BINDURA UNIVERSITY OF SCIENCE EDUCATION

CROP SCIENCE DEPARTMENT

Effectiveness of hot water treated seed for controlling pest and diseases in different mechanically harvested sugarcane varieties

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS OF THE BACHELOR OF AGRICULTURAL SCIENCES HONOURS DEGREE IN CROP SCIENCE

(CROP SCIENCE)

JUNE 2025

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DEDICATION

This project is dedicated to my beloved parents and all sugarcane farmers in Zimbabwe.

ACKNOWLEDGMENT

I would firstly like to express my gratitude to the Almighty for the opportunity he has granted me and from whom all wisdom and knowledge flows and whose mercy has made it possible.

I would also sincerely thank my supervisor; Mr. J. Chitamba for the unyielding support that he extended to me to come up with a quality write-up. I appreciate his efforts because he offered me all the necessary guidelines, I needed during the preparation for this research project. My gratitude also goes to the Agronomy Department at Green fuel Estate especially Mr W Mukoka and Mr D Nkosa for their undivided support throughout the project.

Finally, I deeply thank my family and close friends Lonvedmah Simango and Prince Muchati for the moral support and encouragement extended during this study.

ABSTRACT

One of the most important areas of research for sustainable sugarcane production is the extent to which hot water treatment of sugarcane seeds controls diseases and pests in various ratoon cycles in mechanically harvested sugarcane systems. This study examined how hot water treatment affects disease suppression, pest incidence and seed viability throughout a range of ratoon cycles. Key agronomic factors such as plant vigor, levels of pest infestation and disease prevalence across several ratoon generations, were evaluated. The experiment was carried out as a 2×3 factorial, laid in a randomized complete block design (RCBD) with three replications. Results revealed that hot water treatment significantly ($p<0.001$) reduced smut disease incidence, with untreated ZN10 showing the highest incidence as compared to treated N53. Similarly, hot water treatment seed cane consistently exhibited lower Eldana infestations across tested varieties, with untreated varieties showing high Eldana population than hot water treated varieties. The analysis of Eldana damage intensity further confirmed significant differences ($p<0.001$), with untreated varieties suffering from high damage intensity rates. Regarding ratoon stunted disease, untreated ZN10 had the highest incidence while hot water treated N53 showed remarkable resistance incidence. These findings underscore the potential of hot water treatment as an effective pest and disease management strategy in sugarcane cultivation, promoting healthier crops and potentially increasing yields in mechanized farming systems. Future research should explore optimal treatment conditions and long-term impacts on sugarcane productivity.

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CHAPTER 1: INTRODUCTION

1.1 Background of the study

Sugarcane (*Saccharum officinarum*) is known as a tall perennial grass which belongs to the Poaceae family. It is mostly cultivated for its high sugar content, which is extracted from the stems of the plant (FAO, 2020). Sugarcane is believed to have originated in New Guinea and spreading to other parts of the world through human migration and trade (Singh, 2018).

Ancient Chinese and Indian literature provide proof that sugarcane has been cultivated for thousands of years (Singh, 2018). Around the eighth century, Arab traders brought it to the Mediterranean region, and during the era of exploration, it spread to other regions of the world, including Europe, Africa and the Americas.

Sugarcane is primarily grown in tropical and subtropical regions due to its preference for warm climates. It requires abundant rainfall or irrigation, well-drained soil, and a frost-free environment to thrive (Garside & Bell, 1998). It is a C4 plant, which means it has a specialized method of carbon fixation that allows it to efficiently convert carbon dioxide into sugars (Moore, 2005). In Zimbabwe it is mainly in the low veld areas like Chiredzi , Chisumbanje and Tanganda areas under irrigation.

The plant typically reaches a height of 2 to 6 meters and has stout, jointed stalks that are filled with sweet sap. The stalks are rich in sucrose, which is the main component of sugar. After the sugarcane is harvested, the stalks are crushed to extract the juice, which is then processed to remove impurities and crystallize the sugar (Garside & Bell, 1998).

Sugarcane is not only a major source of sugar but also used for the production of other products such as molasses, ethanol, and biofuels. Furthermore, bagasse the fibrous waste left over after sugar is extracted is used to make paper, pulp and building materials as well as biofuel (Garside & Bell, 1998).

Brazil, India, China, Thailand and Pakistan are the top producers of sugarcane worldwide. A major amount of the world's sugar production comes from sugarcane, of which Brazil is the biggest producer and exporter (FAO, 2020). Sugarcane (*Saccharum officinarum*) is a tropical and subtropical crop that has specific soil and climatic requirements for optimal growth and productivity. Here are the soil and climatic requirements of sugarcane:

The optimum soils for sugarcane growth are those that drain well and have a high water-holding capacity. Loamy soil is the best kind for growing sugarcane since it contains a balanced amount of clay, silt, and sand particles. The optimum soil pH range for sugarcane cultivation is between 5.5 and 8.0. Sugarcane can tolerate slightly acidic to mildly alkaline soils. Soils with a significant amount of organic matter are preferred by sugarcane. Soil structure, retention of water and availability of nutrients are all enhanced by organic matter.

Adequate soil drainage is crucial for sugarcane cultivation. Root rot and other diseases can be caused by waterlogged and poor drainage. The optimum temperature for sugarcane growth range from 20°C and 35°C. Sugarcane is sensitive to frost and cannot tolerate temperatures below freezing.

Sugarcane requires a well-distributed rainfall pattern for optimal growth. The crop needs an average annual rainfall of 1,000 to 1,500 millimeters for satisfactory growth. However, sugarcane is also cultivated in regions with lower rainfall by utilizing irrigation methods. Sugarcane is a high-light crop and requires full sunlight for maximum photosynthesis and sugar production.

Pests and diseases, such as Eldana and smut, have been identified as major challenges in sugarcane production. Eldana (Eldana saccharina) is a stem-boring insect that causes extensive damage by feeding on the sugarcane stalks, resulting in yield reduction, sucrose losses and weakened stalks susceptible to lodging. Smut, caused by the fungus *Sporisorium scitamineum*, affects sugarcane inflorescences, resulting in deformities, reduced sugar content and seed contamination (Rutherford *et al*., 2015).

Mechanical harvesting has become increasingly popular due to its efficiency and cost-effectiveness. However, this harvesting method can potentially exacerbate the susceptibility of sugarcane crops to pests and diseases. The mechanical harvesting process exposes the sugarcane stalks to wounds, creating entry points for pests and pathogens. As a result, effective pest and disease control measures are crucial to mitigate the risks associated with mechanical harvesting.

Hot water treatment is a common method used to control diseases in cane seed. It involves immersing the seed in hot water for a specific duration, which helps eliminate pathogens and reduce the risk of disease transmission. Hot water treatment is primarily used as a preventive measure rather than a curative one. It is typically applied to healthy cane seed before planting to reduce the risk of disease establishment and subsequent yield losses (Rott *et al*., 2015)

The temperature and duration of hot water treatment are critical factors in its effectiveness. Generally, cane seed is immersed in water at temperatures ranging from 50°C to 55°C for a period of 15 to 20 minutes (Smith *et al*., 2018). Hot water treatment helps control various diseases in cane seed, including fungal, bacterial, and viral infections. It can significantly reduce the transmission of pathogens, such as smut (*Sporisorium scitamineum*) and ratoon stunting disease (*Leifsonia xyli* subsp. Xyli (Rott *et al*., 2015). The high temperature of hot water treatment kills or weakens pathogens present on the surface of cane seed. It can eliminate spores, mycelia, and other infectious structures, reducing the risk of disease spread during planting (Garside, 2010).

1.2 Problem statement and justification

In Zimbabwe, sugarcane is an essential cash crop but pests and diseases especially in ratoon crops have a major impact on its output. Crop residue from mechanically harvested sugarcane systems may include pests and pathogens which could increase the risk of disease in further ratoon cycles. Traditional chemical treatments are frequently employed to address these problems but they raise production costs, harm the environment, and can result in pesticide resistance.

Sugarcane seed sets treated with hot water (HWT) offer a viable and environmentally responsible way to manage diseases and pests. Its efficacy over several ratoon cycles in mechanically harvested fields is still undetermined yet. The goal of this study is to assess whether hot water treatment increases ratoon longevity and production lowers the incidence of pests and diseases and improves seed health. The results could lessen the need for chemical pesticides and increase farmer profitability by offering insightful information for sustainable sugarcane production.

1.3 Specific objectives.

1. To assess the effectiveness of hot water treated seed cane on Eldana population dynamics in different mechanically harvested sugarcane varieties.

2. To investigate the effectiveness of hot water treated seed cane on smut disease incidence in different mechanically harvested sugarcane varieties.

3. To determine the effectiveness of hot water treated seed cane on ratoon stunted disease incidence in different mechanically harvested sugarcane varieties.

1.4 Hypotheses

1. Hot water treatment has significant effect on Eldana population in different varieties of mechanically sugarcane.
2. Hot water treatment has significant effects on smut disease incidence in different mechanically harvested sugarcane varieties.
3. Hot water treatment has significant effect on ratoon stunted disease incidence in different mechanically harvested sugarcane varieties.

CHAPTER 2: LITERATURE REVIEW

2.1 General background on sugarcane production

Sugarcane (*Saccharum spp*.) is an example of the Poaceae family, which includes big tropical or subtropical grasses that are widely produced within the 30° zone on either side of the equator (Moore, Paterson, and Tew, 2014). *S. officinarum, S. barberi, S. sinence, and S. spontaneum* are the most widely recognized species in the Saccharum genus and are utilized in contemporary breeding initiatives for the generation of commercial sugarcane hybrids (Ngomane 2015).

Sugarcane is grown on over 23 million hectares of land in more than 90 countries worldwide (Mnisi and Dlamini 2020). Around 75 percent of the sucrose produced worldwide comes from sugarcane (Da Silva and Bressian 2005). A significant renewable energy source that has recently drawn attention due to the manufacturing of ethanol, sugarcane is also used to produce raw sugar. According to Meyer *et al.,* (2019), Brazil is the world's largest producer of sugarcane, with over half of its output going into ethanol.

Sugarcane production in Zimbabwe is primarily concentrated in the Lowveld regions, particularly in the southeast around Chiredzi and Triangle, and the northwest around Chisumbudzi and Chechete (Morandini *et al.,* 2006). These regions enjoy favorable climates, with warm temperatures, plenty of sunshine, and sufficient water supply from perennial rivers such as the Runde and Save. Thomas Murray McDougall planted sugar cane in the Triangle for the first time in 1931, and it was processed for the first time in 1939. Hippo Valley Estates was founded in 1956 as a citrus estate and quickly expanded by planting its first cane three years later in 1959. Until the 1970s, when the price of canned crush dropped, Hippo Valley fruit was exported throughout Southern Africa. In 1975, the company developed its sugarcane irrigation programs to irrigate its sugar plantations.

2.2 Sugar cane germination and growth process

2.2.1 Germination

The process by which sugarcane cultivated via vegetative propagation begins to grow from buds that are found in the planted setts of the stools that remain in the soil following the previous crop's harvest is known as germination (Willcox *et al*., 2000). Typically, cultivars require different temperatures for germination. Most cultivars have a low capacity for germination at temperatures below 18 °C, but germination will grow rapidly up to 35 °C. Additionally, good germination is induced by cultivating seed cane under favorable conditions, such as adequate soil water and aeration, as well as healthy soil nutrition. Internal factors, such as sett moisture, nutrient levels and bud health, may influence germination (Hossain 2010).

2.2.2 Tillering

According to Moore and Botha (2014), tillering is the process by which side shoots grow from an existing culm's auxiliary buds to generate new culms. The tillering stage, which can last up to 120 days from planting, starts about 40 days after planting and results in the production of many cane stalks that form a stool. Although the degree of tillering and the tillers' ability to survive to maturity are partially determined by genetics, they are also impacted by climatic factors like as light, temperature, and soil moisture, as well as soil and nutritional conditions (Donaldson 2017). Until the tiller population peaks, this process keeps going.

2.2.3 Stem elongation

The intercalary meristem creates cells that thereafter grow, a process known as stem elongation (Moore and Botha 2014). As long as the cane has ideal circumstances, such as daytime temperatures over 25 °C and nocturnal temperatures of 15 °C, enough soil water, and enough radiation levels, stalk elongation rates of about 2 cm/day can be observed in tropical environments (Soopramanien 2000). During the maturity and ripening period, the amount of sucrose increases and the growth rate drops. Throughout the stem's maturity, each internode operates independently. The internodes finish elongating the cells, thickening the cell wall, and filling with sucrose while the green leaf is still attached. While the upper portion of the stem is still developing, the lower internodes are practically ripe. However, when conditions are not favorable for photosynthesis, the stored sugar can still be translocated to enable additional tillering or growth (Bull, 2000).

2.3 Impact of hot water treatment on setts germination

Studies have reported significant increases in sugarcane germination after treated seeds with hot water compared to untreated controls (Zhou & Chen, 2012; Singh *et al.*, 2018). The optimal temperature and duration of treatment vary depending on variety and local conditions, but typically range from 50°C to 54°C for 20-30 minutes (Kumar *et al*., 2015). Hot water treatment effectively eliminates fungal pathogens residing on the seed surface or within the seed coat, preventing disease transmission and seedling mortality (Pandey *et al*., 2020). This is particularly beneficial for managing diseases like red rot and smut caused by fungal pathogens that can weaken the seed coat, facilitating water uptake and imbibition necessary for germination in seeds with physical dormancy (Sirohi *et al*., 2016). This can be advantageous for varieties exhibiting dormancy characteristics. Optimal temperature and duration of hot water treatment need to be carefully calibrated for each sugarcane variety to avoid damaging seed tissues (Pandey *et al.*, 2020).

2.4 Effects of hot water treatment on growth parameters

Studies have shown that hot water treatment can significantly increase germination rates in sugarcane compared to untreated setts. This is attributed to the weakening of seed dormancy. Hot water exposure disrupts the seed coat's physical and biochemical barriers, allowing for easier water imbibition and subsequent germination (Yohannes *et al.,* 2012). Elimination of pathogens hot water treatment helps in controlling fungal and bacterial pathogens residing on the sett surface or within the buds, promoting healthy seedling development. (Johnson and Tyagi, 2006) Research suggests that hot water treatment can positively influence shoot emergence, plant height, and tillering in sugarcane. This is likely due to Stimulation of enzymatic activity: Hot water exposure can activate enzymes involved in various physiological processes, leading to increased cell division and shoot growth. Improved nutrient uptake: Hot water treatment may enhance root development and nutrient uptake efficiency, contributing to better plant growth and yield.

2.5 Optimal conditions for Hot water treatment

Sugarcane encompasses diverse varieties with varying dormancy mechanisms, seed coat characteristics, and sensitivity to heat (Pandey *et al.,* 2020; Liu *et al.,* 2022). Varieties with physical dormancy might benefit from hot water treatment to soften the seed coat, while physiologically dormant varieties might require additional treatments (Ahmed *et al.*, 2017). Larger setts might require higher temperatures or longer durations compared to smaller ones, and immature setts might be more sensitive to hot water treatment (Yadav *et al.,* 2018). Hot water treatment targets specific pathogens. Identifying prevalent diseases in a particular variety helps determine desired inactivation temperatures (Singh *et al.,* 2021).

2.6 Methods of Optimising Germination Potential

Cane and sugar yields are increased when cane setts germinate vigorously and the plant grows quickly in the early stages. Germination and subsequent growth of the sugarcane are influenced by environmental conditions, variety, cane quality, cane age, length of setts, initial bud position on the stalk and treatments like fungicides and thermotherapy. To increase the viability and vigor of the setts and resulting plants, these characteristics must be evaluated to identify areas for improvement.

2.6.1 Treatment of setts

2.6.1.1 Long hot water treatment

The only method currently used in South Africa to treat SBS and whole setts (WS) to eradicate *C. x. xyli* is hot water treatment (HWT) at 50 °C for 120 minutes (Carvalho *et al.*, 2016). The rate of heat transfer varies depending on the sett's length, diameter, and heterogeneity in structure, but it also depends on how well the setts can withstand heat stress and how long it takes to cure ratoon stunted disease (Croft & Ricaud, 2013). The death rate increases with treatment duration because fewer plant cells survive to generate roots and shoots (Benda, 2019). Cane is almost killed by the combination of temperature and time needed to eradicate ratoon stunted disease. The N14, N17, N10, and N21 cultivars are reported to be very sensitive to the standard heat treatment of 50°C for 120 minutes in South Africa. To ascertain if heat treatment of SBS at 50 °C is effective in suppressing *Leifsonia xyli subsp. xlyl*i an experiment was conducted at SASEX.Cane is almost killed by the combination of temperature and time needed to eradicate ratoon stunted disease. The N14, N17, N10 and N21 cultivars are reported to be very sensitive to the standard heat treatment of 50°C for 120 minutes in South Africa. To find out how well SBS heat treatment at 50 °C controlled *Leifsonia xyli subsp. xlyli*, an experiment was conducted at SASEX. It was discovered that *Leifsonia xyli subsp. xlyli* was not well controlled by treatments lasting 30 or 60 minutes and infection persisted even after 90 minutes of treatment. A 120-minute treatment was sufficient to completely suppress *Leifsonia xyli subsp. xlyli* (Anon., 1988a). In Hawaii, *Leifsonia xyli subsp. xlyli* was completely controlled after treatment at 50°C for 120 minutes, while infected seed pieces treated at 52°C for 30 minutes had 20.6% of the infection remaining. According to Benda (2019), setts treated at 52°C for 30 minutes for three days in a row showed higher growth and sufficient control of *Leifsonia xyli subsp. xlyli* (1.2% infection persisting) compared to treatment at 50°C for

120 minutes. When heat-sensitive cultivars' stalks cannot be treated at the highest temperatures possible, serial heat treatments are advised. To help the cane adjust to the high temperature, it must be pre-treated for a brief time at the necessary temperature. After that, the cane is more resilient to further treatments and can tolerate higher temperatures and longer treatments than untreated cane (Lemma, 2013). One to five days before to treatment at 50°C for 120 minutes, young heat-sensitive cane is frequently pre-treated for 10 to 20 minutes (Viswanathan, 2012).

2.6.1.2 Short heat treatment

Early development and germination have been enhanced by brief hot water treatments. The percentage of buds that germinate as well as the rate at which roots and shoots germinate may both rise when heat doses are not fatal (Benda & Ricaud, 2011). Sugarcane undergoes several physiological changes after a brief heat treatment, such as enhanced sugar secretion (Bailey, 2017) and loss of apical dominance due to the bud region's hormonal balance being established (Brandes & van Overbeek, 2015). When two varieties, NCo376 and J59/3, were heat treated for a brief length of time to promote sett germination, a significant amount of the abscisic and IAA (Indole Acetic Acid) leached out of the setts into the water in the SASEX trials.

According to studies conducted in Taiwan and Pakistan, soaking sugarcane setts in water at 52 °C for 20 minutes accelerated the growth of young cane stools and buds, and at three months after planting, the number of shoots had grown dramatically (Peng, 2018). Additionally, Comstock *et al.,* (2018) found that germination rates were higher after 15 and 20 minutes of treatment at 52°C. In comparison to benomyl in cold water, germination was enhanced by 10–90% when seed pieces were treated with benomyl in hot water (52 °C) for 10 and 20 minutes (Comstock *et al.,* 2018). The highest germination of the three kinds was obtained when (Sheets, 2014) treated setts at temperatures ranging from 35 to 60°C for 5, 10, 15 and 20 minutes. Additionally, treatment at 40°C and 45°C for five minutes produced the best results.

2.7 Ratoon Stunting Disease

Subsp. xyli of Clavibacter xyli Ratoon stunting disease (RSD) is caused by the xylem-limited bacteria Davis *et al., (C. x. xyli*) (Davis *et al.,* 1980, 1984. The most common sugarcane disease in South Africa, according to Bailey and Bechet (2018), causes shorter, thinner stalks and fewer stalks overall, which drastically reduces yields. In a study conducted under rainfall conditions at Mount

Edgecombe, RSD infection caused substantial yield declines in a first ratoon crop for cultivars N17 (-36%), N14 (-24%), NCo376 (-24%), and N21 (-20%), whereas yield reductions were moderate for N12 (-14%) and N19 (-13%). According to Bailey and Bechet (1986), the signs of a *C. x. xy* infection are subtle, and direct immunofluorescence microscopy (IFM) or phase-contrast microscopy (PCM) are used at SASEX to identify the pathogen. The first methodology requires just 3.1 x 103 cells.mt1 in naturally-infected sugarcane sap, making it more accurate than the PCM method, which requires an amount of 2 x 106 cells.ml'1 for detection (Guzman & Victoria, 2016).

Controlling *C. x. xyli* requires strategies other than varietal resistance because none of the commercial cultivars have complete resistance or tolerance to the disease. Cutting instruments contaminated by harvesting infected volunteers are the primary source of *C. x. xyli* transmission. Thus, it is crucial to grow seedcane free of *C. x. xyli* in order to keep the disease out of nurseries and commercial fields. Hot water treatment is the only method for eliminating *C. x. xyli* from infected setts. All sett tissues must reach the required temperature and time threshold in order for the pathogen to perish (Gopitha *et al*, 2010). Around the world, hot water treatment at 50°C for 120–180 minutes is widely utilized (Damann, 2013). In South Africa, this is the only approach.

2.8 *Eldana saccharina*: Biology and Control

Eldana saccharina, a major sugarcane stalk borer in sub-Saharan Africa, bores into stalks, reducing plant vigor and facilitating secondary infections. Infestation correlates with varietal susceptibility, trash retention, and mechanical damage (Leslie, 2010). While HWT is not a direct pesticide, it can destroy Eldana eggs laid on seed cane. A trial by SASRI showed that HWT-treated cane had a 45% reduction in initial Eldana infestation (Keeping *et al.*, 2008). A study in southern Malawi revealed that hot water-treated cane in resistant varieties (e.g., N14) resulted in less than 20% infestation compared to 60% in untreated, susceptible varieties (Mwale & Banda, 2015). This demonstrated the combined power of treatment and varietal resistance.

2.9 Impact of Mechanical Harvesting on Seed Cane Health

Mechanical harvesting, though labor-efficient, causes significant physical damage to stalks, especially at the nodes and internodes. These injuries provide entry points for pests and pathogens and reduce germination viability (Glyn & Stirling, 2004). The likelihood of smut and RSD transmission increases with mechanical harvesting, as cutting tools often serve as vectors. Studies from Brazil indicate a 25% rise in RSD incidence in fields harvested mechanically compared to manual harvesting (Ricaud *et al.,* 1989). In South Africa, SASRI implemented clean seed programs using HWT for mechanically harvested seed cane. Results showed a 30–50% reduction in RSD and smut disease prevalence after two years of consistent treatment (Way *et al*., 2006).

CHAPTER 3: MATERIALS AND METHODOS

3.1 Description of the study area

The investigation was carried out at Green Fuel Chisumbanje Estate located in Chisumbanje, Manicaland Zimbabwe situated 61,79km east of Chiredzi. The area is located between 20.7684° S and 32.2285° E, at an altitude of 408 m above sea level. The estate has a total area of 40 000 hectares and the area with existing cane area (11 000 hectares). Rainfall occurs in this area from late December to March, whereas the dry season lasts from April to early December. Rainfall in Chisumbanje averages 600.7 mm annually. The average low temperature is 23°C, and the average high temperature is 37°C. Overlying worn basalt, the dark grey to black vertic soil (Chisumbanje 3B soil) has a clay percentage of 60–75% and varies in depth from relatively shallow to moderately deep (500–1000mm). The chemistry of soil exhibits a strong phosphate fixing capacity together with a broad range of phosphate levels. The area has problems of saline and sodic soils.

3.2 Experimental design and treatments

The experiment was as a 2x3 factorial treatment structure laid in Randomized Complete Block Design (RCBD), with 6 treatments replicated 3 times to give a total of 18 experimental units (plots).

3.3 Field layout

The field layout of the experiment is shown on Table 3.1 below.

Table 3.1: Experimental field layout

Block 1	Block 2	Block 3
HWT VAR1	CTRL VAR2	CTRL VAR3
CTRL VAR2	HWT VAR3	HWT VAR3
HWT VAR3	HWT VAR1	HWT VAR1
CTRL VAR3	CTRL VAR1	HWT VAR2
CTRL VAR1	HWT VAR2	CTRL VAR2
HWT VAR2	CTRL VAR3	CTRL VAR1

Key:

- HWT VAR1 ---Hot water treated seeds variety N53
- HWT VAR2 --- Hot water treated seeds variety ZN10
- HWT VAR3 --- Hot water treated seeds variety M1400/86
- CTRL VAR1 --- Untreated seeds variety N53
- CTRL VAR2 --- Untreated seeds variety ZN10
- CTRL VAR3 --- Untreated seeds variety M1400/86

3.4 Experimental procedure

3.4.1 Project duration

The project started in September 5 2023 and ended on June 11 2024.

3.4.2 Land preparation

Sugarcane planting was done by hand. Each plot size was 5m by 1m, on double rows on beds at an inter-row spacing of 30cm. An additional one-meter border of sugarcane was also be planted around the plots. Irrigation was done using drip irrigation. Monoammonium phosphate (MAP) fertilizer was applied via drip system because it is water soluble. The application rate was 350kg/ha.

3.4.3 Variety selection

The varieties M1400/86, N53 and ZN10 were selected for the trial. The selection was done after direct cane analysis on the cane where quality parameters such as Pol % (percentage of sucrose), fibre %, TF and moisture are assessed. The selection was based mainly on the fibre content of the cane.

3.4.4 Preparation and hot water treatment of setts

Healthy, disease-free sugarcane setts of uniform size and age were selected on each variety. Then cut to appropriate lengths (typically 2-3 nodes) with clean, sharp tools and trim off any excessive roots or leaves. The tank was filled with clean water and heated to a desired temperature (typically 40-60°C) using a thermometer and heat source. The temperature was maintained throughout all the treatments. The setts were immersed in the hot water for 1 hour 30 minutes ensuring all parts are submerged. The setts were agitated gently to maintain even heat distribution. After treatment, the setts were quickly cooled by dipping them in cool water (20-25°C) for 10-15 minutes before planting.

3.4.5 Date collection procedure

Data on smut was collected three months after planting. Data was taken in a randomized manner, number of infected whips were counted and recorded, 50 stalks were collected as sample, this was done for every treatment in every block and calculate the overall infection percent was calculated using the formula,

$$Overall\ Smut\ Infection\ Percent = \frac{Total\ whips}{Total\ sample} \times 100$$

Data on eldana was collected eight months after planting. A cane stalk was picked at random at the edge of the field on the first cane line, 50 stalks were collected. Sampled stalks were counted and the total number of Eldana larvae or pupae found per stalk was recorded.

The internode on each stalk was counted and recorded, examining every stalk by slicing it lengthwise. The bored internode was recorded including those with red rot on each stalk, finding the totals and the percentage bored internodes. This is called eldana percentage damage intensity (how much damage has been done) and is given by the formula,

$$Eldana\ Percent\ Damage\ Intensity = \frac{Total\ internodes\ bored}{Total\ number\ of\ internodes} \times 100$$

Data on ratoon stunted disease was collected after eight months after planting. 50 stalks were collected in each block at random, then they were taken to the laboratory for disease detection.

$$Disease\ incidence\ (\%) = \frac{Total\ infected\ plants}{Total\ sample} \times 100$$

3.4.6 Data analysis

To achieve normal distribution, the data on % overall smut infestation, % Eldana population, % Eldana damage intensity and % RSD incidence were square root transformed, while Eldana larvae counts were $\log_{10}(x+1)$-transformed. The data was then subjected to analysis of variance (ANOVA) using GenStat discovery edition 3 statistical package and the least significant difference (LSD) was used for mean separation.

CHAPTER 4: RESULTS

This chapter presents the outcomes of the study on the effectiveness of hot water treated seed cane on controlling pests and diseases which are Eldana saccharina, smut disease and ratoon stunted disease (RSD) across selected mechanically harvested sugarcane varieties. Results are organized according to the study's three objectives.

4.1 Effect of hot water treated seed cane on smut disease incidence in different mechanically harvested sugarcane varieties

There was highly significant difference (p < 0.001) in smut disease incidence among the treatments, with percentage smut incidence significantly lower in treatments where hot water treated seed cane was used. Smut incidence varied among varieties, with untreated seeds ZN1O recording the highest incidence (mean = 38.67%) and hot water treated seeds N53 the lowest (mean = 9.67%). This is shown on Figure 4.1.

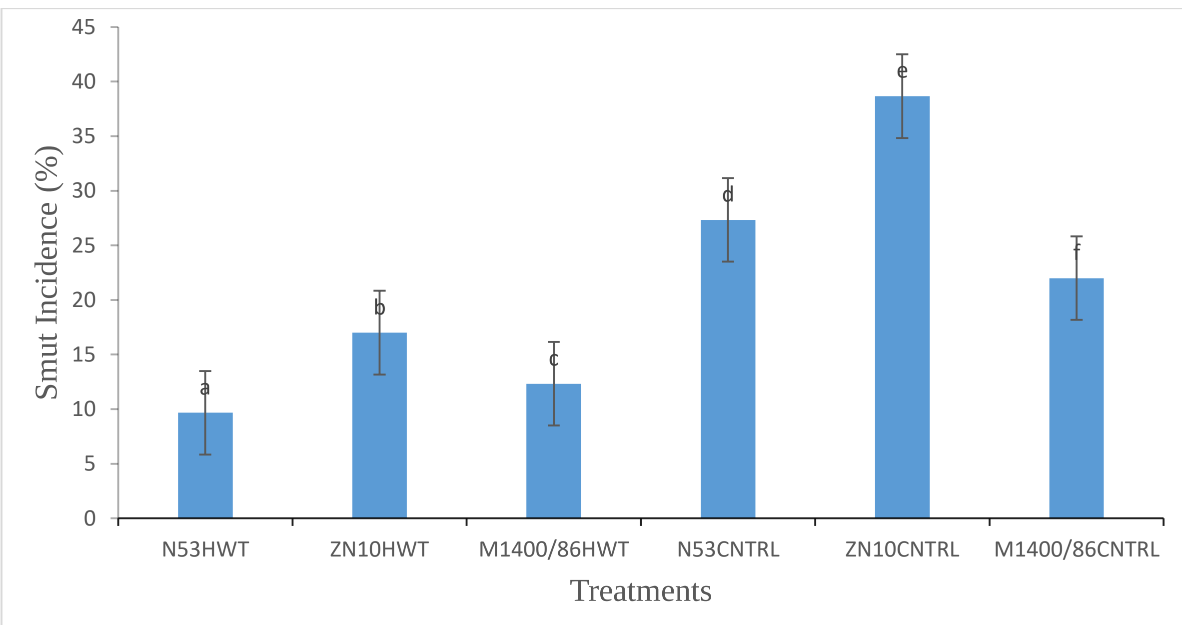

Figure 4.1: Effect of hot water on smut disease incidence (% plants with smut whips)

4.2 Effect of hot water treated seed cane on Eldana population dynamics in different mechanically harvested sugarcane varieties

There was highly significant difference ($p < 0.001$) in Eldana population dynamics among the treatments, with populations significantly lower in treatments where hot water treated seed cane was used (Table 4.1). In all tested varieties, untreated seed cane consistently exhibited higher Eldana infestations compared to hot water treated seed cane.

Table 4. 1: Effect of hot water on Eldana population

Variety	Eldana population
Hot water treated seeds variety N53	**15.3 [a]**
Hot water treated seeds variety ZN10	**15.7 [a]**
Hot water treated seeds variety M1400/86	**14.3[a]**
Untreated seeds variety N53	**57.7[b]**
Untreated seeds variety ZN10	**62.0[b]**
Untreated seeds variety M1400/86	**60.0[b]**
Grand mean	**37.5**
Fprob	**< 0.001**
l.s.d	**14.17**
CV%	**20.8**

4.2.1 Percentage damage intensity

ANOVA results showed a highly significant difference ($p < 0.001$) in Eldana damage intensity among the treatments, with percentage damage intensity significantly lower in treatments where hot water treated seed cane was used (Table 4.2).

Table 4.2: Effect of hot water treatment on Eldana damage intensity (%) across sugarcane varieties

Variety	Eldana damage intensity (%)
Hot water treated seeds variety N53	6.2[a]
Hot water treated seeds variety ZN10	8.6[a]
Hot water treated seeds variety M1400/86	7.2[a]
Untreated seeds variety N53	63.1[b]
Untreated seeds variety ZN10	59.3[b]
Untreated seeds variety M1400/86	71.9[b]
Grand mean	36.1
Fprob	< 0.001
l.s.d	12.64
CV%	19.3

4.3 Effectiveness of hot water treated seed cane on ratoon stunted disease incidence in different mechanically harvested sugarcane varieties

There was highly significant effect ($p < 0.001$) of hot water treatment and variety on RSD incidence, untreated variety (ZN10) exhibiting the highest mean RSD incidence (66.3%) and hot water treated variety (N53) the lowest (6.7%). Fig. 4.2 shows the results.

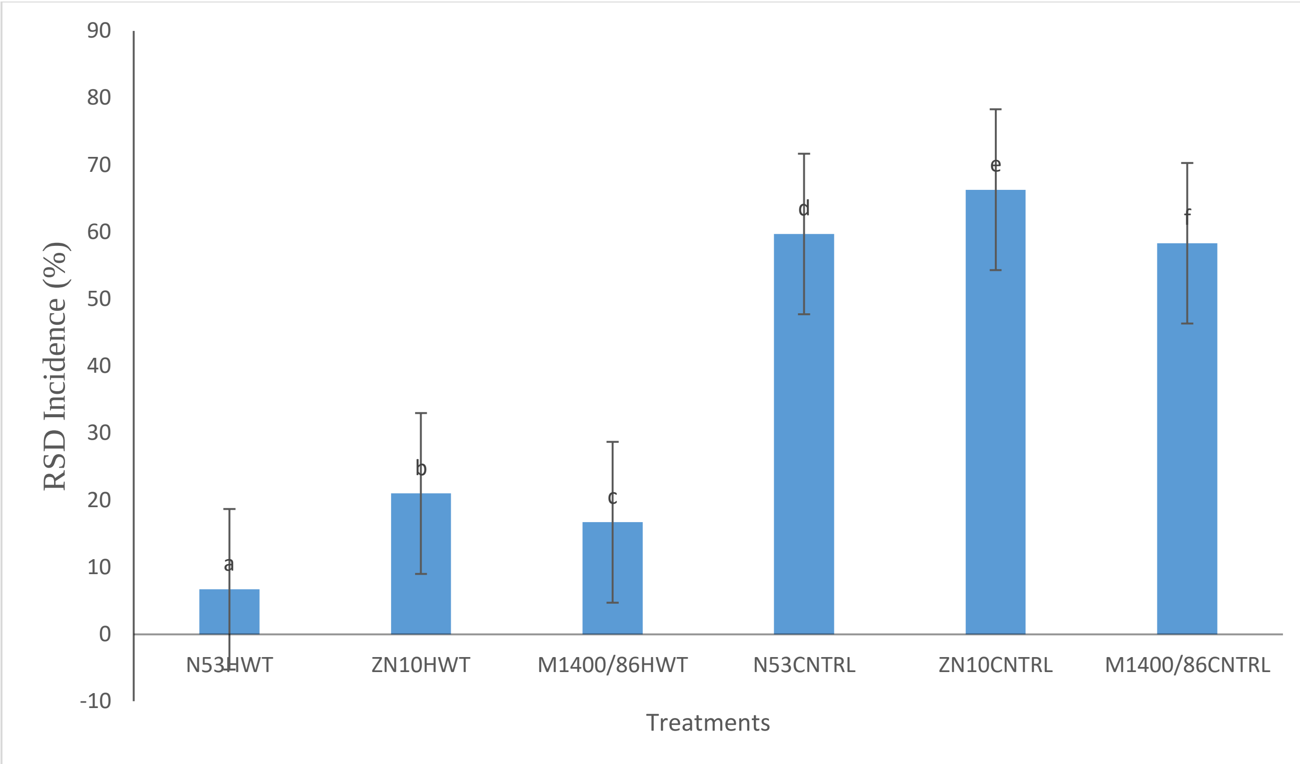

Figure 4.2: Effect of Hot Water Treatment on Ratoon Stunted Disease Incidence (%)

CHAPTER 5: DISCUSSION

The main aim of this study was to assess the efficacy of hot water treatment on seed cane as a sanitary intervention for reducing pest and disease incidence specifically smut (caused by *Sporisorium scitamineum*), Eldana (*Eldana saccharina*) population and ratoon stunted disease (RSD) across different mechanically harvested sugarcane varieties. The discussion presented here interprets and compares findings from the study with published literature to establish the relevance of hot water treatment in integrated pest and disease management strategies.

5.1 Effectiveness of hot water treatment on smut disease incidence

The results clearly demonstrated that hot water treatment significantly reduced smut disease incidence across all tested sugarcane varieties. Untreated ZN10 exhibited the highest smut incidence (38.67%), while the lowest incidence (9.67%) was observed in hot water treated N53. This reduction is attributed to the inactivation of *Sporisorium scitamineum* teliospores on the surface of the seed cane through exposure to elevated temperatures.

These outcomes are consistent with those of Bhuiyan *et al.* (2013), who reported that hot water treatment at 50–52 °C for 30 minutes significantly reduced smut infections. The effectiveness of the treatment depends largely on the thermal sensitivity of the pathogen and the timing of treatment relative to seed cane cutting and planting. Since *S. scitamineum* survives primarily on setts, thermal treatment effectively sterilizes the cane surface without affecting internal bud viability.

Varietal response played a role in susceptibility, with N53 appearing more resistant than ZN10. This may be due to inherent genetic differences in defense mechanisms or bud structure that reduce fungal colonization, highlighting the importance of integrating varietal resistance with seed treatment for comprehensive smut management.

5.2 Effectiveness of hot water treatment on Eldana population dynamics and damage intensity

Eldana infestation, measured both in terms of Eldana individual observed and percentage damage intensity, was significantly lower in plots where hot water treated seed cane was used. The results affirm the hypothesis that hot water treatment can suppress early pest population buildup by eliminating larval stages or insect eggs present on planting material.

Eldana (*Eldana saccharina*) is known to bore into the internodes of cane stalks, causing significant yield losses and increasing susceptibility to secondary infections. By reducing the pest load at planting, hot water treatment interrupts the pest cycle and delays population establishment. This finding supports earlier studies by Way *et al*. (2010), which found that sanitation and clean seed sources are key in integrated pest management (IPM) for Eldana. Kamat *et al*., 2023 reported that hot water treatment can eliminate eggs and larvae present on seed cane, significantly lowering initial pest loads. The differences in infestation and damage intensity between varieties also point to intrinsic resistance, potentially due to physical characteristics like rind hardness or chemical factors such as phenolic content

The significant varietal differences in damage intensity observed in this study could be due to structural or biochemical traits that affect larval survival or feeding. For example, varieties with harder rind tissue or higher silica content may offer more resistance. This highlights the need for future breeding programs to incorporate resistance traits alongside sanitation practices like hot water treatment.

5.3 Effectiveness of hot water treatment on ratoon stunted disease (RSD) incidence

Ratoon stunted disease incidence was also significantly reduced in plots established using hot water treated seed cane, with untreated ZN10 recording 66.3% infection, compared to only 6.7% in treated N53. RSD, caused by *Leifsonia xyli subsp. xyli*, is a systemic bacterial disease with no visible symptoms in early stages, making it a major silent yield reducer.

Ratoon stunted disease is transmitted via infected planting material and mechanical harvesting tools, the use of hot water treated seed cane plays a crucial role in breaking the cycle of infection (Philip 2016). The significant reduction in incidence supports the findings Yulianti *et al* (2020), who reported that hot water treatment (50–52 °C for 2–3 hours) was effective in reducing RSD bacterial load in seed cane without impairing germination.

The absence of significant block effects indicates consistency across replications, further reinforcing the reliability of the treatment's effectiveness. This suggests that integrating hot water treatment in seed cane preparation could significantly improve ratoon management and long-term productivity in mechanically harvested systems, where disease spread via harvesters is common.

5.4 Integration of findings and implications for management

The consistency of hot water treatment efficacy across pests and diseases in this study affirms its role as a foundational component in sugarcane disease and pest management. When applied before planting, it improves crop establishment and reduces early pest and pathogen pressure.

Combined with good agronomic practices such as proper drainage, sanitation, and varietal selection, this method could serve as a cost-effective and environmentally sustainable strategy for small- and large-scale sugarcane production systems (Viswanathan & Rao, 2011; Conlong, 2001).

Moreover, the results encourage further research on varietal tolerance and the incorporation of resistant genes through breeding. Integrated Pest Management (IPM) and Integrated Disease Management (IDM) strategies should prioritize hot water treatment as a preventive approach to enhance yield stability.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The results clearly demonstrated that hot water treatment significantly reduced smut disease incidence across all tested varieties. Untreated seed cane consistently showed higher levels of smut whips, indicating the presence of active spores that were effectively inactivated through heat treatment. Eldana population dynamics and damage intensity were significantly lower in plots established with hot water treated seed cane. This highlights the role of hot water treatment in disrupting the early life stages of the pest and reducing initial infestation. RSD incidence was substantially reduced in hot water treated seed cane compared to untreated cane. This supports the effectiveness of hot water in eliminating the bacterial pathogen *Leifsonia xyli* subsp. *xyli* on planting material.

Varietal differences were observed in response to each pest and disease, with some varieties (such as N53) demonstrating lower susceptibility, indicating that genetic factors also play a role in pest and disease resistance.

6.2 Recommendations

The researcher advices sugarcane farmer, particularly those using mechanical harvesting methods, should adopt hot water treatment for all seed cane prior to planting to reduce disease and pest load. Varieties such as N53, which showed lower susceptibility to smut, Eldana, and RSD, should be promoted in regions with a high incidence of these pests and diseases. Farmers and commercial growers should integrate hot water treatment with other sanitary practices such as sterilizing cutting tools, removing infected stalks, and managing trash to maintain field hygiene.

Long-term studies should be conducted to assess the impact of repeated use of hot water treated seed cane over multiple ratoon cycles. Further research is needed to identify and develop varieties with dual resistance to smut and Eldana while maintaining high yield potential. Studies should explore the economic viability and scalability of hot water treatment units for smallholder farmers

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APPENDICES

Variate: Eldana damage intensity (%)

SOURCE OF VARIATION	D.F.	S.S.	M.S.	V.R.	F PR.
BLOCK STRATUM	2	5.48	2.74	0.06	
BLOCK.*UNITS* STRATUM					
VARIETY	5	15103.74	3020.75	62.60	<.001
RESIDUAL	10	482.56	48.26		
TOTAL	17	15591.78			

Variate: Eldana population

SOURCE OF VARIATION	D.F.	S.S.	M.S.	V.R.	F PR.
BLOCK STRATUM	2	22.33	11.17	0.18	
BLOCK.*UNITS* STRATUM					
VARIETY	5	9053.83	1810.77	29.86	<.001
RESIDUAL	10	606.33	60.63		
TOTAL	17	9682.50			

Variate: Ratoon stunted disease incidence (%)

SOURCE OF VARIATION	D.F.	S.S.	M.S.	V.R.	F PR.
BLOCK STRATUM	2	67.44	33.72	0.78	
BLOCK.*UNITS* STRATUM					
VARIETY	5	10234.44	2046.89	47.18	<.001
RESIDUAL	10	433.89	43.39		
TOTAL	17	10735.78			

Variate: Smut_Incidence_%

SOURCE OF VARIATION	D.F.	S.S.	M.S.	V.R.	F PR.
BLOCK STRATUM	2	16.333	8.167	1.84	
BLOCK.*UNITS* STRATUM					
VARIETY	5	1717.833	343.567	77.50	<.001
RESIDUAL	10	44.333	4.433		
TOTAL	17	1778.500			

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