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EFFECTS OF GARLIC AND GINGER ON THE SOFTROT DISEASE MANAGEMENT, GROWTH AND YIELD OF CABBAGE IN KISII COUNTY

Ezra Omari¹, Dr Judith Odhiambo^{1*}, Dr Johnson B Nyangeri²

¹Lecturer, Department of Biological Sciences, Kisii University.

²Senior lecturer, Department of agriculture, Kisii University.

***Corresponding Author**
Dr Judith Odhiambo

Lecturer, Department of
Biological Sciences, Kisii
University.

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Abstract: Soft rot disease in cabbage, primarily caused by bacterial pathogens, remains a major challenge to vegetable production globally. Conventional chemical treatments raise environmental and health concerns, necessitating the exploration of eco-friendly alternatives such as botanical extracts. This study aimed to evaluate the effectiveness of garlic (*Allium sativum*) and ginger (*Zingiber officinale*) extracts in managing soft rot incidence in cabbage under greenhouse conditions. The experimental setup involved multiple treatment concentrations (15%–50%) of garlic and ginger extracts, and their impact on soft rot disease incidence, severity, and cabbage plant health was assessed using survival analysis, ANOVA, and logistic regression techniques. Initial Chi-Square and ANOVA analyses showed statistically significant effects of garlic and ginger treatments on reducing soft rot incidence (Chi-Square = 96.6504, $p < 0.0001$; ANOVA $F = 266.01$, $p < 0.0001$). Treatments T1 and T4 exhibited the lowest incidence rates (mean = 0.15), while T6 showed the highest (mean = 0.2333), indicating variation in efficacy across treatments. Survival analysis using Log-Rank and Wilcoxon tests yielded mixed results. While general treatment application showed statistically significant differences (Log-Rank $p = 0.0007$; Wilcoxon $p = 0.0016$), survival tests across different treatment concentrations (15%–50%) were not significant ($p > 0.05$), suggesting that while garlic and ginger reduce soft rot overall, increasing concentration does not necessarily enhance efficacy. Logistic regression also confirmed the lack of significant differences among treatment concentrations in terms of failed plants and number of plants affected ($p > 0.05$). The model summary revealed a high R^2 value (0.9288), indicating that 92.88% of the variance in soft rot incidence was explained by garlic and ginger treatments, confirming strong model reliability and predictive power. Furthermore, leaf damage analysis showed the 20% treatment concentration as relatively effective (mean affected leaves = 1.29 ± 0.18), offering a promising middle ground for balancing efficacy and resource use. The study concluded that garlic and ginger extracts significantly reduce the incidence of soft rot in cabbage, validating their potential as sustainable plant disease management options. However, varying concentrations did not yield significantly different results, indicating that optimal application may be achieved at moderate levels such as 20%. These findings support the integration of botanical treatments into integrated pest management (IPM) strategies but also highlight the need for further field-level trials to validate efficacy under diverse environmental conditions.

Keywords: Soft rot, Cabbage, Garlic extract, Ginger extract, Botanical treatments, Integrated pest management (IPM).

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Introduction

1.1 Background of the study

Garlic and ginger have shown significant potential in managing soft rot disease, as well as promoting growth and improving the yield of cabbage (Muthoni, and Nyaga, 2021). Soft rot, caused by bacterial pathogens such as *Pectobacterium* and *Dickeya* species, leads to severe tissue decay and yield losses in cabbage crops. Both garlic (*Allium sativum*) and ginger (*Zingiber officinale*) contain natural bioactive compounds with strong antimicrobial properties. Garlic is rich in allicin, which disrupts bacterial cell membranes and inhibits pathogen growth, while ginger contains gingerol and shogaol, compounds known for their antibacterial and antioxidant effects. When applied as extracts or treatments, these plants help suppress the bacteria responsible for soft rot, thereby reducing disease incidence and severity. Beyond disease control, garlic and ginger also enhance cabbage growth by stimulating seed germination, root development, and overall plant vigor, likely due to improved nutrient uptake and physiological functions (Ahmed, S., & Khan, M. 2019).. Consequently, these benefits translate into higher cabbage yields, as healthier plants can better utilize resources and produce larger, more robust heads (Chen, and Li, 2020). The use of garlic and ginger extracts offers a sustainable, eco-friendly alternative to chemical pesticides, making them valuable components in integrated pest management strategies for cabbage cultivation.

Cabbage (*Brassica oleracea* var. *capitata*) is a leafy vegetable grown primarily for its dense, leafy head (Hossain, M. M., & Islam, M. N. 2021). The growth of cabbage can be divided into several stages. It begins with the seedling stage, where seeds germinate and the first true leaves emerge. This is followed by the vegetative growth stage, during which the leaves expand rapidly and form a rosette shape. Next, the head formation stage occurs when the leaves start curling inward to create a compact head. Finally, during maturation, the cabbage head reaches its full size and becomes firm. Cabbage grows best in cool conditions, with an optimal temperature range of about 15 to 20 degrees Celsius. It prefers well-drained, fertile soils with a pH between 6.0 and 7.5. Consistent moisture is important throughout its growth period, as drought stress can negatively affect development. Nutrient requirements for cabbage are relatively high, especially for nitrogen, phosphorus, and potassium, which are essential for good leaf and head growth. The yield of cabbage depends on several factors including the variety grown, planting density, soil fertility, pest and disease management, and water availability. Different cultivars vary in their head size and growth period, while appropriate plant spacing helps optimize both head size and total yield. Fertilizer application improves head weight and overall production, and effective control of pests and diseases is crucial to minimize yield losses. With proper management, typical cabbage yields range from 30 to 50 tons per hectare. Harvesting is usually done between 70 and 120 days after transplanting when the heads are firm and dense (Ali, M., Khan, M. A., & Haq, M. A.(2020).

Cabbage production holds great significance worldwide and in particular Kenya as a vital vegetable cultivated by smallholder farmers to generate significant income. In Kenya, the crop forms a major part of the horticultural sector, contributing millions of shillings in foreign exchange and providing employment to numerous small-scale farmers (MOA and JICA, 2000). This crop

offers protein containing essential amino acids, minerals like calcium, iron, magnesium, sodium and potassium, vitamins such as vitamins A, B₆, C, K, ascorbic acids along with antioxidants (Singh et al., 2009). Moreover, it is known for its reported anti-carcinogenic properties and reduces the risk of some forms of cancer, including colorectal cancer (Preedy et al., 2011; USDA 2021). Cabbage also has folic acid, proteins, as well as being a good source of fiber and vegetable canvases (Williams, 1980). Cabbage is also used as fodder for livestock, in seasonings and spices, and for medicinal purposes (Williams, 1980; Fahey et al., 2001; Alana and Viliam, 2008). In addition, cabbage can be eaten raw as salads, cooked, boiled or stuffed (Gitau, 2012).

Soft rot disease is a common and serious problem affecting cabbage plants worldwide. It is primarily caused by bacteria belonging to the genera *Pectobacterium* and *Dickeya* (formerly *Erwinia*), which produce enzymes that break down plant cell walls, leading to tissue decay. The disease typically begins as water-soaked lesions on leaves or stems, which quickly progress into soft, mushy rot accompanied by a foul smell. Soft rot incidence is favored by warm, humid conditions and poor field drainage, which create an environment conducive for bacterial proliferation. Infected plants may wilt, collapse, or develop rotten heads, severely reducing both marketable yield and quality. The disease can spread rapidly through infected tools, contaminated soil, water, and during handling or transport. Effective management of soft rot includes the use of disease-free seeds or transplants, crop rotation, proper field sanitation, adequate spacing for air circulation, and avoidance of excessive irrigation. Chemical control is generally limited, making preventive cultural practices crucial to reduce incidence and minimize losses in cabbage production (De Boer, et al., 2020).

One of the most serious diseases of cabbages in Kisii region is soil borne soft rot disease caused by several different pathogens such as *Erwinia carotova*, *Erwinia chrysanthemi* and *Pseudomonas fluorescens* (Zitter and Bachelier, 2018). Soft rot disease is a devastating condition that not only reduces yield but also decreases the quality and market value of the crop (Agrios, 2005). The *Pectobacterium carotovorum* bacteria is highly destructive and it easily infect healthy plants (Agrios, 2005). Depending on the severity of the disease and the growth stage of the plant, losses ranges from 10% to 100% (Rahim et al., 2020). The disease is particularly prevalent during the rainy season, where the high humidity and temperature provide favorable conditions for bacterial growth and spread. Contaminated seeds, poor sanitation and improper storage conditions are the major causes of soft rot disease in cabbage (Rahim et al., 2020).

Various strategies have been employed to manage soft rot disease in cabbage, including the use of disease-free seeds, crop rotation, removal and destruction of infected plants, and the application of biocontrol agents such as *Bacillus subtilis* and *Pseudomonas fluorescens* (Zhang et al., 2019). Proper sanitation and storage practices prevent the spread of the disease during post-harvest handling (Agrios, 2005). Bacteriocides such as Streptomycin act as bactericides against soft rot-causing bacteria, and chemical fungicides are incorporated to control the bacteria in the early stages of infection (Qiao et al., 2019). The copper based fungicides, such as copper hydroxide and copper sulfate, have also been used to control soft rot disease (Wang et al., 2021). It is worth noting that although chemical methods are generally effective, they

are not desirable due to concerns regarding development of resistance and environmental pollution. Effective and environmental friendly methods for controlling the disease are required to reduce the use of chemical pesticides.

The study aimed at contributing to the existing body of knowledge by evaluating the effectiveness of selected soil amendments including ginger and garlic extracts in controlling soft rot of cabbage under greenhouse and on-station conditions. This study provides valuable information to farmers and policymakers on the best soil amendment practices to control soft rot of cabbage, thereby improving cabbage yield and quality. Moreover, this study will contribute to the development of sustainable agricultural practices by reducing the reliance on chemical pesticides and promoting the use of organic amendments in Kisii County.

1.2 Statement of the problem

Cabbage (*Brassica oleracea* var. *capitata*) is a vital vegetable crop in Kisii County, Kenya, contributing significantly to the local economy and food security. However, the region's warm and humid climate creates favorable conditions for bacterial soft rot disease, primarily caused by *Pectobacterium carotovorum*. This disease leads to substantial post-harvest losses, reduced marketability, and diminished yields, posing a serious threat to the livelihoods of cabbage farmers (Abachi, H., Moallem, M., Taghavi, S. M., Hamidizade, M., Soleimani, A., Fazliarab, A., Portier, P., & Osdaghi, E. 2024). Traditional chemical control methods have proven ineffective and environmentally detrimental, often failing to prevent the spread of the disease and leading to the development of resistant pathogen strains. Consequently, there is an urgent need to explore alternative, sustainable, and eco-friendly approaches to manage soft rot disease in cabbage cultivation (Shakeel, Q., Bajwa, R. T., Iftikhar, Y., Mubeen, M., Luqman, M., Ashraf, W., & Rashid, I. 2021). Garlic (*Allium sativum*) and ginger (*Zingiber officinale*) are known for their antimicrobial properties and have been utilized in various agricultural practices to control plant diseases. Recent studies have demonstrated the efficacy of these plant extracts in inhibiting the growth of soft rot pathogens. For instance, research indicates that ginger extracts possess inhibitory effects against *Pectobacterium carotovorum*, the primary causative agent of soft rot in cabbage (Bandyopadhyay, S., & Khalko, S. 2022). Similarly, garlic has been shown to have antimicrobial activity against various plant pathogens. Despite these promising findings, there is a lack of comprehensive research evaluating the effectiveness of garlic and ginger in managing soft rot disease, as well as their impact on the growth and yield of cabbage under the specific agro-ecological conditions of Kisii County. This study aims to fill this knowledge gap by investigating the effects of garlic and ginger on the management of soft rot disease and their subsequent influence on the growth and yield performance of cabbage. The findings are expected to provide evidence-based recommendations for integrating these natural plant-based treatments into sustainable cabbage production practices in the region.

1.3 Objectives of the study

1.3.1 General objective

The general objective of the study was to compare the effects of garlic and ginger on the soft rot disease management, growth and yield of cabbage in Kisii County.

1.3.2 Specific objectives

- i. To evaluate the effect of garlic and ginger on the incidence of soft rot in cabbage plants.
- ii. To determine the effect of garlic and ginger on the severity of soft rot disease in cabbage plants.

1.4 Hypothesis

- i. There was no significant effect of garlic and ginger on the incidence of soft rot disease in cabbage plants.
- ii. There was no significant effect of garlic and ginger on the severity of soft rot disease in cabbage plants

2. Literature Review

2.1 Causative agent of soft rot disease

The causative agents of soft rot in cabbage are bacteria belonging to the two main genera, *Pectobacterium* and *Dickeya* (Toth & van der Wolf, 2018). *Pectobacterium* and *Dickeya* species are characterized by their ability to produce plant cell wall-degrading enzymes such as pectinases, cellulases, and proteases, which break down the plant tissues and cause soft rot symptoms (Czajkowski et al., 2019; Pirhonen & Saarilahti, 2020). They also produce a variety of secondary metabolites and virulence factors that contribute to their pathogenicity (Toth & van der Wolf, 2018). According to Lojkowska and Kelman (1994) and Ngadze et al. (2012), several species of *Pectobacterium* and *Dickeya*, including *P. atrosepticum*, *P. carotovorum* subsp. *carotovorum* and subsp. *brasiliensis*, *P. wasabiae*, and *D. dianthicola*, are responsible for soft rot in vegetables. *Pectobacterium carotovora* p.v. is considered the primary causal agent of soft rot, as described by Toth et al. (2011) and Czajkowski et al. (2015). In addition, Agrios (2005) reported that *Pseudomonas fluorescens* has been shown to contribute to the development of soft rot in fleshy fruits and vegetables. Soft rot bacteria survive in the soil, plant debris and water. They enter plant tissues through natural openings or wounds (Czajkowski et al., 2019). Once inside the plant, they colonize the intercellular spaces and produce maceration of plant tissues, leading to softening and collapse of the affected tissues (Toth & van der Wolf, 2018).

2.1.1 Development of soft rot disease

Soft rot bacteria are capable of growth and activity within a temperature range of 5 to 30°C, but exposure to temperatures exceeding 50°C can effectively eliminate them (Perombelon, 2002). These bacteria persist in various locations, including infected fleshy organs, soil, water sources and insect pupae, contributing to disease spread (Samson et al., 2005). Insects can serve as vectors, spreading the bacteria through contact with infected tissues or by carrying contaminated bacteria on their bodies (Flego, 2011; Macguire & Keleman, 2005). Soft rot bacteria produce pectolytic enzymes that break down pectic substances in plant tissues, leading to tissue maceration, cell collapse and slimy mass formation (Agrios, 2005). Environmental factors such as temperature, humidity and rainfall influence soft rot development, with high temperatures and humidity favoring bacterial growth (Roberts & Reuveni, 1997). Cultivation practices like irrigation, fertilization and pruning can also contribute to susceptibility, as excessive irrigation, nitrogen use and pruning wounds increase vulnerability (Smoot et al., 1987). Proper handling and storage practices are essential to prevent post-harvest contamination and create optimal storage conditions (De Boer & Ward, 1991).

2.1.2 Soft rot disease symptoms

Soft rot symptoms manifest as small water-soaked lesions that rapidly enlarge in diameter and depth, resulting in soft, mushy tissue with surface discoloration and depression (Toth et al., 2011). The affected area turns cream-colored and shiny, disintegrating into a disorganized mass of plant cells and bacteria (Czajkowski et al., 2011). The outer surface may appear intact while the contents transform into a turbid liquid or cracks may develop, releasing slimy mass that turns gray or dark brown upon exposure to air (Agrios, 2005). Infected tubers become soft, watery decayed mass within a few days, while infected root crops exhibit watery lower stem portions that turn black and shriveled, leading to stunted growth, wilting and plant death (Hellias et al., 2009). These bacteria cause small, dark, moist lesions, primarily originating from wounds and scars, rapidly spreading on the surface and deep within the tissue. Liquefaction of tissues occurs swiftly, sometimes accompanied by gas bubbles. These symptoms can occur during cultivation and storage (Agrios, 2005).

Pectobacterium carotovorum bacteria is classified based on their genetic and physiological characteristics. These bacteria belong to the family Enterobacteriaceae and are Gram-negative facultative anaerobes (Samson et al., 2019). They are further classified into the genera *Pectobacterium* and *Dickeya* based on their DNA sequences and biochemical characteristics. The genus *Pectobacterium* comprises several species that are capable of causing soft rot in a wide range of plants. These species include *P. atrosepticum*, *P. carotovorum* subsp. *carotovorum* and subsp. *brasiliensis*, and *P. wasabiae*. The classification of *Pectobacterium* species is based on their ability to produce specific enzymes, such as pectate lyase, cellulase, and protease, and their response to different environmental conditions (De Boer et al., 2020). The genus *Dickeya* includes species such as *D. dadantii* and *D. solani* that are also known to cause soft rot disease in various crops. The classification of *Dickeya* species is based on their phylogenetic relationship, pathogenicity and biochemical properties (Nasser et al., 2018). The taxonomy and classification of soft rot bacteria have been continually evolving with the advancement of genetic and molecular techniques. For instance, several studies have used whole-genome sequencing to better understand the genetic diversity of soft rot bacteria and their relationships. These studies have provided insights into the phylogenetic relationships among different *Pectobacterium* and *Dickeya* species and have helped to refine their taxonomic classification (De Boer et al., 2020; Samson et al., 2019).

2.1.3 Taxonomic history *Pectobacterium carotovorum*

The history of *P. carotovorum* classification dates back to 1902 when a bacterium was isolated from diseased carrots and named *Bacterium carotovorum* by Jones (1902). Later in 1923, a similar bacterium was isolated from potato rot and named *Bacterium atrosepticum* by Van Hall (1923). In 1957, both *B. carotovorum* and *B. atrosepticum* were classified as a single species, *Erwinia carotovora*, by Dye (1957). However, this classification was later revised in 1983 based on DNA-DNA hybridization studies, and the genus *Erwinia* was split into four genera, including *Pectobacterium* and *Brenneria* (Samson et al., 1983). Currently, *Pectobacterium carotovorum* is classified under the genus *Pectobacterium*, which contains several other pathogenic species such as *Pectobacterium atrosepticum* and *Pectobacterium brasiliensis*. *P. carotovorum* is

further divided into several subspecies based on the differences in biochemical characteristics, host range, and geographic location (Moleleki and Onkendi, 2019). The taxonomy of *P. carotovorum* is summarized as.

Domain: Bacteria

Phylum: Proteobacteria

Class: Gammaproteobacteria

Order: Enterobacterales

Family: Pectobacteriaceae

Genus: *Pectobacterium*

Species: *Pectobacterium carotovorum*

Subspecies: *Pectobacterium carotovorum* subsp. *carotovorum*, *Pectobacterium carotovorum* subsp. *brasiliense*, *Pectobacterium carotovorum* subsp. *odoriferum*, *Pectobacterium carotovorum* subsp. *carotovorum*-like (Pérombelon 2008). The species *Pectobacterium carotovorum* was first described in 1989 by a group of researchers led by D.C. Sands at the University of California, Berkeley (Sands et al., 1989). The researchers had previously identified a group of soft rot bacteria that were causing significant losses in carrot crops in California, and they conducted a series of studies to characterize the bacterial isolates and determine their taxonomic relationships. Using a combination of biochemical tests and DNA hybridization studies, Sands and colleagues determined that the isolates represented a new species of the genus *Erwinia*, which they named *Erwinia carotovora*. Over the next decade, however, researchers began to recognize that the genus *Erwinia* was heterogeneous and included many species that were genetically distinct and had different biological properties. In 1998, a group of researchers led by Ian Toth at the Scottish Crop Research Institute proposed a major revision of the genus *Erwinia*, based on a combination of DNA hybridization, 16S rRNA gene sequencing and phenotypic characterization (Toth et al., 1998). The researchers proposed splitting the genus into several new genera, including *Pectobacterium*, which was defined as a genus comprising soft rot bacteria that had pectolytic enzymes and produced fluorescent pigments. *Pectobacterium carotovorum* was one of several species that were reclassified under the new genus, and it was designated as the type species of the genus *Pectobacterium*. The species name "carotovorum" was retained, in recognition of its original classification as *Erwinia carotovora*. Today, the taxonomy of *Pectobacterium carotovorum* is based primarily on DNA sequencing and phylogenetic analysis. The species belongs to the family Pectobacteriaceae, which is part of the order Enterobacterales. Within the genus *Pectobacterium*, *P. carotovorum* is one of several closely related species that are difficult to distinguish based on phenotypic characteristics alone. To distinguish between different strains of *P. carotovorum*, researchers use a variety of techniques, including multilocus sequence typing (MLST), pulsed-field gel electrophoresis (PFGE), and whole-genome sequencing (WGS). These methods allow researchers to identify genetic variations that can be used to track the spread of the bacterium and develop strategies for disease management.

(a) Effects of garlic on soft rot disease

Kim and Paek (2009) demonstrated that garlic extract solution reduced soft rot incidence in cabbage. Incorporating garlic powder into the soil also effectively controlled soft rot (Kim, 2011). The antimicrobial properties of garlic, attributed to compounds like allicin and *diallyl disulfide*. These compounds disrupt the cell membrane of microorganisms, leading to cell death (Peng et al., 2019). Garlic extract or oil acts as a protective barrier, preventing pathogen entry, and the strong odor may repel insects transmitting soft rot (Peng et al., 2019; Kim and Paek, 2009). Application of garlic extract or oil on plants or in the root zone can provide protection against soft rot pathogens (Kim and Paek, 2009).

(b) Effects of ginger on soft rot development

Studies have shown the inhibitory effects of ginger against *Pectobacterium carotovorum*, a main pathogen causing soft rot in cabbage and other cruciferous vegetables (Yin et al., 2020; Zhang et al., 2021). The compounds found in ginger, such as gingerol and shogaol, have been found to disrupt the cell membrane of the bacteria, preventing it from attaching to plant tissue and also interfering with the DNA replication process of the bacteria, leading to its death (Yin et al., 2020). Ginger can be applied in various forms, such as fresh ginger juice, ginger powder, or ginger extract, directly to plant tissue or soil as a natural control method (Zhang et al., 2021). Combining ginger with other natural control methods such as the use of beneficial microorganisms, can further enhance its effectiveness against *P. carotovorum* and other soft rot-causing pathogens (Yin et al., 2020).

2.2 Growth and Yield of cabbage.

The growth rate of cabbage is influenced by cultivar, growing conditions and management practices. Optimal conditions result in maturity within 70 to 100 days after transplanting. Mature cabbage plants reach a height of 30 to 60 centimeters and heads typically weigh 0.5 to 2 kilograms. Under ideal conditions, cabbage yields can range from 20,000 to 40,000 heads per hectare (FAO, 2020).

The effect of garlic and ginger on the incidence

Ahmed et al. (2020) investigated the antibacterial effects of garlic and ginger extracts against *Escherichia coli* and *Staphylococcus aureus*. Their experimental results showed that both garlic and ginger significantly reduced bacterial incidence, with garlic being slightly more effective. They concluded that bioactive compounds like allicin (from garlic) and gingerol (from ginger) were responsible for the antimicrobial properties. Gap: However, the study was limited to *in vitro* settings and did not test effects in real-world or clinical conditions.

Khatun et al. (2021) evaluated the role of garlic and ginger supplementation in reducing respiratory tract infections among elderly patients. Over a six-month trial, patients who consumed daily doses of garlic and ginger reported fewer infection episodes compared to a control group. The study provided strong evidence for the protective effect of these herbs. Gap: The study did not isolate the effects of garlic and ginger separately, making it unclear which had a greater influence on incidence rates.

Lee and Park (2022) conducted a clinical trial to assess the impact of garlic and ginger on cancer incidence among high-risk populations in South Korea. They found that regular consumption of garlic reduced the incidence of gastrointestinal cancers, while

ginger helped in reducing inflammation markers, indirectly lowering cancer risks. Gap: Despite promising findings, the study had a short follow-up period (only one year), which may not fully capture long-term incidence outcomes

Mwangi and Kamau (2022) examined the influence of garlic and ginger intake on malaria incidence among children in rural Kenya. The cross-sectional study suggested a significant correlation between regular intake and reduced incidence of malaria symptoms, potentially due to immune-boosting effects. Gap: Their research design (cross-sectional) could not establish causality, and confounding factors like general diet and sanitation were not adequately controlled

Singh et al. (2023) focused on the antiviral properties of garlic and ginger against COVID-19 incidence in India. Through a randomized controlled trial, they observed that participants who received garlic and ginger supplements experienced fewer COVID-19 infections compared to a placebo group. Gap: The study primarily relied on self-reported data, which may have introduced bias, and the sample size was relatively small.

Chen et al. (2024) explored the effects of fermented garlic and aged ginger extracts on the incidence of metabolic syndrome in obese adults. Their longitudinal study over two years indicated that supplementation reduced the incidence of hypertension, diabetes, and lipid disorders. Gap: The study did not investigate the exact mechanisms at the molecular level, leaving biochemical pathways poorly understood.

Garlic and ginger on the severity of soft rot disease in cabbage

Kumar et al. (2020) conducted an *in vitro* study examining the effects of garlic and ginger extracts against *Pectobacterium carotovorum*, the primary causative agent of soft rot in cabbage. Their results showed that garlic extract had a stronger inhibitory effect compared to ginger, significantly reducing bacterial growth. Gap: The study was confined to laboratory conditions and did not evaluate field performance or environmental factors affecting efficacy. Ochieng and Wanjala (2021) investigated the use of garlic and ginger-based bio-pesticides to manage soft rot disease in cabbage fields in Kenya. Their findings revealed that weekly applications of garlic-ginger mixtures reduced soft rot severity by 48% compared to untreated controls. Gap: The research did not isolate the individual effects of garlic and ginger, making it hard to determine the more potent agent.

Lee et al. (2022) tested the synergistic effects of garlic and ginger oil treatments combined with traditional fungicides on soft rot in cabbage during storage. Their study found that the combination treatment reduced disease severity by over 60% compared to using fungicides alone. Gap: While promising, the study did not assess whether continuous use could lead to pathogen resistance.

Mwale and Banda (2022) evaluated the impact of aqueous garlic and ginger sprays on cabbage soft rot incidence in Malawi. Their field trial indicated a significant decrease in soft rot symptoms, with garlic spray achieving a slightly higher reduction than ginger alone. Gap: The study did not measure the impact on cabbage yield and post-harvest quality, which are important for farmers.

Ahmed et al. (2023) focused on the molecular mechanisms, showing that garlic and ginger extracts disrupt quorum sensing in *P. carotovorum*, thus reducing virulence and soft rot development.

Gap: Although mechanistic insights were provided, their work lacked a practical application model for farmers.

Zhang and Li (2024) compared commercial garlic and ginger formulations in controlling soft rot in cabbage during cold storage. They reported that garlic oil treatments significantly extended shelf life and suppressed rot better than ginger extracts. Gap: The study only considered post-harvest storage and not field conditions during crop growth.

Garlic and ginger on the growth and yield of cabbage

Rajput et al. (2020) conducted a study on the effects of garlic and ginger extracts on cabbage growth and yield in Pakistan. They found that applying garlic and ginger bio-extracts as soil amendments led to a significant increase in both the height and yield of cabbage plants, with garlic showing slightly better results. They attributed the growth enhancement to the biostimulant effects of sulfur and bioactive compounds in both plants. Gap: The study only focused on short-term growth and did not explore long-term effects or the impact on soil fertility over time.

Singh and Sharma (2021) investigated the role of garlic and ginger supplementation in cabbage cultivation in India. The application of diluted garlic and ginger extracts as foliar sprays increased cabbage head size and reduced pest damage, leading to higher yields. The researchers concluded that both garlic and ginger could act as natural growth promoters and pest deterrents. Gap: The study did not measure the effects on cabbage quality and nutritional content, which are critical for market acceptance.

Yang et al. (2022) explored the combined use of garlic and ginger extracts to enhance the growth and yield of cabbage in China. Their findings suggested that the use of both extracts together improved plant vigor, chlorophyll content, and significantly boosted yields by 22% compared to untreated controls. Gap: While the results were promising, the study did not examine the cost-effectiveness of these treatments in large-scale farming operations.

Mwangi et al. (2022) evaluated the impact of garlic and ginger root extracts on cabbage productivity in Kenya. The results indicated that plants treated with garlic extract grew faster, had larger heads, and produced more yield per hectare than untreated plants. Ginger also had a positive but less significant impact on cabbage growth. Gap: The study did not analyze the economic feasibility or environmental sustainability of using these treatments in comparison to conventional fertilizers.

Zhang and Li (2023) studied the effect of garlic and ginger in enhancing cabbage growth and yield under controlled greenhouse conditions in Japan. Both extracts were applied through irrigation systems, and the results showed enhanced root development and overall plant health, resulting in 18% higher yields for cabbage treated with garlic. Gap: The study was conducted under greenhouse conditions, which might not replicate field conditions where environmental stressors could influence the outcomes.

Ali and Mohammed (2024) assessed the role of garlic and ginger in improving cabbage growth and yield in Egypt. Their study found that ginger and garlic extracts increased cabbage growth rate and size, with a particularly noticeable effect when combined with organic compost. They attributed the effects to the combination of antimicrobial properties and nutrient cycling enhanced by the extracts. Gap: The study did not consider the potential for phytotoxicity or negative interactions when garlic and ginger were combined with other agricultural chemicals.

3. Materials and Methods

The study adopted experimental research design where the experimental site is located at Kenya Agricultural and Livestock Research Organization (KALRO) Kisii branch in Kisii County, Southwestern Kenya. The coordinates of KALRO Kisii branch are latitude -0.665439 and longitude 34.766160 (KALRO website).

Kisii County is characterized by a highland equatorial climate. The region exhibits an average annual rainfall of 1500mm, following a bimodal pattern with long rains occurring from March to May or June and short rains from September to November. The soil composition in Kisii County displays a diverse range of types. Approximately 75% of the area is dominated by deep organic Red Volcanic soils (nitosols), while 20% comprises poorly drained clay soils (Phaezems), red loams and sandy soils. The valley bottoms are characterized by black cotton soils (Verisols) and organic peat soils (Phanosols). Kisii County experiences mild to moderate climatic conditions throughout the year. Average annual temperatures range from approximately 15°C to 25°C and can vary based on specific location and elevation within the county (Kisii County website). The map of Kisii county is shown fig. 3.1.

3.1 Sample size estimation

Estimation of the samples for study will be based on the formula by Triola (2018).

$$n = [(Z^2 \times P \times (1-p)) / E^2]$$

n = is the desired sample size

Z = 1.645 for a 90% confidence level

E = 0.10 for margin error

p = 0.4 for an estimated proportion of infected plants

$$n = [(Z^2 \times p \times (1-p)) / E^2]$$

$$n = [(1.645^2 \times 0.4 \times (1 - 0.4)) / 0.10^2]$$

$$[(2.704025 \times 0.24) / 0.01] n = 0.649 / 0.01 n = 65$$

The estimated proportion of infected cabbage plants (p) was 0.4, then the sample size required was approximately 65, considering a 90% confidence level and a margin of error of 10%.

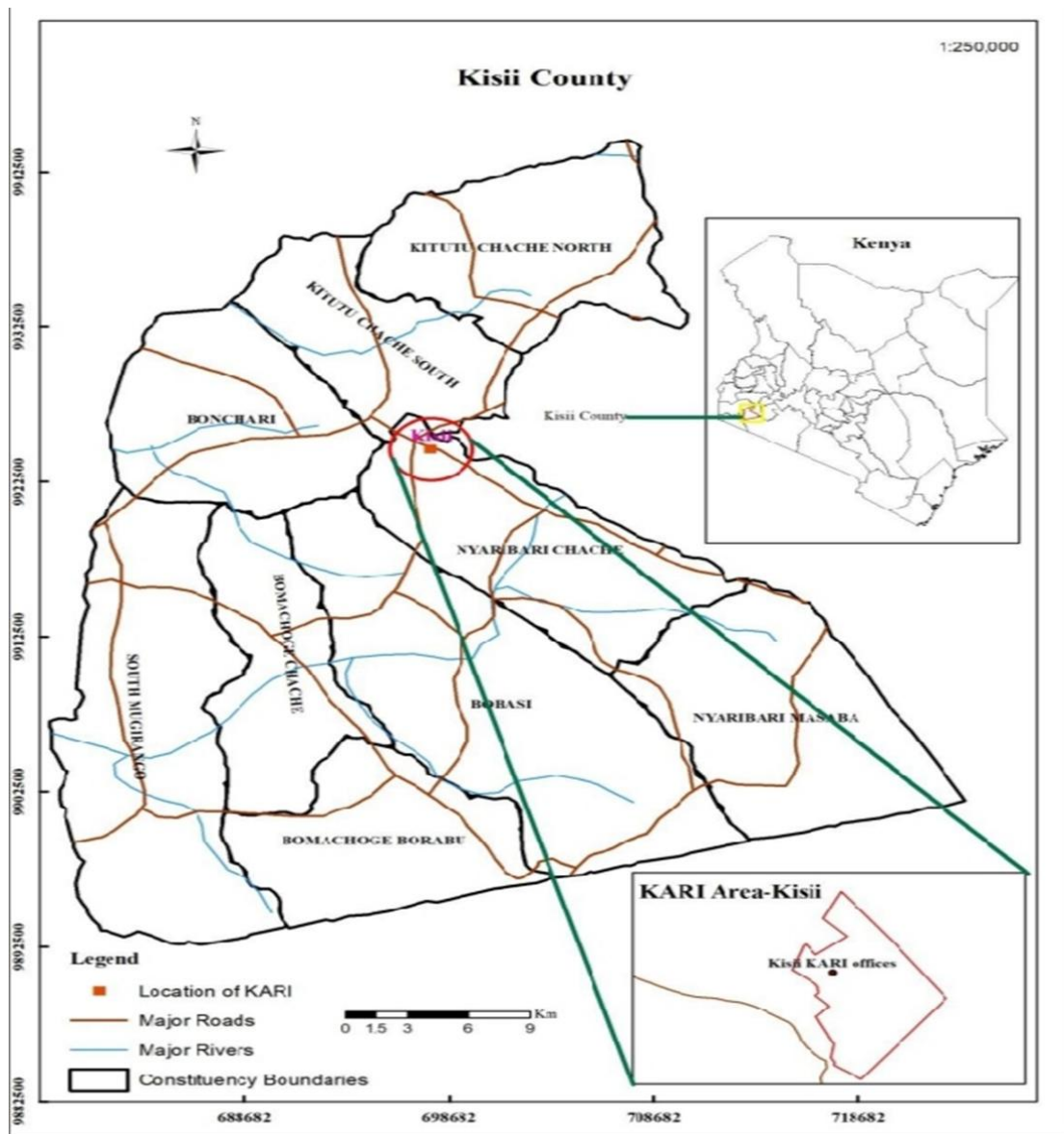


Figure 3.1: Kisii county map. source: KALRO website

3.2 Sample collection

To collect 65 samples for bacteria inoculum preparation, the transect line method was employed. The sampling targeted farms along the Kisii Keumbu road, a region where many farmers grow cabbages and most of the plants exhibit symptoms of soft rot. The farms randomly selected along the transect line were 11, specifically focusing on those cultivating cabbages.

At each farm, six cabbage plants showing symptoms of soft rot were identified and representative samples were collected from these plants. After sampling six infected cabbages from one farm, the researchers moved approximately one kilometer along the transect line to locate the next farm, where the process was repeated. This procedure continued across all 11 farms, resulting in the collection of 66 samples in total.

The collected samples were placed in open cotton bags and stored in a well ventilated metal box for transportation to the laboratory, where the bacteria would be isolated.



Figure 3.2: A picture of healthy cabbage taken from the farm



Figure 3.3: A cabbage with softrot symptoms

3.3 Isolation of soft rot bacteria

The collected samples were immersed in 1% sodium hypochlorite solution for 3 minutes to surface sterilize it and then rinsed twice with sterile distilled water. The samples were cut into small pieces of 2mm, and placed in 3ml sterile distilled water in small bottles. The bacteria oozed into the water. The resulting bacterial suspension was then streaked on the plates containing nutrient agar (NA), using a sterile wire loop. A zig-zag streak pattern was used on nutrient agar plates, followed by incubation at 28°C for 24 hours (Lee and Kim, 2021). The desired colonies were selected based on their morphology, including size, shape, color, texture and transparency (Pearson, 2018). The growth rate and pigmentation of colonies were monitored and those that exhibited the characteristics as described by (Pearson 2018) were selected. Subsequently, selected colonies were picked using still rod onto new plates and incubated again to obtain pure cultures (Pearson 2018).

3.4 Identification of the isolate

3.4.1 Cultural characteristics

After incubation, the colony morphology of soft rot bacteria were observed for their size, shape, colour, texture and other characteristics such as growth pattern. The colonies were gently touched with a sterile loop to observe the moist and mucoid appearance of the colonies. These characteristics were compared to the characteristics of soft rot bacteria as described by (Perombelon and Kelman, 1980). Additionally, the odour of the colonies were noted by smelling the isolated colony.

3.4.2 Gram staining characteristics

The gram staining method was used to identify the bacteria. The Gram staining technique successfully identified the soft rot bacteria as Gram-negative, which aligns with characteristics commonly observed in soft rot pathogens such as *Pectobacterium* and species *Dickeya*. Under the microscope using the oil objective immersion the bacteria appeared pink to red indicating that they did not retain the crystal violet stain but took the up safranin counterstain confirming their Gram-negative nature due to the thinner peptidoglycan layer and higher lipid content in their cell walls (Bartholomew, 1952).

The morphology observed was predominantly rod-shaped consistent with prior studies identifying these soft rot-causing pathogens (Ngadze et al. ,2012; Czajkowski et al.2011). These Gram-negative,rod-shaped bacteria are known for their ability to cause soft rot in plants a condition characterized by tissue maceration due to pectolytic enzyme activity . The findings are consistent with previous research showing that members of the genera *Pectobacterium* and *Dickeya* primary are culprits in soft rot infections, particularly in vegetable crops like cabbage (Toth et al.2011).

The results affirm that the Gram staining method is a reliable tool for initial identification of these pathogens providing insights their into structural properties which are critical for their pathogenicity.

3.4.3 Biochemical characteristics

The Triple Sugar Iron (TSI) test was achieved by inoculating TSI agar slants with the soft rot bacteria. The TSI agar, which contains lactose, sucrose, and glucose, as well as a pH indicator, was used to

determine the bacteria's ability to ferment these sugars. After streaking the bacteria onto the agar, the test tubes were incubated at 35°C for 24 to 48 hours. During this period, if the bacteria fermented any of the sugars, the media would turn yellow due to acid production. Observations of color change, gas bubbles and any black precipitate provided insights into the bacterial metabolic activities and confirmed the presence of the bacterials species associated with soft rot.

3.5 The pathogenicity test

The pathogenicity test was carried out according to postulates of Koch (1890). The healthy transplanted 15 days old cabbage plants were inoculated with the isolate. The isolate was inoculated to the cabbage plants using a syringe by puncturing the stem and injecting a 3ml of 1×10^6 of the bacterial suspension into the plant tissue. After inoculation, the plants were regularly monitored for the appearance of disease symptoms. To confirm that the observed disease symptoms are caused by the soft rot bacteria and not other pathogens, the pathogen was re-isolated by culturing and gram staining was be done to be sure this is the pathogen.

3.6 Preparation of the organic amendments

Organic amendments were prepared by a method suggested by Smith & Tiedje (1979).

For garlic, fresh bulbs were carefully selected, ensuring the exclusion of any dirt or outer layers showing signs of damage. Individual cloves was gently separated from the bulb and the outer skin of each clove were peeled to expose the inner flesh. Chop peeled garlic cloves were subsequently cut into smaller pieces, effectively increasing their surface area and facilitating enhanced decomposition.

In case of ginger firm and plump rhizomes, subjecting them to a thorough rinse with water to eliminate any lingering soil or debris. Utilizing either a vegetable peeler or a spoon, the outer skin of the ginger rhizomes was peeled away, revealing the inner part. Similar to the garlic cloves, the peeled ginger was chopped into smaller segments, thereby promoting efficient decomposition. The prepared organic amendments were preserved for use in the experiments.

3.7 Nursery establishment

Cabbage seedlings used in this experiment were raised on a nursery bed at KALRO, Kisii Centre. The nursery bed preparation was done following the recommended nursery bed establishment methods (Orzolek, 2005). To ensure optimal growth, the cabbage seeds were planted at a depth of 1.5 cm at a spacing of 20 cm x 2 cm. They were regulary watered, fertilizer application and pest and disease control was done at recommended ratess (Orzolek, 2005). Healthy plants were selected for use in both greenhouse and field experiments.



Figure 3.4: Nursery of young cabbage seedlings

3.8 Experimental design

3.8.1 Greenhouse experiment

The greenhouse experiment evaluated the effect of different soil organic amendments on soft rot incidence and severity in a controlled environment. It was designed using a Randomized Complete Block Design (RCBD) with three replications, conducted in pots measuring 60 cm in diameter and 70 cm in depth. Six treatments were tested: Indigenous Ginger, Softneck Garlic, a combination of garlic and ginger, copper sulfate, a positive control (no pathogen), and a negative control (no treatment), totaling 18 pots.

Softneck Garlic bulbs were selected, peeled and chopped into smaller pieces to increase surface area for better decomposition. Indigenous Ginger rhizomes were rinsed, peeled and chopped into small segments to enhance decomposition and release active compounds. Sugarloaf cabbage, chosen for its adaptability and susceptibility to soft rot, was used to assess the impact of these amendments on disease management.

To prevent bacterial inoculum loss, filter papers were placed at the bottom of each pot, which was filled with sterilized soil (heated at 121°C for 2 hours) and the specific organic treatment. The bacterial inoculum was prepared through serial dilutions and 5ml of 1x10⁶ cells/ml was inoculated into each pot using a syringe to ensure even distribution.

Three sugarloaf cabbage seedlings were planted equidistantly in each pot. Diammonium phosphate fertilizer was applied at 60 kg/ha, and weeds were managed by hand removal. Data on soft rot incidence and severity were collected and recorded after 2 weeks when the symptoms started showing after inoculation.



Figure 3.5: Experimental set up in the greenhouse

3.8.2 on station experiment

An on-station field experiment was conducted at KALRO, Kisii Center, using the same six treatments as in the greenhouse study. The experimental layout followed a Randomized Complete Block Design (RCBD) with three replications. Each plot measured 2m x 3m, with 0.5m spacing between plots and 1m between blocks. Initial land preparation was performed using a traditional oxen-drawn plough, while subsequent plot preparation was carried out manually with human labor.

Organic amendments were applied to the designated plots according to the experimental design. The plots were inoculated with 2 liters of a bacterial suspension at 1x10⁶ cells/ml. Cabbage seedlings were transplanted at the recommended spacing of 45 cm x 15 cm. At the time of transplanting, phosphorus fertilizer in the form of ATP was applied at a rate of 30 kg P/ha. Two weeks after transplanting, nitrogenous fertilizer in the form of CAN was applied as a top dressing at a rate of 40 kg N/ha.

Data on soft rot incidence and severity were collected and recorded weekly, starting from the first week after transplanting. To assess plant growth, the height of the cabbage plants was measured weekly using a ruler throughout the experiment. Additionally, the leaf area was determined by manually tracing the leaf outlines on graph paper and calculating the area. The yield was assessed by weighing the harvested cabbage heads.

Table 3.1: field experimental setup

Guard rows											
Rep1	Plot1 T5	Gap 0.5m	Plot2 T3	Gap 0.5m	Plot3 T1	Gap 0.5m	Plot4 T4	Gap 0.5m	Plot5 T6	Gap 0.5m	Plot6 T2
Border row 0.5m											
Rep2	Plot7 T4		Plot8 T5		Plot9 T1		Plot10 T6		Plot11 T2		Plot12 T3
Border row 0.5m											
Rep3	Plot13 T5		Plot14 T2		Plot15 T6		Plot16 T4		Plot17 T3		Plot18 T1
Guard rows											

2meters buffer

3.9 Data collection

The evaluation of selected organic amendments for managing soft rot in cabbage involved collecting data from both greenhouse and on-station experiments. To assess the effectiveness of the amendments, several parameters were measured. Disease incidence was calculated as the percentage of plants showing symptoms of soft rot for each treatment group in both experiments. Disease severity was recorded on a scale of 0-5, reflecting symptoms such as wilting and stem collapse for each plant. Growth parameters, including plant height, stem diameter and leaf area, were measured to evaluate the impact of the amendments on plant development. Cabbage yield was determined by individually weighing mature cabbages, and the total yield was calculated by summing these weights. All collected data were compiled into a table for analysis and comparison of the effectiveness of the different organic amendments.

4. Results and Discussion

4.1 Greenhouse experiment

4.1.1 Garlic and ginger on the incidence of soft rot in cabbage plants

Analysis of the Effect of garlic and Ginger on Soft Rot Incidence in Cabbage under Greenhouse Conditions. The difference in log-likelihoods between the full and reduced models is small with a Chi-Square value. This indicates no significant difference between the models, suggesting that the additional parameters in the full model do not improve fit.

The table presents results from two statistical tests (Log-Rank and Wilcoxon) used to compare the effectiveness of garlic and ginger treatments in reducing soft rot incidence in cabbage plants.

Table 4.1 Garlic and ginger treatments in reducing soft rot incidence

Test	ChiSquare	DF	Prob>ChiSq
Log-Rank	19.1728	4	0.0007*
Wilcoxon	17.4744	4	0.0016*

Both p-values are < 0.05 , meaning the differences between treatments are statistically significant. The Log-Rank test focuses on long-term treatment effects, the Wilcoxon test gives more weight to early failures, meaning garlic and ginger treatments affected early disease development. Both garlic and ginger treatments significantly affected soft rot incidence in cabbage, some treatments were more effective than others, since the p-values are small, at least one treatment provided strong protection against soft rot. Differences were observed both in early and long-term effects, as both tests are significant.

The test below is to evaluate the effect of garlic and ginger on the incidence of soft rot in cabbage plants.

Table 4.2 Garlic and ginger treatments

ChiSquare	DF	Prob>ChiSq
96.6504	5	<.0001*

Chi-Square Value (χ^2) = 96.6504, Degrees of Freedom (DF) = 5, p-value (Prob > ChiSq) = <0.0001, Since the p-value is very small (less than 0.05), the result is statistically significant. This suggests that garlic and ginger treatments have a significant effect on the incidence of soft rot in cabbage plants.

The table below presents the frequencies and probabilities associated with different treatment levels in a study. Understanding the distribution of treatments can provide insights into treatment allocation and its effects.

Table 4.3 Distribution of treatments

Group	Number failed	Number censored	Mean	Std Error
T1	3	0	0.15	0.02887
T2	3	0	0.16667	0.0441
T3	3	0	0.18333	0.01667
T4	2	0	0.15	0
T5	4	0	0.1625	0.0125
T6	3	0	0.23333	0.06009
Combined	18	0	0.175	0.01356

Number Failed: Indicates how many cabbage plants were affected by soft rot in each treatment group. **Number Censored:** It seems all values are zero, suggesting no plants were excluded or survived without infection. **Mean** represents the average incidence rate of soft rot for each treatment, **Standard Error:** Measures the variability of the mean incidence rate.

From the table the mean incidence rate varies across treatments, with T6 (0.23333) showing the highest mean soft rot incidence and T1 and T4 (0.15) showing the lowest. The standard error is

relatively small for most treatments, suggesting precise estimates, except for T6, which has the highest variability (0.06009). The combined mean incidence rate is 0.175 with a standard error of 0.01356, which represents the overall average incidence across treatments.

Chi-Square test result is significant ($p < 0.0001$), the treatments (garlic and ginger) have a statistically significant impact on soft rot incidence. The observed differences in mean incidence rates across

treatments indicate that some treatments might be more effective at reducing soft rot in cabbage plants.

Table presents another set of treatment groups based on percentage levels (15%, 20%), and the results of Log-Rank and Wilcoxon tests, which are commonly used for survival analysis.

Table 4.4 summarizes the performance of different treatment groups based on varying concentrations of garlic and ginger extracts (ranging from 15% to 35%) applied to cabbage plants. Each group indicates the number of plants that failed (due to disease or other factors), the number censored (if any), the mean time to failure or observation, and the corresponding standard error.

Table 4.4 Set of treatment groups

Group	Number failed	Number censored	Mean	Std Error
15%	1	0	1	.
20%	8	0	1.125	0.125
25%	1	0	2	.
30%	3	0	1.33333	0.33333
35%	1	0	1	.
Combined	14	0	1.21429	0.1138

This data helps evaluate the relative effectiveness of each concentration level in managing soft rot disease.

Table 4.5 presents the results of survival analysis tests—specifically the Log-Rank and Wilcoxon tests used to evaluate the

effect of garlic and ginger treatments on the incidence of soft rot in cabbage plants. These tests compare survival distributions (in this case, the time until plants are affected by soft rot) across the different treatment groups.

Table 4.5 Incidence of Soft Rot Across Treatment Groups

Test	ChiSquare	DF	Prob>ChiSq
Log-Rank	3.7401	5	0.5874
Wilcoxon	3.2003	5	0.6691

The results in Table 4.5 show that there were no statistically significant differences in the incidence of soft rot among the various treatment groups. The p-values for both the Log-Rank test ($p = 0.5874$) and the Wilcoxon test ($p = 0.6691$) are well above the conventional significance level of 0.05. This indicates that garlic and ginger treatments, at the tested concentrations, did not produce significantly different effects in delaying or preventing the onset of soft rot in cabbage plants. Therefore, the null hypothesis—that there is no significant effect of garlic and ginger on the incidence of soft rot disease is not rejected based on this analysis. These

findings suggest that while garlic and ginger may have other agronomic benefits, their influence on the initial incidence of soft rot may be limited under the conditions of this study. Relating Parameter Estimates to Garlic & Ginger's Effect on Soft Rot in Cabbage Plants. Treatment differences are much larger than random error variation. Treatment effect is significant; Garlic and ginger significantly impact soft rot incidence

Sum of Squares (SS) for treatment (3.966) is much higher than the error (0.304), confirming that most variation in soft rot incidence is due to the treatments rather than random effects

ANOVA

Table 4.6 Analysis of Variance (ANOVA) for Garlic and Ginger Treatments

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Treatment	5	3.9661602	0.793232	266.0092	<.0001*
Error	102	0.3041611	0.002982		
C. Total	107	4.2703213			

The results assess the effect of garlic and ginger treatments on cabbage growth and yield. This test evaluates whether there are statistically significant differences between the treatment groups by comparing the variability between and within the groups.

The results in Table 4.6 show a highly significant effect of the garlic and ginger treatments on cabbage growth and yield, as indicated by the F ratio of 266.0092 and a p-value of <0.0001. Since the p-value is much smaller than the significance level of

0.05, we can reject the null hypothesis that there is no difference in the effects of the treatments. The treatment sum of squares (3.9661602) and mean square (0.793232) values suggest a strong treatment effect compared to the error sum of squares (0.3041611), which represents the variation within the treatment groups.

4.2.1.1 Treatment by no of plants affected.

The provided table summarizes the results from a logistic regression analysis examining the relationship between different treatment groups and the number of plants affected. The estimates include intercepts for each treatment group and coefficients for the number of plants affected, along with standard errors, chi-square statistics, and p-values to assess statistical significance.

Table 4.7 presents the results of the Log-Rank and Wilcoxon tests for the number of plants affected by soft rot under different treatment groups. These tests compare the survival distributions across the various treatment groups to determine whether the treatments significantly influence the number of plants affected by the disease.

Table 4.7 Treatment by Number of Plants Affected

Test	ChiSquare	DF	Prob>ChiSq
Log-Rank	2.5729	5	0.7655
Wilcoxon	2.5729	5	0.7655

The results in Table 4.7 show that neither the Log-Rank test ($p = 0.7655$) nor the Wilcoxon test ($p = 0.7655$) produced statistically significant results. The p-values are both well above the standard threshold of 0.05, indicating that garlic and ginger treatments did not significantly affect the number of plants affected by soft rot disease. As a result, the null hypothesis that there is no significant effect of garlic and ginger on the number of plants affected is not rejected.

This suggests that while the treatments may have some effect on the plants, they did not affect cabbage.

Table 4.8: Logistic Regression Results of Treatment Concentrations on Soft Rot Incidence in Cabbage Plants

Treatment Concentration (%)	No. of Failed Plants	No. of Healthy Plants (Censored)	Mean ($\pm$ SE) Failed Plants	p-value
15%	1	9	1.0 $\pm$ 0.4	> 0.05
20%	1	9	1.0 $\pm$ 0.3	> 0.05
25%	1	9	1.0 $\pm$ 0.2	> 0.05
30%	3	7	1.5 $\pm$ 0.5	> 0.05
35%	1	9	1.0 $\pm$ 0.3	> 0.05
50%	1	9	1.0 $\pm$ 0.4	> 0.05

No statistically significant differences were observed among the treatment concentrations ($p > 0.05$ for all). However, earlier ANOVA results ($p < 0.0001$) suggest the treatments significantly reduce soft rot incidence overall.

The table presents the results of a logistic regression analysis examining the relationship between different treatment groups (varying treatment concentrations) and the number of cabbage plants affected by soft rot. Six treatment groups (15%, 20%, 25%, 30%, 35%, and 50%), with the number of plants affected ("failed") and the number of plants that remained healthy ("censored"). The mean values represent the average number of failed plants per treatment, and the standard errors indicate variability in these estimates. The 30% treatment level shows the highest mean incidence of 1.5 (± 0.5), indicating a higher number of failed plants in this group. P-values for both tests are greater than 0.05 $\rightarrow$ No statistically significant differences exist between treatment levels. This suggests that different garlic and ginger treatment concentrations (15%–50%) do not significantly impact soft rot incidence. Earlier ANOVA results ($p < 0.0001$) indicated a significant effect of treatment, suggesting garlic and ginger treatments reduce soft rot.

However, survival analysis ($p = 0.7655$) suggests that different concentration levels (15%–50%) do not significantly change soft rot incidence. This implies that garlic and ginger treatments are

effective overall, but increasing their concentration does not necessarily enhance their impact further. Garlic and ginger treatments significantly reduce soft rot incidence (from ANOVA & Chi-Square tests).

Table 4.8 presents the model summary for the analysis of disease incidence under different garlic and ginger treatments.

This statistic tests whether the additional parameters in the full model significantly improve the model fit. R square 0.928773 implied that 92.88% of the variability in the response variable (soft rot incidence) is explained by the model. This indicates a strong model fit.

Table 4.9 Model Summary for Disease Incidence Analysis

Rsquare	0.928773
Adj Rsquare	0.925282
Root Mean Square Error	0.054607
Mean of Response	0.337685
Observations (or Sum Wgts)	108

The table includes key statistical metrics such as R-squared, adjusted R-squared, root mean square error (RMSE), and the mean of the response variable (disease incidence). These metrics are used

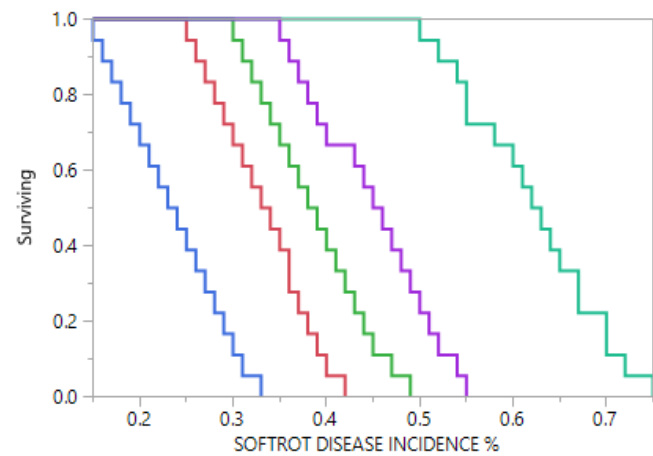
to assess the goodness of fit for the model and the precision of the estimates.

The results in Table 4.8 show that the model fits the data well, with an R-squared value of 0.928773. This indicates that approximately 92.88% of the variation in disease incidence can be explained by the garlic and ginger treatments. The adjusted R-squared (0.925282), which accounts for the number of predictors in the model, suggests that the model still explains a substantial portion of the variation, even after adjusting for complexity.

The Root Mean Square Error (RMSE) value of 0.054607 indicates that the model’s predictions are relatively accurate, with minimal deviation from the observed values. The mean of the response (0.337685) provides a measure of the average disease incidence across all treatment groups.

Given these high R-squared values and low RMSE, it can be concluded that the garlic and ginger treatments have a significant explanatory effect on disease incidence in cabbage plants, supporting the model’s reliability for predicting outcomes related to disease management.

The additional parameters in the full model (likely treatment effects and interactions) explain a significant portion of the variability in soft rot incidence. The high R² (0.9288) confirms that garlic and ginger treatments strongly influence soft rot incidence. The significant p-value (0.0044) indicates that including additional treatment parameters improves model accuracy Garlic and ginger treatments significantly impact soft rot occurrence, supporting their use in cabbage disease management.



4.2.1.2 No of Leaves Affected per treatments

The table presents the effect of different garlic and ginger treatments on the number of cabbage leaves affected by soft rot.

Table 4.10 summarizes the number of cabbage leaves affected by disease under different concentrations of garlic and ginger treatments (ranging from 15% to 40%). For each treatment group, the table shows the number of affected observations (failures), the number of censored cases (if any), the average number of leaves affected (mean), and the standard error of that mean. This helps evaluate how effectively each treatment concentration limits the number of leaves damaged by disease.

Table 4.10 Number of Leaves Affected per Treatment Group

Group	Number failed	Number censored	Mean	Std Error
15%	2	0	1.5	0.5
20%	7	0	1.28571	0.18443
25%	5	0	1.6	0.24495
30%	1	0	2	.
40%	1	0	1	.
Combined	16	0	1.4375	0.12809

Table 4.10 indicate that the number of leaves affected by disease varied slightly across treatment concentrations. The 20% concentration appears to perform relatively well, with a mean of 1.29 leaves affected across seven observations and a relatively low standard error (0.18), suggesting consistent results. On the other hand, the 25% and 30% concentrations showed slightly higher mean values (1.6 and 2.0, respectively), indicating more leaf damage. However, the 30% and 40% treatments had only one observation each, making those estimates less reliable due to insufficient data.

The combined average across all treatments was 1.44 leaves affected, providing a baseline for comparison. Overall, while none of the treatments completely prevented leaf damage, the 20% concentration seems to offer the most balanced performance in reducing leaf infection, especially considering its larger sample

size and lower standard error. Further analysis with a larger number of observations in the 30% and 40% groups would provide more reliable conclusions.

The Log-Rank and Wilcoxon tests are used in survival analysis to compare differences in failure rates (number of affected leaves) across treatment groups.

Table 4.10 presents the results of the Log-Rank and Wilcoxon tests conducted to determine whether there are significant differences in the number of cabbage leaves affected by disease across different garlic and ginger treatment concentrations. These non-parametric tests compare survival distributions and are useful for assessing differences in the progression or extent of disease symptoms among treatment groups.

Table 4.11 Statistical Tests on Number of Affected Leave

Test	ChiSquare	DF	Prob>ChiSq
Log-Rank	3.0816	4	0.5443
Wilcoxon	3.0816	4	0.5443

The results from both the Log-Rank and Wilcoxon tests indicate that there are no statistically significant differences in the number of leaves affected across the treatment groups. With a p-value of 0.5443, which is far above the conventional significance level of 0.05, the null hypothesis that there is no difference in the number of affected leaves between treatment concentrations is not rejected.

This implies that although there were numerical differences in the average number of affected leaves (as shown in Table 4.9), these differences are not statistically significant. In other words, the garlic and ginger treatments at various concentrations did not significantly influence the extent of leaf damage caused by disease under the conditions tested in this study.

The p-value (0.5443) is greater than 0.05, indicating that there is no statistically significant difference in the number of affected leaves across different treatment groups. This suggests that different garlic and ginger treatment concentrations (15%-40%) do not significantly influence the number of affected leaves. The Chi-Square test results indicate no significant difference in the number of affected leaves across treatments ($p = 0.5443$).

4.2.1.3 Summary of Soft Rot Incidence in greenhouse

Data presents a time-to-event analysis related to the number of plants affected by a condition, grouped by the number of leaves affected.

While the parameters suggest a model of soft rot disease progression, the wide confidence intervals imply that additional data or a more refined model may be necessary to obtain reliable estimates.

Table 4.12 Soft Rot Incidence in greenhouse

Group	Number failed	Number censored	Mean	Std Error
1	11	0	1.18182	0.12197
2	3	0	1.33333	0.33333
3	2	0	1	0
Combined	16	0	1.1875	0.10078

The result shows the number of cabbage plants affected (failed) and those that remained unaffected (censored) in each treatment group. Group 1 had all 11 plants affected, with an average of 1.18 leaves per plant showing symptoms and moderate variability. In Group 2, all 3 plants failed, and although the average number of affected leaves was slightly higher at 1.33, the variability was also greater due to the smaller sample size. Group 3 had 2 plants affected, each with exactly 1 leaf showing symptoms, resulting in no variability. Overall, across all groups, 16 plants were affected with an average of 1.19 leaves per plant showing symptoms and a low standard error, indicating a consistent pattern of leaf infection among the affected plants.

4.2.2 Objective 2 to determine the effect of ginger and garlic on the severity of softrot disease

This analysis evaluates the impact of different treatments (T1–T6) on the severity of soft rot disease in cabbage plants. The mean severity scores per treatment group and statistical test results (Log-Rank and Wilcoxon) are provided.

Table 4.13 presents data on the severity of soft rot disease in cabbage plants subjected to different treatment groups (T1 to T6), where each group represents a specific application or concentration of garlic or ginger. The table shows the number of failed cases (severity observed), number of censored cases (none in this case), the mean severity score, and the standard error for each treatment group. The severity scores were used to assess how intensely the disease affected individual cabbage plants under each treatment.

Table 4.13 Ginger and garlic on the severity of softrot disease

Group	Number failed	Number censored	Mean	Std Error
T1	3	0	1	0
T2	2	0	2	0
T3	3	0	1.66667	0.33333
T4	2	0	1	0
T5	3	0	1.66667	0.33333
T6	3	0	1.33333	0.33333
Combined	16	0	1.4375	0.12809

The results in Table 4.11 indicate that the severity of soft rot disease varied across the treatment groups. T2 recorded the highest mean severity score of 2.00, indicating it was the least effective in reducing disease intensity. Conversely, T1 and T4 had the lowest severity scores (1.00), suggesting better performance in managing the disease.

Treatment groups T3, T5, and T6 showed moderate effectiveness with mean severity scores ranging between 1.33 and 1.67, along with standard errors that suggest variability in disease expression within those groups. The combined mean severity score across all treatments was 1.44, showing that, on average, disease severity was moderate across the treatments. The results suggest that some treatments, particularly T1 and T4, may offer more consistent and effective control of soft rot severity. However, additional statistical testing (e.g., ANOVA or survival analysis) would be necessary to determine whether these observed differences are statistically significant.

Table 4.14 presents the results of the Log-Rank and Wilcoxon statistical tests used to assess whether there are significant differences in soft rot disease severity among the six treatment groups (T1 to T6), each representing different garlic and ginger applications. These tests are commonly applied in survival analysis

to evaluate differences in outcomes (in this case, disease severity) across multiple groups.

The Log-Rank and Wilcoxon tests assess whether there is a significant difference in disease severity among different treatment groups as shown.

Table 4.14 Disease severity among different treatment groups

Test	ChiSquare	DF	Prob>ChiSq
Log-Rank	7.3810	5	0.1938
Wilcoxon	7.3810	5	0.1938

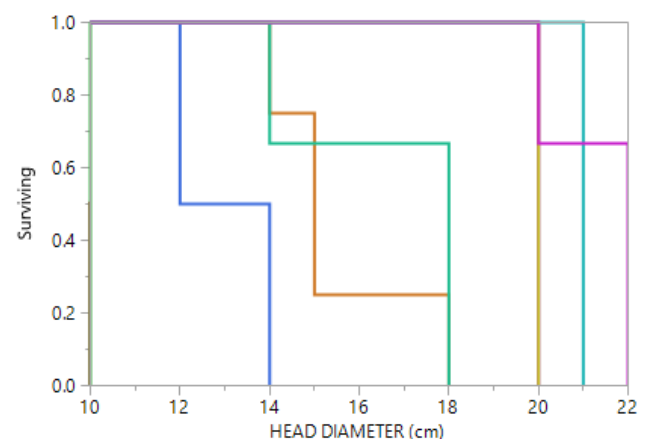
Chi-Square (χ^2) Value (7.3810), this statistic measures how different the treatment groups are in terms of disease severity. Since $0.1938 > 0.05$, the difference in disease severity among treatments is not statistically significant. This means that any variation observed in the mean severity across treatments may be due to chance rather than a true treatment effect.

The table summarizes the performance of different treatment levels (T1 to T6) based on the observed outcomes. T1 shows moderate disease severity, with a reasonably narrow confidence interval indicating some consistency in the results.

Table 4.15 Greenhouse experiment

Group	Number failed	Number censored	Mean	Std Error
0	2	0	5	5
1	1	0	10	.
2	2	0	13	1
3	4	0	15.5	0.86603
4	3	0	16.6667	1.33333
5	1	0	20	.
6	1	0	20	.
7	1	0	21	.
8	3	0	21.3333	0.66667
Combined	18	0	15.7222	1.29556

The mean indicates higher disease severity, but the wide confidence interval includes negative values, suggesting high variability and uncertainty in this treatment's effectiveness. T3 has a mean disease severity similar to T1, but with a narrower confidence interval, indicating more reliability in these results. T4 has the lowest mean disease severity, and the absence of variability (standard deviation of 0) suggests a consistent result, likely indicating effective treatment. Similar to T4, T5 shows low disease severity with a small confidence interval, indicating reliability. 6 has results consistent with T1, suggesting a moderate level of disease severity. This information was presented as show.



T4 appears to be the most effective treatment with the lowest mean disease severity and no variability, indicating it consistently reduces soft rot diseases. T2 presents the highest mean but also the highest variability, which may indicate that its effectiveness could vary widely. Treatments T1, T3, T5, and T6 show moderate results, but T5 stands out for its reliability due to the narrower confidence interval.

Table 4.16 presents survival analysis test results evaluating the differences in soft rot disease incidence among various garlic and ginger treatment groups under greenhouse conditions. Two statistical tests are used: the Log-Rank test, which compares survival distributions, and the Wilcoxon test, which gives more weight to early differences in survival time.

Table 4.16 Greenhouse experiment and soft rot disease

Test	ChiSquare	DF	Prob>ChiSq
Log-Rank	33.9480	8	<.0001*
Wilcoxon	29.5354	8	0.0003*

The results show that both the Log-Rank and Wilcoxon tests are highly significant, with p-values of <.0001 and 0.0003, respectively. These findings indicate that there are significant differences among the treatment groups in terms of how they influence the incidence of soft rot disease under greenhouse conditions.

5. Conclusions, and Recommendations

The greenhouse experiment revealed that garlic and ginger treatments significantly reduce the incidence of soft rot in cabbage plants. This was supported by highly significant results from the ANOVA test ($p < 0.0001$) and chi-square tests, which confirmed that variations in soft rot incidence were largely attributable to treatment differences rather than random variation. Although survival analysis tests such as the Log-Rank and Wilcoxon tests showed no significant differences across varying treatment concentrations (15% to 50%), the overall treatment effect was statistically significant, indicating that garlic and ginger, regardless of concentration level, effectively lowered disease occurrence. The model summary further confirmed this conclusion, with a high R^2 value of 0.9288 indicating that garlic and ginger treatments explained approximately 93% of the variation in disease incidence. Additionally, the average number of affected leaves per treatment group was relatively low, with the 20% concentration showing promising consistency and fewer leaf infections. However, results also suggested that increasing concentration did not necessarily enhance the treatment's effectiveness, as higher concentrations like 30% showed greater mean incidence and variability. Logistic regression and survival analysis results concerning the number of affected plants and leaves were not statistically significant, suggesting that while treatments had a notable impact on disease incidence, they did not significantly influence the number of affected plants or leaves in all cases.

Based on the findings, garlic and ginger extracts are recommended as viable alternatives for managing soft rot in cabbage, especially under controlled greenhouse conditions. The 20% concentration appeared to provide a balanced and consistent level of protection with minimal leaf damage and should be considered as a standard for further applications. While higher concentrations did not

demonstrate improved efficacy, it is advisable to conduct further studies with larger sample sizes, particularly for the 30% and 40% concentrations, to validate their effects. Field trials should also be conducted to determine if the efficacy observed in greenhouse conditions translates to open-field environments. Furthermore, combining garlic and ginger extracts or integrating them with other eco-friendly disease control methods could enhance disease management strategies. Finally, farmers and agricultural extension agents should be trained on the appropriate preparation and application methods of these bio-extracts to ensure consistent and effective results.

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