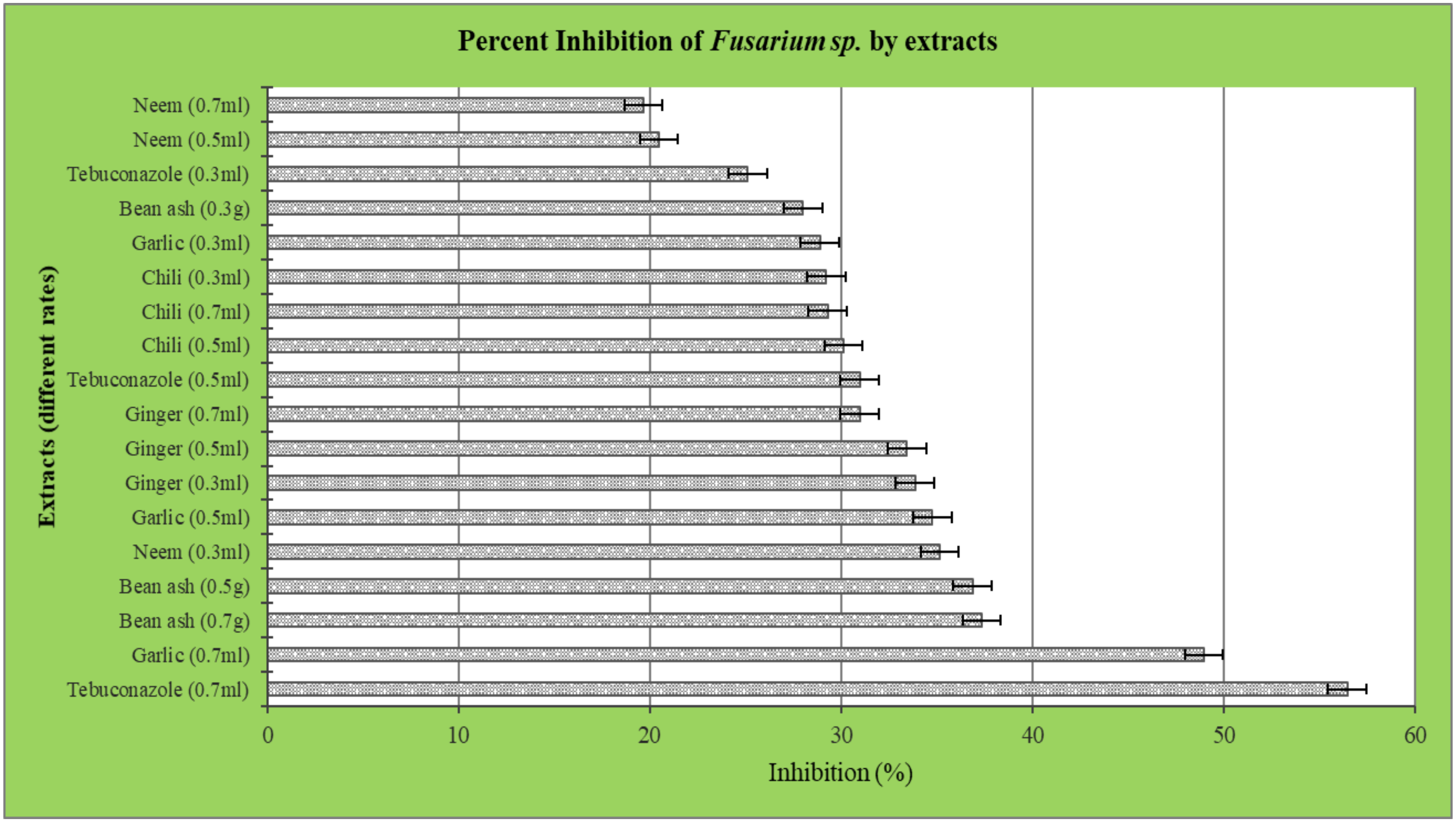


Figure 4.21: Inhibition of *Fusarium* sp by the botanical extracts used in the study. None of the treatments was able to completely inhibit the pathogen.

Fusarium sp. had the greatest resistance to the botanical extracts of all the fungal infections tested. In other words, the effectiveness of the botanical extracts against this fungus was the lowest. This fungus was not as well controlled by the fungicide, which was utilized as a positive control, as it was for the previously stated others (Plate 4.9).

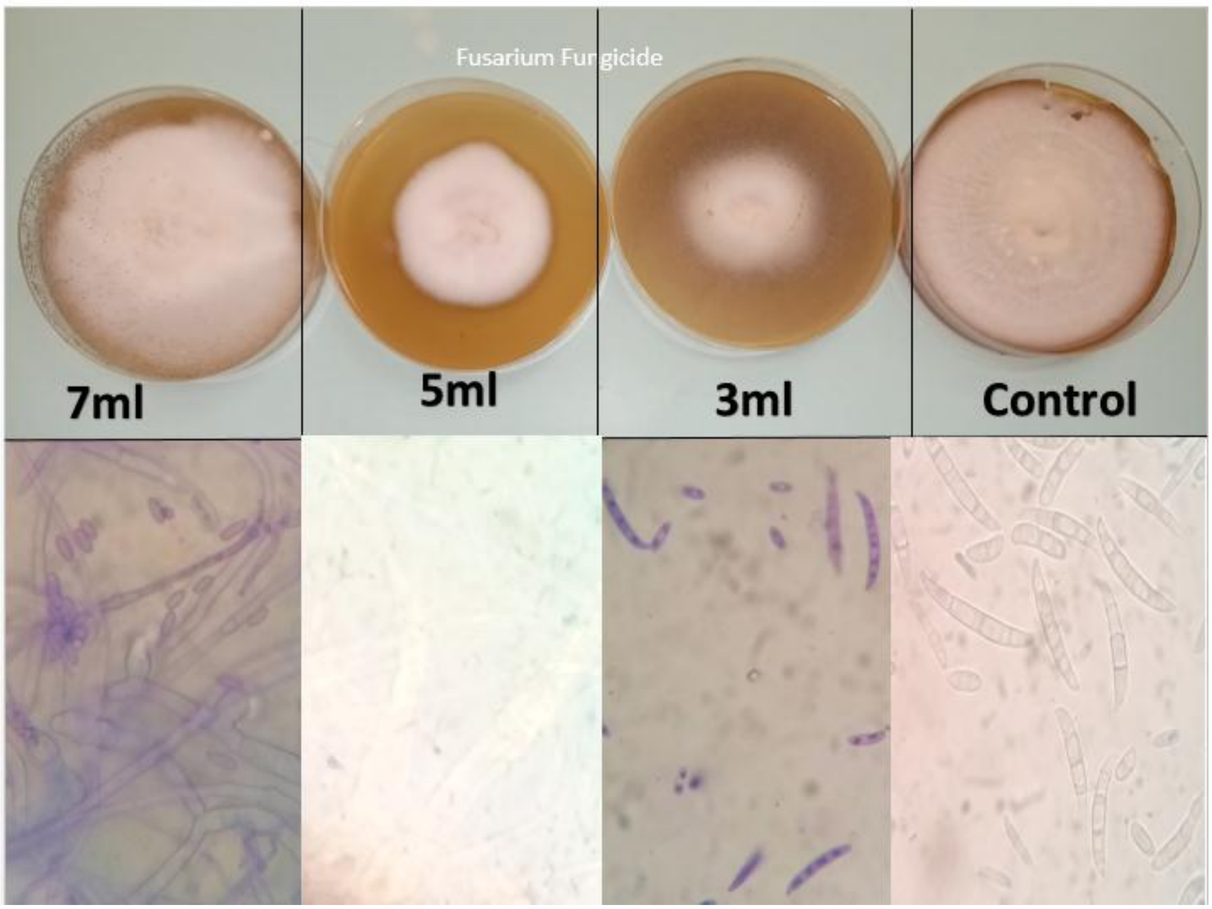


Plate 4.8: *Fusarium* sp growing on media amended with different concentrations of the fungicide. Dose dependent control of the fungi is clearly evident.

It was the only fungal species for which no therapy ever completely inhibited the growth of a fungal colony. With the exception of the early growth inhibition, the rate of growth matched the negative control throughout the whole research (fig. 4.21).

Fusarium sp grew the least quickly compared to the other fungal species utilized in this investigation, growing to a diameter of around 80 (79.67) mm in 7 days. The maximum dosage of fungicide (56%) and garlic (48%) provided the strongest suppression. It should be emphasized that these percentages reflected the lowest inhibition in the other fungal species. With the exception of the commercial fungicide and garlic, few plant extracts demonstrated an apparent concentration-dependent reduction of the colonies (Plate 4.9).

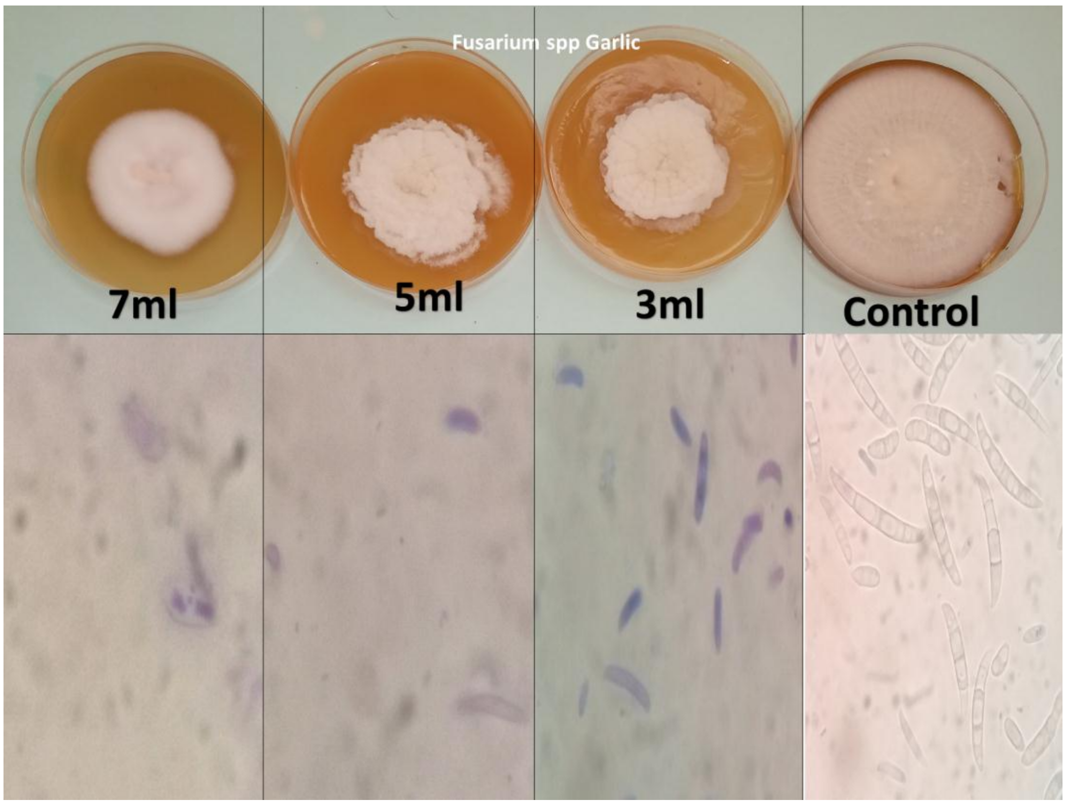


Plate 4.9: *Fusarium* spcolonies growing in media amended with different doses of garlic extracts.

CHAPTER FIVE

DISCUSSION

5.1 The Liberian Seed Industry and Demographic characterization of Rice Farmers

The key informants agreed on the existence of the required policies but decry their implementation. For a country that is still recovering from the scourge of 14-year civil unrest, with multiple development priorities, funding of rice seed industry ranks at the bottom (McNamara and Moore, 2017). For effective running of the policies, there is need for adequate structures including skilled technicians. This cannot be achieved due to the current inadequate budgetary support from the national government. Expert FGDs were also conducted among six organizations which included; Bangladesh Rehabilitation Assistance Committee (BRAC), County Agriculture Coordinators (CAC), College of Agriculture and Forestry (CAF), Center Agricultural Research Institute (CARI), Liberia Agriculture Commodity Regulatory Authority (LACRA), and Ministry of Agriculture (MOA). Organization like BRAC have their own seed testing research and training centre. Experts from this organization acknowledged the limited capacity by the government of Liberia to independently carry out seed business. Due to the lack of seed specialists in all the organizations, the expert discussion had fewer participation than the farmer FGDs and did not follow the gender standards. However, the debate procedure adhered to a similar format to farmers' FGDs.

The discussions were focused on five concerns, including the nation's output of rice, Rice seed systems' characteristics, Research institutes' involvement in the creation of seed systems, Participants examine the Liberian rice system and the formal method for quality control of seeds provided. Farmers heavily rely on the informal seed system. This was also acknowledged by the head of seed unit at CARI. Indeed, the informal seed unit is also an important source of seeds to many farmers in Africa (Bèye & Wopereis 2014). However, for effectiveness of the system there has to be some form of regulation so as to minimize cases such as occurrence of pests and diseases. As pointed out by the lead expert at CARI, such regulation frameworks are lacking in Liberia but are present in the neighboring countries. For this reason therefore, the haphazard way by which farmers acquire their seeds results in poor yields even when the climatic conditions are suitable (Kontgis *et al*., 2019). For the viability of the informal seed system some regulation ought to be put in place (Herpers *et al*., 2017). Nigerian farmers produce greater rice quantities than Liberia despite the climate and soils there being less favourable (FAOSTAT 2020). Acquisition of proper seeds is among the factors contributing to this discrepancy.

Among the respondents there was slightly higher number of women engaged in rice farming. It is however only Nimba County where majority of the women originate. Worldwide, it is said that women produce about 60-80% of the important food stuff and yet still 70% are languishing in abject poverty (Ahn *et al.*, 2020). This could be particularly so because men are mainly engaged in cash crop farming which have more financial returns. This is mainly so true for Nimba where men are primarily engaged in tree products like rubber harvesting, cocoa farming and mining activities which explains why majority of the farmers in this particular county are women (Enaruvbe *et al.*, 2019). The World Bank estimates that 61% of males are engaged in cash and tree crops compared to women who make up a paltry 39% (World Bank, 2010). Even though there appears to be gender parity in rice farming among the sampled counties, women are weighed down by more challenges than men.

From the survey conducted in this study, large proportion of the farmers lack basic education, of which women form the majority. This is in conformity with the study by (Witinok-Huber *et al.*, 2021), where they observed that women were more illiterate than men. Benefits likely to be accrued due to this apparent achievements of gender parity may be dented by the poor academic status of women. Saysay *et al.* (2018), found that Liberian rice farmers with more years of schooling are more efficient in rice farming due to their ability to apply better farming technologies. Therefore, the deprivation of education to women renders them technically inefficient and therefore remain in poverty. In this study, there were very few women with a tertiary level of education. In this regard government policies should be inclined at empowering women farmers by providing agricultural extension services.

But with a history of conflict, there are some other unique constraints that face women in Liberia. In Nimba for example, women appear to be a soft target for trespassers and many of them have reported that their crops are being stolen while in the farm (Ahn *et al.*, 2020). It is no wonder that in counties near the capital Monrovia, (Montserrado and Bong) women seem to shun agricultural activities as reflected by their low numbers in the survey. This hints to urban migration by women and contrasts heavily with the arguments by Witinok-Huber *et al.* (2021), that women are more vulnerable to rural isolation. However, the danger of rural isolation could be true for Nimba County where youthful males engage in a lot of mining activities.

Majority of the farmers are aged between 30-60 years. Several factors however come into play leading to the variation in the age groups involved in agricultural activities. The youthful population (15-25 years) is attracted to non-farm economic activities like motorcycle, taxi business (Peters *et al.*, 2018). This is particularly the case for Montserrado County which housed the country's capital. In Nimba, the illegal gold mining is prevalent and this can be touted as the reason in the shift of age groups engaged in agricultural activities in this region (Enaruvbe *et al.*, 2019). It is only in Nimba where population aged 45-60 years form the major farm workforce. Lofa being a major agricultural county, most of the farmers belong to 30-60 years age range.

Youths could also be facing more constraints when it comes to land access. Many young people do not have access to farms or have significant levels of land tenure uncertainty (Louis *et al.*, 2020). Females and 'stranger youth' suffer significantly more hurdles to land access than male youths' locals to a particular place. Most of them were mobilized into war during the period of conflict and therefore do not have adequate skills to pursue farming activities.

Old age among the farmers could be an indicator of experience and according to findings by (Saysay *et al.*, 2018), it implies efficient farming. However, this study showed that among the senior population, adoption of improved farming technologies like fertilizer application, was more unlikely compared to younger farmer's despite being more educated. Perhaps simply put, old habits die hard. Liberian farmers mainly practiced shifting cultivation, a traditional practice to maintain nutrient balance, to contain nutrients in the soil (Prince *et al.*, 2019). But as this practice is becoming more and more unsustainable, farmers, both old and young ought to adopt better ways of plant nutrition.

In all the counties there were very few farmers who were older than 65 years. This was also reflected by (Tokpah *et al.*, 2019), in their study of tomato bacterial wilt disease. Dwindling physical energy can be used to explain this.

Literacy levels appears to be low in Liberia. Women are less literate compared to men and this conforms to several other studies. While assessing the effect of literacy on health (Murendo and Murenje, 2018), found that literacy levels among the rural men to be 62% while that of their female counterparts is 32%. As earlier argued, this has great implications on the efficiency of agricultural activities as women are greatly involved. The more educated group, in terms of having a higher academic qualification, is found between the ages 30-60 years old. This is understandable since higher academic training is obtained during this period. The ages 15-25 years old have the lowest number of individuals lacking a basic education. This is a reflection of the impact of the civil war (Liu, 2022). This hints to a steadily growing school enrollment. None of the individuals in the 15–25-year-old bracket had a tertiary level of education which is understandable since the commencement of that level of education normally occurs beyond 25 years of age.

Saysay *et al.* (2018), argue that the longer the number of years of schooling the efficient a farmer becomes especially in the uptake of better farming technologies. This study confirmed that but also shed light on some other determinants. Looking at fertilizer use for example, only 5 (2.2%) of those who have not received any basic education (238) reported that they use it. This overwhelmingly low numbers of farmers in this group using fertilizer can only be attributed to their lack of basic education. Education in rural regions is widely acknowledged as a critical component of enhanced agricultural output, particularly when it comes to the adoption of new methods, inputs, and technologies (O'Donoghue and Heanue, 2018). Fertilizer use was more widespread among the educated but in contrast to (Saysay *et al.*, 2018), its use did not increase with academic rank. Of all the farmers with technical/vocational academic qualification, only 9.5% of those applied fertilizer to their crops. Compare that with those farmers with junior high school qualification where about 27.8% use fertilizer. Therefore, adoption of improved farming technologies not only depends on the level of education but also age. By saying this, it is assumed that the majority of the people with junior high school qualification are young.

Younger people seem to be more receptive of newer technologies. As shown earlier, shift cultivation was the main mode of maintenance of soil nutrients in Liberia for a long time. Perhaps therefore, this kind of farming is highly entrenched among the older generation that it is difficult to let go. Some studies put to question the quality of Liberia's higher education and its impacts on the recipients (Moses and Jackollie, 2020). Perhaps this is reflected by the number of educated people who still use traditional technologies in agriculture. Liberia still has among the lowest Human Development Index (HDI) worldwide (Moses and Jackollie, 2020). This would impact negatively on agricultural activities through inadequate extension officers and therefore, farmers continue to stick to their old ways of farming.

5.2 Pre and Post-harvesting Practices of Rice Farmers in Liberia

Many farmers obtained their rice seeds form friends and also their own saved seeds. This appears to be common practice as Topkah *et al*., (2018), found that 51% of tomato farmers obtained their seeds from other farmers. The same was also reported in Tanzania where farmers mainly used their own saved seeds for rice production (Kwaloe *et al.*, 2018). Another important source was the market while very few sourced their seeds from an agro-shop.

Though fewer farmers reported not having any knowledge on the benefits of using certified seeds, most of them admitted that they have seen differences in yields between their own seeds and certified seeds. Lack of ready market and inadequate infrastructure have been widely mentioned as the reasons barring many farmers from adopting the use of certified seeds (Miklyaev *et al.*, 2017). Though the technologies are highly efficient, the limited market access for the products makes their adoption not financially viable. The alternative seed sources however, presents greater danger to the farmers as sharing of seeds between farmers fuels the spread of seed-borne diseases.

In the study a good number (about 50%) of the farmers reported having experienced fungal infections in their seed rice. Kwaloe *et al.* (2018) reported disease incidence in the rice seeds stored by farmers in Morogoro region of Tanzania to be as high as 64.5%. Such facts underscore the dangers faced by farmers while sharing rice seeds as this is a fertile ground for disease epidemics in rice fields.

Even though many farmers use more than one type of seeds, majority rely on traditional seed varieties. This is also true for other developing countries like Indonesia (Jayatissa *et al.*, 2019). The traditional varieties however are low yielding and takes long to mature.

Just as explained in the uptake of other technologies, cost is the major barrier that prevents most farmers from using better rice varieties. Ndebeh *et al.* (2018), recommend varieties NERICA 8, ARICA 5, and NERICA 4 to smallholder farmers in the upper highlands forest zone of Liberia due to their high yielding properties.

Broadcasting and scratching are the most popular method of rice propagation. This method is compatible with manual techniques which more farmers have been shown to employ. Burning of straws as a way of cleaning the fields is another way that is synonymous with manual farming. Little is known on the effect of such burning on the various biotic stresses like disease spread (Nguyen and Nguyen, 2019). Farmers consider straw burning as more convenient since it does not involve a lot of labour (Dobermann and Fairhurst, 2002). However, due to the environmental damaging effects, burning of straws have been banned in some countries (Kumar *et al.*, 2019; Nguyen and Nguyen, 2019). The overwhelming number of farmers who burn straws could have a debilitating effect on the areas around rice farming regions.

Majority of the farmers do not apply any form of mechanization. The heavy reliance on rain also attests to this. Poor financial status of the farmers is a reason for this. Other major factors include poor infrastructure especially road networks (Miklyaev *et al.*, 2017). In many sub-Saharan countries, most farmers would for example hire a tractor when they do not have one of their own. Poor primary and secondary road network in Liberia makes the acquisition of such services difficult. Further, the inadequate electricity supply as portrayed by (Abarcar *et al.*, 2020) would hamper postharvest processing like rice milling.

The low mechanization status in Liberia rice farming is further evidenced by the number of the farmers using manual methods of harvesting. This reflects the state of affairs in many developing countries where harvesting is manual and which is slow and highly labor intensive (Kumar and Kalita, 2017). Rice farming regions of Liberia are known to use *Kuu* labourers during the planting and harvesting seasons (De la Fuente *et al.*, 2020). In such cases, during the peak harvesting season acute shortage of the laborers might result in delays in harvesting occasioning large losses (Grover & Singh, 2013). In India for example, postharvest loss of rice due to delayed harvesting stood at 1.92% (Elumalai *et al.*, 2015). With the majority of farmers in Liberia using manual methods of rice farming, losses here can be predicted to be considerably high.

Large proportion of the farmers store their rice seeds in the kitchen attic. The kitchen attic is a storage place constructed above the kitchen fire. It is widely known that in the developing countries about 50-60 % of the grains are kept in traditional stores (Kumar & Kalita, 2017). Constant heating from the fire would reduce the moisture content of the stored grains and thus makes it inhospitable for most fungal contaminants. Further the conditions in the attic have been found not to affect (more importantly it does not reduce) the longevity of viability of the rice seeds (Wang *et al.*, 2018). However, seed borne infections may not be affected much by the storage at the kitchen attic gauging from the number of farmers who attest to experiencing fungal infections in their farms despite majority of the keeping the seeds in the kitchen attic.

Proper assessment ought to be done to ascertain the effectiveness of kitchen attic storage in minimizing seed-borne infections. An obvious challenge with the storage of seeds in the kitchen attic is the limited space since, farmers also store other types of seeds in the attic (Tokpah *et al.*, 2019). The house attic which is also another storage place may not guarantee shielding of the grains from damage by fungi or pests. Most of the farmers store the seeds for a period of one year. This is so because of the seasonal use of the seeds from one year to another.

5.3 Seed Quality Analysis of Rice seeds sourced from Liberia

NERICA L-19 which is a lowland rice variety had the best germination rate. In a previous study, this variety was the most preferred rice among 75 other low-land varieties by farmers in Liberia (Adetumbi *et al.*, 2016). It is therefore not surprising that it has the best germination rate which is definitely a factor desirable to farmers. It has also very desirable qualities too. It can adapt to all levels of stress and hence cultivated both in upland and swamps (Adeyemi *et al.*, 2017). Further, they take a shorter time to mature compared to the other rice varieties.

Yarka and Gizzie on the other hand, are indigenous varieties with no improvement (Lamberti *et al.*, 1991). Hence, in the current experiments, it can be seen that Gizzie had the poorest germination rate in all but one county. Generally, this is an unproductive rice variety. The downside of lack of genetic improvement in Yarka variety can also be seen in its weight. It had the lowest weight recorded for rice in all the counties. The seed itself is flat, thin with small weight (Abdulwahab *et al.*, 2019). Lower weight would therefore translate to lower yields and smaller profit margins to the farmers growing this type of seeds. The scatter plots further provide a clearer picture of these facts. In terms of a thousand seed weight, Yarka is located furthest from these environments meaning that it had very low performance compared to the other varieties. The same can be observed for Gizzie. Gizzie variety grown in Montserrado had the poorest vigour.

LAC23- Red, named for its colour, is also an indigenous rice variety but improved. It can be grown both as a low land and a highland rice variety (Tokpah *et al.*, 2019). But from the results here, it can be inferred that it is favoured more by the lowland because it performance in lowland region is better than in the uplands. LAC23-Red obtained from Nimba for example, had the poorest germination rate. Nimba is an upland area. This variety was improved at the Center for Agricultural Research Institute (CARI) located in Bong County (Prince *et al*., 2019). This explains the observations that most of the optimum performances of this variety is found in Bong County. The highest vigour index recorded was by the LAC23-Red variety from Bong County.

According to Mannaa *et al*. (2017), a variety of fungal species can contaminate stored grains, including rice. The two taxa of fungus that have a higher propensity to infect the stored grains are Aspergillus spp. and *Penicillium sp*p. (Bertuzzi *et al*., 2019; Gonçalves *et al*., 2019). The current investigation supports this finding. From all of the rice samples from all of the Counties, black colonies of *A. niger*, green colonies of *A. flavus*, and *Penicillium sp*p. were isolated. Additionally, the presence of these fungi in the grains is encouraged by an inappropriate drying environment, which is mostly brought on by warm, humid subtropical regions (Bertuzzi *et al.*, 2019; Lv *et al.*, 2019). Given that Liberia as a whole is close to the coast and has a tropical environment, the demand for contamination of grains is undoubtedly significant (Nzabarinda *et al*., 2021). Therefore, it is not unexpected that these two genera of fungus are found in all samples of rice. In addition to Aspergillus and *Penicillium sp*ecies, *Fusarium sp*ecies was also discovered to be widespread. This three-gene abundance of fungus has also been confirmed in a different research by Shanakht *et al*. (2014). The samples of rice utilized in their investigation were from Pakistan. Pakistan also produces a significant amount of rice and has the same weather characteristics as Liberia. These two elements may play a significant role in explaining this seeming homogeneity.

Majority of the farmers who responded admitted to keeping their rice grains in the kitchen attic, where constant heating from the fire below renders the conditions utterly inhospitable to fungal growth. The rampant presence of the prolific contaminants is a pointer to poor drying conditions prior to storage. Upon storage, poorly dried rice grains become substrates for the contaminating fungi (Iqbal *et al.*, 2014). Further, under such conditions, the more water stress resistant *Aspergillus* spp will dominate as proven here.

Lofa County is a lowland with heavy rainfall where rice is grown in swamp. The region is therefore characterized with very high humidity and warmth, which is a very ideal condition for the propagation of fungal diseases (Kakoti *et al.*, 2020). This therefore explains the apparent flourishing of fungal diseases in Lofa County as this was highest pathogen diversity was recorded here. Further, Lofa is the food basket of the country since larger tracts of land for rice farming is found here. Greater farming of a particular crop imposes a greater selection pressure for the pathogens and hence more pathogens in Lofa County. The opposite can be true for Montserrado County. It is characterized by smaller rice fields and it appears to the smallest diversity of the pathogens.

5.3.1 Fungal Pathogens of Rice seed collected from Liberia

A. niger was the most prevalent isolate overall, even among the top three. This fungus has the potential to infect grains at several processing phases, including pre-harvesting, drying, storage, and transportation (Silva *et al*., 2020). Therefore, some or all of the phases can be used to explain the fungus' abundance. Pre-harvest contamination is mostly caused by the environment and can be exacerbated by weather conditions. Any actions intended to lessen the presence of *A. niger* in grains should be addressed at these phases of handling since the other stages of contamination have a chance of cross-contamination as a result of improper handling. *Aspergillus spp*. grows while drying since it is not a field fungus (Tournas and Niazi, 2018). Additionally, compared to other possible contaminants, this fungus is more tolerant to dry environments.

The fact that *Penicillium* spp is the second most abundant genera contaminating rice, has been mentioned in many studies (Manaa *et al*., 2017). This was also true for this study. As also echoed by Pitt (1988), *Penicillium* spp isolated from rice samples from all the regions in their study had closed texture and greenish blue colonies. It is difficult to separate *Penicillium* into various species based solely on physical characteristics because of their morphological similarity (Mannaa and Kim, 2016; Yin *et al*., 2017). In addition, several species exhibit intraspecific differences (Samson *et al*., 2004). Because this is a natural property of the fungus, the variance of *Penicillium sp*p. reported during the current investigation may thus be less influenced by different locales. However, environmental and physiological factors also have an impact on *Penicillium sp*ecies variation (La Guerche *et al.*, 2004). It is extremely improbable that environmental and physiological factors are the causes of the observed differences as all of the isolates were cultivated in the same growth medium under the same circumstances. Therefore, in this instance, the fungus' inherent variation potential only accounts for variations in the traits that were evaluated for homogeneity.

Another fungal isolate that was relatively prominent was *Fusarium* spp. The fungus was present in all the counties except for Montserrado. Fusarium did not appear to be as prevalent as *Aspergillus spp*., which contradicts with numerous research conducted in temperate areas. In the majority of Italian rice samples, *Fusarium* was found to outweigh *Aspergillus* (Bertuzzi *et al*., 2019). In Brazil, the same thing happened (Katsurayama *et al*., 2020). As was previously noted, this is a result of the warm, muggy weather seen in tropical nations like Liberia. Therefore, it is not unexpected that there were no *Fusarium spp*. identified from the rice samples gathered in Montserrado, the coastal county. *Aspergillus spp*. must thrive in these circumstances to the exclusion of other contaminants like *Fusarium spp*. Even though this fungus has been identified in the field, drying has been demonstrated to significantly lower its occurrence (Phan *et al*., 2021). As many farmers said in the study, drying in the sun followed by storage in the kitchen attic will undoubtedly further limit the frequency.

The isolated *Fusarium spp*. from each of the participating counties differed noticeably from one another in terms of spore form, size, and sporulation. This type of diversity has also been seen in other places (Dong *et al*., 2020). The discrepancies in that instance appeared to be caused by various agro-climatic zones. Based on the morphology of the spores, Lofa had two varieties of the fungus, whereas Bong and Nimba only had one. Rice is a main cuisine in Liberia, which is known as Lofa. Massive acreages dedicated to one type of crop would put more diseases under selection pressure. The apparent variety of *Fusarium* isolated from this county may be explained by this. *Fusarium spp*. have also been observed to damage rice types more easily, including jasmne and DT8 (Phan *et al*., 2020). Liberia cultivates a wide variety of rice. There must be a bigger variety of rice kinds in a wealthy rice-growing area like Lofa. The growth of *Fusarium spp*. in this area is therefore fueled by the susceptible varieties, resulting in the existence of many morphotypes of the fungus.

The *Pyricularia oryzae* (also known as *Magnaporthe oryzae*) is a different fungus pathogen that has only been identified from Lofa and Nimba. Every part of the world where rice is grown is affected by this extremely destructive fungus, which causes rice blast disease (Aruna *et al*., 2016). The disease manifests itself in the seed, panicles, necks, collars, leaves, and nodes during the whole rice development cycle (Kim *et al*., 2018). Blast lesions on leaves are the main signs, and it is simple to isolate the disease from these areas (Rajashekara *et al*., 2017). Therefore, it seems sense that the pathogen output would be minimal when fungal contaminants were isolated from preserved rice grains, as is the case with the current investigation. The two main rice-growing counties in Liberia are Lofa and Nimba, where this fungus was first discovered. So it seems to reason that more germs would be found in such an area. Despite *P. oryzae* being referred to as the main danger to rice, there may be other explanations for the disease's seeming rarity. cultivation of rice types that are sensitive to the illness is one cause of its development. *Oryza sativa L* (Asian) and *O. glaberrima* (African) are the two rice species that are used in cultivation worldwide (Kawasaki-Tanaka *et al*., 2016). In West Africa, *Oryza glaberrima* is widely grown because it is resistant to the rice blast disease.

The prevalence of rice blast disease is exacerbated by the overuse of nitrogen-based fertilizers (Barnwal *et al*., 2012). Nearly all of the farmers questioned for the present study's survey reported not using any fertilizer at all in their paddies. Therefore, it is anticipated that denying this essential component will prevent rice blast disease from spreading in this area. In fact, it has been demonstrated that using fewer nitrogen-based fertilizers would result in fewer instances of rice leaf blast (Lee *et al*., 2010). According to research by Agbowuro *et al*. (2020), burning straws is a cultural practice that helps to cut down on the amount of disease inoculum spread to the following season. According to the report, this is a common practice among the farmers in this area. The apparent low prevalence of the pathogen in seeds is caused by these three primary factors.

5.4 Efficacy of Botanical Extracts

The most effective plant biofungicide in the current investigation was unquestionably the common bean ash utilized as powder. According to Natabirwa *et al*. (2018), research has indicated that ordinary beans have antibacterial and antiviral properties. Soda, which contains the antifungal peptide vulgarinin from common beans, has broad-spectrum antifungal properties (Wong and Ng, 2005). *Fusarium oxysporum, Botrytis cinerea*, and *Mycosphaerella arachidicola* were three phto-pathogenic fungi that were negatively impacted by its antifungal effect. Therefore, this quality gives it the capacity to manage the *Fusarium spp*. in the present investigation. Reduced mycelial development is a hallmark of the antifungal action of legume antifungal proteins against these phytopathogens (Ng & Ye, 2003). The efficiency of this peptide against *Fusarium spp*. in particular, as well as its antifungal activity as seen here, may indicate its potency. It must have been these two active chemicals that gave it the wide antifungal action seen here.

A defensin known as PvD1 that was discovered from common bean is another antifungal substance (Games *et al*., 2008). Additionally, it was suppressive to several *Rhizoctonia solani* and *Fusarium sp*ecies as well as other phyto-pathogenic fungi. Another substance from common beans with a defensin-like sequence was also discovered, and it suppressed the growth of *M. arachidicola* and *F. oxysporum* (Wu *et al*., 2011). One of the tested mechanisms of action for several antifungal proteins is cell-free translation inhibition (Ng & Ye, 2003). Translation of the mRNA would be hindered, which would affect the production of proteins and growth. Since the second mechanism of antimicrobial action of protein-based drugs is tightly controlled within the cell, it's possible that a living cell is necessary to see its activity. As a result, using bean ash does not include using these substances for commercial purposes.

Similar to many other plants, Capsicum spp. contains bioactive phytochemicals with both biological and antibacterial action. According to Fieira *et al*. (2013), capsaicin extract has a preventative effect against *Penicillium expansum* in fruits in vivo. In the first two weeks of testing, it may slow the fungus' development (Daz Dellavalle *et al*., 2011). Accordingly, on the *Penicillium* isolates discovered here, chilli had the highest antifungal impact. By preventing spore germination in vitro, extracts from C. chinense, C. annuum, and *C. fructescens* restrict the development of *Botrytis cinerea* (Wilson *et al*., 2008). It has been demonstrated that the triterpene saponin CAY-1, which was isolated from cayenne pepper, possesses antifungal properties against *Aspergillus fumigatus* (Abad *et al.*, 2006). These demonstrate the extracts from *Capsicum spp.'*s ability for both treatment and prevention. However, the majority of the pathogens in the current investigation did not respond well to the chilli in the study.

Additionally, garlic was found to be quite effective against all of the phytopathogens in this investigation. Numerous research support the conclusions given here. According to Hossen *et al*. (2017), garlic extracts not only prevented chilli seeds from being infected by fungi but also enhanced the germination of the seeds. *Aspergillus spp*. and *Fusarium spp*. were also included in their study as seed-infecting fungus since these phytopathogens are virtually always present in seeds. Its capacity to have advantageous effects *in vivo* may be inferred from the fact that it was able to enhance the germination of the chilli seeds.

The antibacterial properties of garlic are mostly attributed to its essential oils (Hosseini *et al*., 2020). When the cloves are damaged, garlic essential oils are created, which give crushed garlic its very strong aroma. The plant uses it as part of its own insect defense system. Its primary method of action is to breach cellular membranes and compromise their integrity (Mugao *et al*., 2020). This interferes with the cell's ability to operate normally. This could apply to the subject under consideration. The strong essential oils were created by first crushing the garlic cloves employed in the current investigation. Inhibition of the fungal pytopathogens serves as proof of the oils' effectiveness.

Neem extracts entirely prevented *A. flavus* from growing, however they were the least effective against Penicillium and *Fusarium sp*ecies. This in no way suggests that it is a subpar biofungicide; it was just not as effective as the other biofungicides employed here. Recently, delayed release fertilizer has been produced using this plant, which has several uses in animal health (Linquist *et al*., 2013). By preventing the soil microorganisms that hasten the fertilizer's leaching, the nitrogen fertilizer's delayed release is made possible. These inhibiting properties of the neem plant are also being used in research projects examining the plant's potential as a biofungicide. It has been demonstrated to operate just as well against foliar plant infections as a synthetic fungicide and a bio-fungicide based on Trichoderma (Mahmud and Hossain, 2017). However, it was also shown to be less successful in this experiment, particularly in terms of how long the effects lasted on the plant.

Neem, which functions as a fungicide, prevents the development of fungus spores (Acharya *et al*., 2017). If this is the primary route of action, then the results of the current study are not unexpected. The major mechanism of proliferation was mycelial growth rather than spore germination, and the inoculum was invariably a mycelial plug. Similar to the other botanical extracts, there were moderate but noticeable disruptions in spore production. Generally speaking, the antifungal effects on the leaves don't endure very long (Mahmud and Hossain, 2017). More research is required to determine whether it lasts longer on seeds. However, its roles in extending the life of nitrogen fertilizer in delayed release fertilizer technology can be deduced as evidence for its durability in soil and potential benefit to seedlings.

Ginger did not exhibit strong antifungal action against most fungus, notably *Aspergillus* spp. and *Penicillium* sp., when compared to the other herbal remedies. In comparison, it was effective against *Fusarium* sp. This extract and the other botanicals interact in a completely different way. Because *Fusarium* spp., the extracts that were particularly effective against the aforementioned diseases, were quite weak. According to research by Polo *et al*. (2002), ginger extracts totally prevent the development of *Fusarium* *oxysporum*. The *Fusarium spp*. that are employed here are closely linked to this fungus. But the extract concentration employed here was greater than the one used elsewhere. Comparatively to *Aspergillus spp.* and *Penicillium sp*., *Fusarium spp*. can also be a foliar pathogen. In order to compliment the majority of the other extracts utilized here, ginger extracts can be employed.

In addition, ginger extracts were similarly effective in suppressing *Colletotrichum gloeosporioides* of dragon fruit as synthetic fungicides (Bordoh *et al*., 2020). However, the extracts' concentration was higher than the ones employed here. More so than *Aspergillus* and *Penicillium*, *Fusarium* species are closely related to this fungus. The deformation of the hyphae and suppression of spore production are the primary mechanisms behind the antifungal effect of ginger (El Khetabi *et al.*, 2022). In the current investigation, changes in mycelial development were unquestionably seen. But because the *Fusarium spp*. utilized in the current study produced few spores, it was challenging to determine how well any of the extracts affected sporulation. The pace of growth was one natural distinction between *Fusarium spp*. and the other three fungal isolates. The fungi with the slowest growth rates, such as *Fusarium sp*., may be more vulnerable to ginger extracts.

CHAPTER SIX

CONCLUSIONS, RECOMMENDATIONS AND WAY FORWARD

6.1 Conclusions

1. Liberia's seed industry is dominated by the informal seed sector and a very poor formal seed system was fund during this study.

2. Both genders equally participate in rice farming although the ratios might differ in different counties and the majority of the rice farmers have primary education as their highest academic level.

3. Key informants are well aware of the government seed policies and regulation but an overwhelming majority of farmers are unaware of such policies. A large proportion of the rice farmers use locally available rice varieties from the informal seed system whereas very few use improved seed varieties from the formal seed systems.

4. Lofa County is the leading rice producer followed by Nimba, Bong and finally Montserrado. All of the counties experienced incidences of seed borne fungal pathogens with incidence occurring in Lofa followed by Nimba then Bong and least Montserrado.

5. The improved rice variety (NERICA L-19) had the best physiological qualities as compared to indigenous varieties of rice (Yarka, Gizze, LAC23-RED, and LAC23-White). NERICA L-19 had best germination percentage, vigour, and highest weight.

6. Bean ash was the best performing botanical powder in all the pathogens (*A. flavus, A. niger,* and *Penicillium* sp) except *Fusarium* sp. *A. flavus* was the most susceptible fungus to all of the botanicals and the synthetic fungicide. It was also the fastest growing fungus. On the other hand, *Fusarium* sp was the most resistant pathogen against all the botanicals

treatments and the synthetic fungicide used in the study. It was also the slowest growing pathogens *in vitro*.

6.2 Recommendations

1. More resources should be directed to effect the functioning of the formal seed system and also organize the informal seed sector.

2. Farmer education on good agricultural practices should be improved to ensure that bulk of the farmers are equipped with general agricultural knowledge. Farmers need to be sensitized on the government policies affecting rice seed farming so as to make informed decisions in their farming practices. The government should ensure that the certified rice seeds are easily accessible to the rice farmers.

3. Farmers should be encouraged to use NERICA L-19 throughout the country and with other improved short duration and disease resistant rice varieties for both upland and lowland.

4. There should be deep analysis (active ingredients) on common bean ash, formulation of locally available, sustainable and environmentally friendly botanical extracts to manage fungal diseases of rice seeds.

6.3 Way forward

There should be public private partnership in the seed industry so as to develop the seed industry in Liberia.

There should be further studies conducted on other rice varieties on diseases (viruses, bacteria) throughout the country (Liberia).

Further studies should be done to assess the *in vivo* effectiveness of the botanicals tested here.

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APPENDICES

Appendix I: Focus Group Discussion Guide

Greeting's ladies and gentlemen,

Welcome to the focus group discussions (FGDS) regarding different rice seed systems and consequential rice production in this county. I am Ousman Sarlia Dorley, a Ph. D. student at the University of Eldoret (Kenya) and my colleague assisting me with video recording is Mr. Amadu Dorley. We are glad to welcome you to these discussions aimed at providing the information on the state of rice production in Liberia with focus on the seed systems, challenges and local made solutions by farmers and other stakeholders. Similar discussions have/are planned to be conducted in other counties.

You were selected to participate in these discussions because we understand and appreciate the roles and responsibilities you undertake to make crop production by our farmers efficient and sustainable. Your experience in dealing with farmers is of paramount importance to Data collected from this FGDs will be used to inform the relevant stakeholders on the state of rice production and seed systems that exists in the value chain. The data will also be used to contribute towards achievement of the Ph. D. course requirement in seed science and technology

Before we start the discussions let me highlight some of the guidelines that will help our discussions to be successful;

1.0 All participants are encouraged to air out their opinions freely without fear of discrimination

2.0 We appreciate that every opinion matters and none is considered better than the other or wrong. We believe the more we differ the better our understanding is in regard to the subject matter

3.0 We'll use the first name in this discussion and don't feel offended when I miss out on yours

4.0 We will also be video recording every person's contribution; however, this should not compromise your opinions. The video will be handled with utmost confidentiality and will only be used for information analysis towards the said objectives.

5.0 I request that all the participants switch off their mobile phone devices or put them on the silent mode. In case of an important call, kindly walk out silently and after you have responded rejoin the meeting quickly

6.0 I as the moderator, my role will be to guide the discussions. Feel free to discuss the matter within yourselves if need arises.

Questions:

1.0 What is your take on the current rice production trend?

2.0 Which County has better rice production in the country?

3.0 When you compare our national general rice production with other neighbor countries like Nigeria, how can you rate our production?

4.0 Which range of production do you think is optimal given our country soil, climatic condition, agronomic practices and germplasm?

5.0 What are the common rice varieties grown in this county?

6.0 What are the challenges facing our rice production sector?

Seed system questions:

1.0 What channels farmers use in sourcing their planting materials?

2.0 How developed is the channels?

3.0 Can a farmer access certified rice seeds in the county?

4.0 Does the use of locally sourced seeds contribute to the poor yield?

5.0 What other challenges are associated with the use of locally sourced rice seeds?

6.0 Which type of diseases are common in rice grains and on field crops?

Solutions:

1.0 What is the government doing to provide a solution?

2.0 What are farmers doing to ensure the planting materials are of good quality?

3.0 What measures is the government and other agriculture stakeholders putting in place to manage rice diseases?

4.0 What are your suggestions to the problems in the rice production sector?

Conclusion:

I wish to thank you all from my heart for your substantial participation and every opinion registered will be considered in providing information to stakeholders and contribution towards my Ph. D. requirement.

Appendix II: Survey on rice seed systems in Liberia

Consent

Greetings, I 'am [name of enumerator] and am grateful for your warm welcoming in this home. Am here to collect information regarding your rice seed management and storage practice and general perception on the rice production, challenges and local solutions. The collected data will be treated with utmost confidentiality and will only be used to mainstream rice production across the country, help advocate for adoption of local solutions in improving rice production and informing development or amendment of associated policies. The data will be also utilized as a partial fulfillment of Ph. D. research which is grounded in rice seed. Your participation is voluntary and you are free to decline or stop answering the questions at any time of the interview process. Am here on behalf of a Ph. D. student undertaking his studies in University of Eldoret (Kenya) East Africa. The research has collaboration with the University of Liberia and RUFORUM, a non-governmental organization support research and learning in developing nations. The survey will be conducted in four counties; Lofa, Bong, Montserrado and Nimba. As stated above your participation is voluntary and there will be no direct benefit/s by participating and responding to questions herein. The survey also assumes that (1) You (Respondent) is not under influence of any substance, person/s or brain related illness that can interfere with the authenticity of the information you are expected to provide. (2) The responses that you will provide will be consciously made and accurate. Where you find difficult answering a question kindly request for further explanations. I hereby request you to participate in the survey.

WELCOME

Agreed to participate………... (Yes / No). Respondent Sign……………...

SECTION ONE: Identification of the farmers or respondents

1. Town/village: ____

2. Name of District: ____

3. Name of county: ____

4. Longitude…………………………. Latitude………………………….

5. Altitude………………………………………………………………

SECTION TWO: Social demographic characteristics of the farmers' or respondents

Please provide responses which best suit or describe your situation. Tick [ ]

6. Sex: Male [ ] Female [ ]

7. Age: A. 15-25 [ ] B. 30-40 [ ] C. 45-60 [ ] D. 65- 75 [ ] E. 75+ [ ]

8. Household number……………………………………

9. What is your level of education?

A. No former school [ ] B. Primary [ ] C. JHS. [ ] D. SHS [ ] E. TECH/VOC. [ ] E. Tertiary [ ]

10. What is your main source of household income……………………………………………

11. Do you have specialization in Agriculture related course? (Must have a certificate)

Yes [ ] No [ ]

Farmer/Respondent Land ownership

1. How did you acquire your land?

A. Inherited [ ] B. Purchased [ ] C. Leased [ ] D. Given by Government [ ]

2. What is the total size of the ARABLE land? (acres)

…………………………………………………………………………………………

3. What size of the land is allocated to rice production? (Total in acres)

…………………………………………………………………………………………

4 How would you describe your rice farming? (Tick in the relevant box)

a) (i) Rain fed [ ] (ii) Irrigated [ ] (iii) Both [ ]

b) (i) Mechanized [ ] (ii) Not mechanized [ ]

SECTION THREE: Farmer awareness on best agronomic practices (BAP) in rice production.

1. (a)Which varieties of rice do you cultivate? (Tick where applicable (√))

i. A NERICA L- 19 [ ]
ii. B NERICA 14 [ ]
iii. C NERICA 1 [ ]
iv. D NERICA 2 [ ]
v. E FKR [ ]
vi. F SUACOCO 8 [ ]
vii. LAC 8 [ ]
viii. LAC 23 [ ]
ix. (Traditional varieties) [ ]
x. Other [ ]

(b) specify any other rice variety grown…………………………………………………

2. (a) How do you clean your farms before cultivation:

A. Brunings straws [ ]B. Throwing of straws C. Spraying straws [ ] D. Leaving straws to decompose [ ], E. Other [ ]

(B) Specify other method of cultivation…………………………………………………

(c) Why do you use the selected method/s?...

3. (i) How do you propagate your rice? (Select all the methods used)

A. Broadcasting without scratching [ ] B. Dibbling [ ] C. Transplanting [ ] D. Broadcasting with scratching [ ] E. Any other [ ]

(ii) Specify other seed propagation method---

4.0 (a) Do you apply fertilizer: A. Yes [ ] No [ ]

(b) If yes, at what stage, type of fertilizer and amount?

(i) Planting [ ], fertilizer type---------------------------, Amount--------------------------------

(ii) Top dressing [ ], fertilizer type---------------------------, Amount--------------------------

5.0 (i)Do you weed? A. Yes [ ] B. No [ ]

(ii) If yes, how many times do you weed? A. Once [ ] B. Two [ ] C. Three [ ] D. Four [ ] E. More than four times [ ]

(ii) When do you start weeding? A. Two weeks after planting [ ] B. Three weeks after planting [ ] C. Four weeks after planting [ ] D. More than four weeks

6.0 How do you harvest your rice?

A. Manual [ ], B. Use of Combined Harvest [ ], C. Both [ ]

7.0 (i) Amount of shelled rice harvested in 2018…………………………………… (90kg bag unit)

(ii) Amount of shelled rice harvested in 2019…………………………………… (90kg bag unit)

(iii) Amount of shelled rice harvested in 2020…………………………………… (90kg bag unit)

SECTION FOUR: Farmer knowledge on fungal contaminant.

4. Do you experience mold growths on stored rice grains?

Yes [ ] No [ ]

5. Describe their appearance by color?

………………………………………………………………………………………………

At what stage do you notice molds on your rice grains? (Select all that applies to you)

A. Farm [ ] B. Storage [ ] C. Other [ ]

6. What time of the season is the molds noticed mostly?

A. Dry season [ ] B. Rainy season [ ] C. Both seasons [ ]

7. How do you use the grains affected by molds?

A. Plant [ ] B. Sell [ ] C. Eat [ ] D. Discard [ ]

8. (a) How do you manage the infection on the seed rice?

A. Spraying [ ] B. Sorting [ ] C. Sundry drying [ ] D. Used as feed [ ]

E. Others [ ]

(b) Specify other use…………………………………………………………………….

SECTION FIVE: Farmer's source of seed rice

1. Where do you get your seed rice from?

A. Market [ ] B. Friend [ ] C. LNGO [ ] D. Agro-shop [ ] E. Own saved [ ]

2. If it is saved seed rice, how old is the seed?

A. Six months [ ] B. One year [ ] C. Two years D. Unknown [ ]

3. If you acquire seeds from the Agro- shop, are they certified?

Yes [ ] No [ ]

4. (i) If yes, how do you establish their authenticity?

A. Look at the labels [ ] B. Appearance [ ] C. extension officers [ ]

D. Other [ ]

(ii) Specify other…………………………………………………………………………

5. If you use certified seeds, do you experience difference in yields compared to farmers who use non-certified seeds?

Yes [ ] No [ ]

6. (i) Where do you store your rice grains meant for seeds?

A. Kitchen Attic [ ] B. House attic [ ] C. Containers [ ]

D. Sacks [ ] E. Others [ ]

(ii) Specify other…………………………………………………………………………

7. What are the challenges faced in using local seeds? List?

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8. What challenges hinder you from using certified seed? List

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(i) Are you aware of the health problems associated with using mold infested rice grains for seeds?

Yes [ ] No [ ]

(ii) If yes list some that you know

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(i) Are you aware of the challenges associated with not using certified seeds?

Yes [ ] No [ ]

(ii) If yes state some

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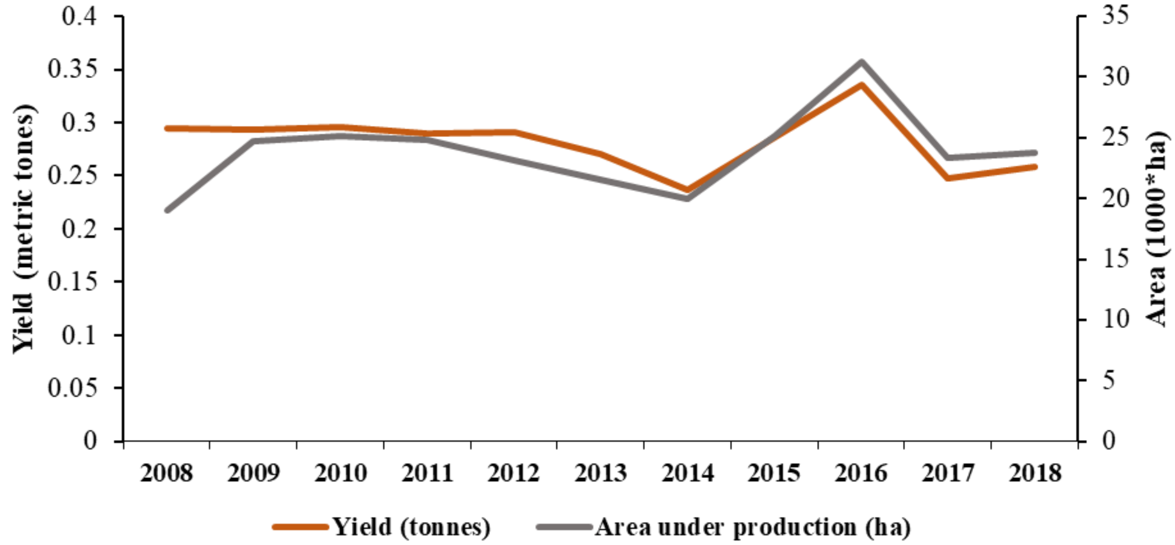
11.Are you aware of national government policy on seeds in Liberia or any other policy and regulations on agriculture? (i) Farmer Yes [ ] (ii) Farmers No [ ]

(i) Informants Yes [ ] (ii) Informants No [ ]

This is the end of interview

Thank you for your time and cooperation

Appendix III: Global Rice yields trends in between the year 2008 and 2018



Appendix IV: ANOVA table on germination count

Analysis of variance **Variate: GERM_COUNT** **Source of variation**	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
County	3	163.51	54.5	1.12	0.343
Variety	4	1482.9	370.72	7.59	<.001
DAS	5	147869.56	29573.91	605.36	<.001
County.Variety	12	683.75	56.98	1.17	0.306
County.DAS	15	9263.38	617.56	12.64	<.001
Variety.DAS	20	31224.8	1561.24	31.96	<.001
County.Variety.DAS	60	13536.55	225.61	4.62	<.001
Residual	360	17587.25	48.85		
Total	479	221811.7			

Appendix III: ANOVA table on colony diameter

Analysis of variance **Variate: Colony_diameter_mm** **Source of variation**	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Plant_extract	17	32460.791	1909.458	452.15	<.001
Pathogen	3	59474.654	19824.885	4694.45	<.001
Time_DAI	6	86520.607	14420.101	3414.62	<.001
Plant_extract.Pathogen	51	37936.528	743.853	176.14	<.001
Plant_extract.Time_DAI	102	9913.22	97.188	23.01	<.001
Pathogen.Time_DAI	18	31483.058	1749.059	414.17	<.001
Plant_extract.Pathogen.Time_DAI	306	18231.281	59.579	14.11	<.001
Residual	1008	4256.833	4.223		
Total	1511	280276.972			

Appendix IV: Plant extracts x pathogen species x time interval interactions

PLANT EXTRACT	FUNGAL PATHOGEN	TIME INTERVAL (DAYS AFTER INCUBATION - DAI)						MEAN
		1DAI	2DAI	3DAI	4DAI	5DAI	6DAI	
Bean ash (0.3g)	*A. flavus*	0.00	0.00	1.50	1.50	1.50	1.50	**1.00**
	A. niger	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	Fusarium spp	0.00	8.67	13.33	25.67	34.33	48.00	**21.67**
	Penicillium sp	0.00	0.00	0.00	4.33	8.33	12.33	**4.17**
Bean ash (0.5g)	*A. flavus*	0.00	0.00	1.50	1.50	1.50	1.50	**1.00**
	A. niger	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	Fusarium spp	0.00	10.33	11.67	25.67	32.00	43.67	**20.56**
	Penicillium sp	0.00	0.00	0.00	3.67	8.33	10.00	**3.67**
Bean ash (0.7g)	*A. flavus*	0.00	0.00	1.50	1.50	1.50	1.50	**1.00**
	A. niger	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	Fusarium spp	0.00	3.00	11.33	20.00	28.67	30.33	**15.56**
	Penicillium sp	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Chili (0.3ml)	*A. flavus*	0.00	7.00	10.33	17.00	17.00	17.00	**11.39**
	A. niger	0.00	9.67	16.67	27.67	34.33	34.33	**20.44**
	Fusarium spp	0.00	6.00	6.33	13.33	18.33	47.67	**15.28**
	Penicillium sp	0.00	0.00	6.33	13.33	18.33	22.67	**10.11**
Chili (0.5ml)	*A. flavus*	0.00	5.00	7.00	14.00	14.00	14.00	**9.00**
	A. niger	0.00	8.67	20.67	25.33	32.33	32.33	**19.89**
	Fusarium spp	0.00	12.00	6.00	11.00	14.33	34.00	**12.89**
	Penicillium sp	0.00	0.00	6.00	11.00	14.33	19.67	**8.50**
Chili (0.7ml)	*A. flavus*	0.00	2.67	3.00	13.33	13.33	13.33	**7.61**
	A. niger	0.00	6.33	14.00	19.33	23.00	23.00	**14.28**
	Fusarium spp	0.00	2.67	4.33	8.00	11.00	24.33	**8.39**
	Penicillium sp	0.00	0.00	4.33	8.33	11.00	17.00	**6.78**
Garlic (0.3ml)	*A. flavus*	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	A. niger	0.00	5.33	13.33	24.33	36.67	36.67	**19.39**
	Fusarium spp	0.00	11.00	24.33	29.33	39.33	45.00	**24.83**
	Penicillium sp	0.00	0.00	7.00	10.33	15.67	21.00	**9.00**
Garlic (0.5ml)	*A. flavus*	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	A. niger	0.00	3.00	8.33	14.00	18.00	18.00	**10.22**
	Fusarium spp	0.00	7.67	22.33	27.67	34.67	40.00	**22.06**
	Penicillium sp	0.00	0.00	1.33	6.33	10.33	18.00	**6.00**
Garlic (0.7ml)	*A. flavus*	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	A. niger	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	Fusarium spp	0.00	0.00	17.33	21.67	30.33	33.00	**17.06**
	Penicillium sp	0.00	0.00	4.00	7.00	11.67	15.67	**6.39**
Ginger (0.3ml)	*A. flavus*	8.67	15.00	19.33	36.33	36.33	36.33	**25.33**
	A. niger	0.00	5.33	13.00	19.33	27.00	27.00	**15.28**
	Fusarium spp	0.00	11.33	22.67	34.67	46.67	44.67	**26.67**
	Penicillium sp	0.00	9.00	13.67	17.33	19.67	21.33	**13.50**
Ginger (0.5ml)	*A. flavus*	0.00	10.33	26.00	23.67	23.67	23.67	**17.89**
	A. niger	0.00	4.00	11.33	21.67	25.00	25.00	**14.50**
	Fusarium spp	0.00	11.00	23.67	32.00	44.33	48.00	**26.50**
	Penicillium sp	0.00	8.33	10.00	12.67	15.00	19.33	**10.89**
Ginger (0.7ml)	*A. flavus*	0.00	5.67	18.00	17.67	17.67	17.67	**12.78**
	A. niger	0.00	5.67	12.67	16.00	20.67	20.67	**12.61**
	Fusarium spp	0.00	7.33	21.00	32.67	39.67	39.67	**23.39**
	Penicillium sp	0.00	4.00	8.00	9.33	14.33	18.33	**9.00**
Neem (0.3ml)	*A. flavus*	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	A. niger	0.00	6.00	13.67	21.33	31.00	31.00	**17.17**
	Fusarium spp	0.00	13.00	16.00	25.00	27.67	32.00	**18.94**
	Penicillium sp	0.00	7.33	13.33	21.00	26.00	32.00	**16.61**
Neem (0.5ml)	*A. flavus*	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	A. niger	0.00	6.00	14.00	20.33	28.33	28.33	**16.17**
	Fusarium spp	0.00	8.33	14.33	18.67	19.67	22.00	**13.83**
	Penicillium sp	0.00	6.67	14.67	20.33	24.00	30.33	**16.00**
Neem (0.7ml)	*A. flavus*	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	A. niger	0.00	3.33	9.00	13.33	19.00	19.00	**10.61**
	Fusarium spp	0.00	2.00	11.33	16.33	18.00	20.00	**11.28**
	Penicillium sp	0.00	4.33	9.00	16.00	20.00	25.00	**12.39**
Tebuconazole (0.3ml)	*A. flavus*	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	A. niger	0.00	5.33	6.33	11.00	15.00	15.00	**8.78**
	Fusarium spp	0.00	9.00	15.33	25.33	38.67	47.67	**22.67**
	Penicillium sp	0.00	0.00	5.00	9.33	14.00	19.33	**7.94**
Tebuconazole (0.5ml)	*A. flavus*	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	A. niger	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	Fusarium spp	0.00	8.33	11.67	24.67	32.00	40.00	**19.44**
	Penicillium sp	0.00	0.00	5.33	9.00	12.00	17.00	**7.22**
Tebuconazole (0.7ml)	*A. flavus*	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	A. niger	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
	Fusarium spp	0.00	5.67	11.00	20.33	31.00	31.33	**16.56**
	Penicillium sp	0.00	0.00	3.33	6.33	12.33	16.00	**6.33**
MEAN (DAI)		0.12	4.05	8.56	13.30	17.12	20.04	**10.53**

Statistics	**Plant extract (PE)**	**Pathogen (P)**	**Time (DAI)**	**PE x P**	**PE x DAI**	**P x DAI**	**PE x P x DAI**
Probability	<.001	<.001	<.001	<.001	<.001	<.001	<.001
S.E	0.2242	0.1057	0.1398	0.4484	0.5932	0.2797	1.1865
S.E.D	0.3171	0.1495	0.1977	0.6342	0.839	0.3955	1.6779
%CV	17						

Appendix V: ANOVA table on percent inhibition by plant extracts

Analysis of variance Variate: %_Inhibition Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Extract	17	17343.43	1020.2	44.9	<.001
Pathogen	3	105210.07	35070.02	1543.5	<.001
Extract.Pathogen	51	15817.42	310.15	13.65	<.001
Residual	144	3271.84	22.72		
Total	215	141642.77			

Appendix VI: Table of means on percent inhibition by plant extracts

Pathogen x plant extract interaction	% Inhibition (Mean)	Tukey's test
A. flavus Bean ash (0.3g)	100	a
A. flavus Garlic (0.3ml)	100	a
A. flavus Garlic (0.5ml)	100	a
A. flavus Neem (0.5ml)	100	a
A. flavus Tebuconazole (0.5ml)	100	a
A. flavus Bean ash (0.5g)	100	a
A. flavus Bean ash (0.7g)	100	a
A. flavus Garlic (0.7ml)	100	a
A. flavus Neem (0.3ml)	100	a
A. flavus Neem (0.7ml)	100	a
A. flavus Tebuconazole (0.3ml)	100	a
A. flavus Tebuconazole (0.7ml)	100	a
A. niger Bean ash (0.3g)	100	a
A. niger Bean ash (0.7g)	100	a
A. niger Tebuconazole (0.5ml)	100	a
Penicillium spp Bean ash (0.7g)	100	a
A. niger Bean ash (0.5g)	100	a
A. niger Garlic (0.7ml)	100	a
A. niger Tebuconazole (0.7ml)	100	a
Penicillium spp Bean ash (0.5g)	87.03	ab
Penicillium spp Bean ash (0.3g)	84.53	abc
A. flavus Chili (0.7ml)	83.26	bcd
A. flavus Chili (0.5ml)	82.43	bcde
Penicillium spp Garlic (0.7ml)	80.35	bcdef
Penicillium spp Tebuconazole (0.7ml)	79.9	bcdef
A. flavus Chili (0.3ml)	78.66	bcdef
Penicillium spp Chili (0.7ml)	78.66	bcdef
Penicillium spp Tebuconazole (0.5ml)	78.66	bcdef
A. flavus Ginger (0.7ml)	77.85	bcdefg
A. niger Garlic (0.5ml)	77.41	bcdefgh
Penicillium spp Garlic (0.5ml)	77.4	bcdefgh
Penicillium spp Ginger (0.7ml)	76.99	bcdefgh
A. niger Neem (0.7ml)	76.14	bcdefghi
Penicillium spp Tebuconazole (0.3ml)	75.7	bcdefghij
Penicillium spp Chili (0.5ml)	75.32	bcdefghij
Penicillium spp Ginger (0.5ml)	75.32	bcdefghij
Penicillium spp Garlic (0.3ml)	73.64	bcdefghij
Penicillium spp Ginger (0.3ml)	73.2	bcdefghijk
A. niger Tebuconazole (0.3ml)	72.8	bcdefghijkl
Penicillium spp Chili (0.3ml)	71.54	bcdefghijkl
A. niger Chili (0.7ml)	71.15	bcdefghijkl
A. flavus Ginger (0.5ml)	70.3	cdefghijklm
A. niger Ginger (0.5ml)	68.61	cdefghijklm
Penicillium spp Neem (0.7ml)	67.78	defghijklm
A. niger Ginger (0.7ml)	67.77	defghijklm
A. niger Ginger (0.3ml)	66.06	efghijklm
A. niger Neem (0.5ml)	64.45	fghijklmn
Penicillium spp Neem (0.5ml)	61.92	ghijklmn
A. niger Neem (0.3ml)	61.07	hijklmn
Penicillium spp Neem (0.3ml)	59.83	ijklmn
A. niger Chili (0.5ml)	59.41	jklmn
A. niger Chili (0.3ml)	56.84	klmn
Fusarium spp Tebuconazole (0.7ml)	56.45	lmn
A. flavus Ginger (0.3ml)	54.45	mn
A. niger Garlic (0.3ml)	53.95	mn
Fusarium spp Garlic (0.7ml)	48.95	no
Fusarium spp Bean ash (0.7g)	37.34	op
Fusarium spp Bean ash (0.5g)	36.87	opq
Fusarium spp Neem (0.3ml)	35.15	opqr
Fusarium spp Garlic (0.5ml)	34.77	opqr
Fusarium spp Ginger (0.3ml)	33.85	opqr
Fusarium spp Ginger (0.5ml)	33.44	opqr
Fusarium spp Ginger (0.7ml)	30.97	pqr
Fusarium spp Tebuconazole (0.5ml)	30.97	pqr
Fusarium spp Chili (0.5ml)	30.13	pqr
Fusarium spp Chili (0.7ml)	29.3	pqr
Fusarium spp Chili (0.3ml)	29.22	pqr
Fusarium spp Garlic (0.3ml)	28.88	pqr
Fusarium spp Bean ash (0.3g)	28.01	pqr
Fusarium spp Tebuconazole (0.3ml)	25.12	pqr
Fusarium spp Neem (0.5ml)	20.46	qr
Fusarium spp Neem (0.7ml)	19.66	r

Statistics	Plant extract (PE)	Fungal pathogen (P)	PE x P
Probability	<.001	<.001	<.001
S.E	0.649	1.376	2.752
S.E.D	0.917	1.946	3.892
%CV	6.9		

Appendix VII: Average Rainfall and Temperature data in the four Counties

Predictors	B	S.E.	Wald	df	Sig.	Exp(B)
Annual average rainfall (mm)	0.079	0.023	11.377	1	0.001	1.082
Annual average temp (ºC)	-0.221	0.473	0.217	1	0.641	0.802
Constant	-6.792	8.962	0.574	1	0.448	0.001

Appendix X: Letter from the Seed, Crop and Horticultural Sciences authorizing entry of Rice seed samples from Liberia.

University of Eldoret

P. O. Box 1125 - 30100, Eldoret, Kenya
Tel: +254 53 2033712 - 13
Fax: +254 53 206 3257
E-mail: vc@uoeld.ac.ke
Website: www.uoeld.ac.ke

SCHOOL OF AGRICULTURE & BIOTECHNOLOGY
DEPARTMENT OF SEED, CROP & HORTICULTURAL SCIENCES

REF: UoE/B/SCH/REF/050 DATE: 28th March, 2021

To: **WHOM IT MAY CONCERN.**

Dear Sir/Madam,

RE: PLANT MATERIALS FROM LIBERIA - MR. OUSMAN SARLIA DORLEY (REG NO. SAGR/SCH/P/003/19)

This is to state that the above named person is a Registered PhD student in the Department of Seed Crop and Horticultural Sciences Department, in The School of Agriculture and Biotechnology at University of Eldoret. He is pursuing a PhD degree in Seed Science. Mr Dorley completed his PhD Course work in December 2020 and travelled to his home country (Liberia) to collect Rice samples which he will use for his PhD Thesis Research under Supervision of Prof Julius Ochuodho and Prof Elmada Auma.

As the Head of SCH Department, this is to kindly request that Mr Ousman Sarlia Dorley be accorded any necessary assistance that he may require so that he can get back to Eldoret with the plant samples that he is bringing in from Liberia. This will enable him to complete his PhD Research.

Yours Faithfully

HEAD
SEED, CROP & HORTICULTURAL SCIENCES
UNIVERSITY OF ELDORET

DR. VICTORIA E. ANJICHI
HEAD OF DEPARTMENT, SEED, CROP & HORTICULTURAL SCIENCES

Tel +254720536400 Email:- vickianjichi@gmailcom, and veanjichi@uoeld.ac.ke

Appendix VIII: Phytosanitary Certificate from the Ministry of Agriculture, Liberia

Republic of Liberia

MINISTRY OF AGRICULTURE

P.O Box 10-9010
1000 Monrovia-10, Liberia

DEPARTMENT OF TECHNICAL SERVICES

Phytosanitary Certificate

Revenue Receipt: GRATIS — Certificate No. RL/NQES - 03242021

Plant protection Organization of: LIBERIA

To Plant protection organization(s) of: KENYA

I. Description of Consignment

Name and address of exporter: Dr. Ousman Sarlia Dorley, Bushrod Island/MONROVIA LIBERIA, REPUBLIC OF LIBERIA

Declared name and address of Consignee (s): Dr. Ousman Sarlia Dorley, University of Eldoret, Seed Science & Technology, Eldoret, Kenya, + 254 – 794263238 or + 231 – 778864899/886130511

Number and description of pack: NINE (9) ENVILOPS CONTAINING ASSORTED SEEDS (RICE, PALAVER SAUCE, WATER GREEN, CARELESS GREEN, MAIZE, OKRA, PEPPER, BITTER BALL AND CUCUMBER)

Distinguishing marks: AS SEEN

Place of origin: LIBERIA

Means of conveyance: By Air

Declared point of entry: KENYA

Names of product and quantity to be declared: ASSORTED SEEDS

Botanical name of plant: VIARIETIES

We certify that the plants, plant product (s) or other regulated articles described herein have been inspected, treated and or tested according to appropriate official procedures and are considered to be free from the quarantine pests specified by the importing contacting party and conform with the current phytosanitary requirements of the importing contacting party, including those for regulated non-quarantine pests. Additionally, the consignment declared above is free from injurious insect-pests and diseases.
They are deem practically free from other pests.

II. ADDITIONAL DECLARATION

III. DISINFESTATION AND /OR DISINFECTION TREATMENT

Date: Treatment: Chemical active ingredient:

Duration & Temperature: Concentration:

ADDITIONAL INFORMATION: No chemical treatments apply, only semi processed dried seeds.

Date issue: March 24, 2021 — Place of issuance: Monrovia, Liberia

Official Stamp & Signature:

Name of authorized officer: Augustus Fahnbulleh-Director
Email; augustusfahnbulleh@ymail.com, Cell# +231-886439982

BUREAU OF NATIONAL
QUARANTINE SERVICE
TECHNICAL AFFAIRS DEPT.
MOA / R.L.

Appendix IX: Focus Group Discussions

(Source: Author, 2023).

Appendix XIII: Rice Storage Techniques

(Source: Author, 2023).

Appendix X: Similarity Report

DrillBit

The Report is Generated by DrillBit Plagiarism Detection Software

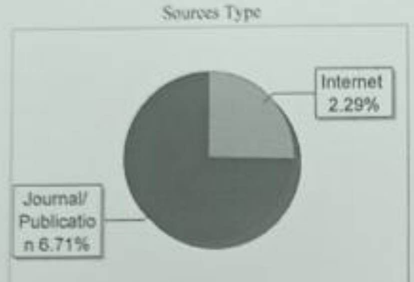
Submission Information

Author Name	Ousman Sarlia Dorley
Title	THE SEED INDUSTRY IN LIBERIA: A CASE STUDY OF R..
Paper/Submission ID	949613
Submission Date	2023-09-04 14:13:12
Total Pages	186
Document type	Dissertation

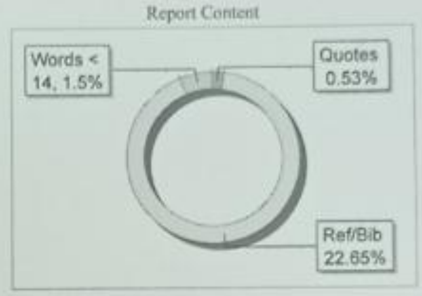
Result Information

Similarity 9 %

Sources Type



Report Content



Exclude Information

Quotes	Not Excluded
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Sources: Less than 14 Words Similarity	Not Excluded
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Excluded Phrases	Not Excluded

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