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# Assessment of the Effect of Neochetina þÿW e e v i l s   S p e c i e s   o n   W a t e r   H y (Eichhornia crassipes) in Earthen Ponds

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**BAHIR DAR UNIVERSITY**

**COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES**

**School of Fisheries and Wildlife**

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**By**

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**February, 2024**

**Bahir Dar, Ethiopia**

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# Assessment of the Effects of Neochetina Weevils' Species on Water Hyacinth (*Eichhornia crassipes*) in Earthen Ponds

**By**

**Tadele Molla**

**A Thesis submitted to the Department of Fisheries and Aquatic Science for partial fulfillment for the degree of masters of sciences in Fisheries and Aquaculture**

**Advisor: Gashaw Tilahun (PhD)**

**February, 2024**

**Bahir Dar, Ethiopia**

## DECLARATION

This is to certify that this thesis entitled **"Assessment of the Effects of Neochetina Weevils' Species on Water Hyacinth (*Eichhornia crassipes*) in Earthen Ponds",** was submitted in partial fulfillment of the requirements for the award of the Degree of Master of Science in **"Fisheries and Aquaculture"** to the Graduate Program of School of Fisheries and Wildlife, College of Agriculture and Environmental Sciences, Bahir Dar University by **Mr. Tadele Molla Alelign** (ID. No. BDU 1401254) is an authentic work carried out by him under our guidance. The matter embodied in this project work has not been submitted earlier for the award of any degree or diploma to the best of our knowledge and belief.

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**I hereby certify that I have supervised, read and evaluated this thesis entitled "**Assessment of the Effects of Neochetina Weevils' Species on Water Hyacinth (*Eichhornia crassipes*) in Earthen Ponds**" by** Mr. Tadele Molla Alelign papered under my guidance. I recommended the thesis be submitted for oral defense.

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As a member of the board of the examiners we examined this thesis entitled **"Assessment of the Effects of Neochetina Weevil Species on Water Hyacinth (*Eichhornia crassipes*) in Earthen Ponds"** by Mr. Tadele Molla Alelign. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of **"Master Science in Fishery and Aquaculture".**

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ABSTRACT

*Comfortable water environment for Neochetina weevils' survival have potential to affect water hyacinth plant parts. The Effect assessment of water hyacinth plant affected by Neochetina weevil species was conducted through physical observation and quantified measures in comparsion treatment and control earthen ponds. The weevils' affect water hyacinth plant growth and reproduction through feeding different plant parts. The study was conducted in January, 2023; by triplicated (treated and controlled) through planting 35 water hyacinth plants in each ponds and 5 weevils' per plant treatments that aimed (1) To investigate temporal environmental variability on the survival and development of the weevils', (2) To determine the abundance of weevils population in the experimental ponds and quantify damage parts of E. crassipes caused by weevils' and (3) To evaluate the effects of weevils' on the growth and proliferation of water hyacinth compared to the control ponds. Sampling were design randomly in triplicate sample biweekly gap for 3 months that weevils' could affect WH; maximum leaf diameter (treatment WH plant decreased by 1.7 ± 0.3cm whereas control WH plant increased by 2.9 ± 0.3cm in mean ), minimum leaf diameter (treatment WH plant decreased by 1.4 ± 0.3cm and control WH plant increased by 2.7 ± 0.3cm in mean ), shoot length (treament WH plant decreased by 9.3 ± 1.7cm and control WH plant increased by 21 ± 1.7cm in mean), root length (treatment WH plant increased by 13.8 ± 1.8cm whereas control WH plant increased by 15 ± 1.8cm rate of increase differ) and fresh WH biomass (treatment WH plant increased by 1258.2 ± 37.8grm and control WH plant increased by 1985.9 ± 37.8grm but rate of increased different). The number of Neochetina weevils' to feeding scar had direct relationship (y=26.8 + 16.9x).Even though insignificant statistical difference was there between experimental and control groups water quality parameter; WH affect the water quality of ponds water temperature (0.1 ± 0.5 and 2.2 ± 0.5$^0$C), dissolved oxygen (0.1 ± 0.3 and 0.4 ± 0.3mg/L), pH (0.2 ± 0.1 and 0.1 ± 0.1) and electrical conductivity (157.7 ± 62 and 105 ± 62 µS/cm) of experimental and control groups respectively. Thus, based on their damage potential and positive impact on water quality parameter, Neochetina weevil species are considered as the best promosing control agent for this invasive weed to Ethiopia water bodies so that before introducing consider area coverage and growth stage of WH.*

***Key Words:*** *Neochetina weevils', Water hyacinth, feeding scar, earthen pond.*

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## ACRONYMS AND ABBREVIATION

| | |
|---|---|
| **ANOVA** | **Analysis of variance** |
| **BDU** | **Bahir Dar University** |
| **BETin** | **Bio and Emerging Technology Institute** |
| **EBTI** | **Ethiopian BioTechnology Institute** |
| **CABI** | **Centre for Agricultural and Bioscience International** |
| **cm** | **Centimeter** |
| **EC** | **Electrical conductivity** |
| **EPPO** | **European and Mediterranean plant protection organization** |
| **DO** | **Dissolved oxygen** |
| **FAO** | **Food and Agriculture Organization of the united nation** |
| **GBICWH** | **Global Working Group for the Biological and Integrated Control of Water Hyacinth** |
| **IWHM** | **Integrated Water Hyacinth (*Eichhorinia crassipes*) Management** |
| **MANOVA** | **Multi-Variants Analysis of Variance** |
| **NFS** | **Number of Feeding Scar** |
| **NW** | **Number of Weevils** |
| **pH** | **Hydrogen Power** |
| ***SEEPPC*** | ***Southeast Exotic Pest Plant Council*** |
| **USEPA** | **United States Environmental Protection Agency** |
| **WH** | **Water Hyacinth** |

# 1. Introduction

## 1.1. Background and Justification

Water hyacinth is the only a pan-tropical aquatic weed from the Pontederiaceae family. There are seven species of water hyacinth which are in one genus Eichhornia, of which *Eichhornia crassipes* is widely distributed species throughout the world. It is a free-floating perennial aquatic plant with bright green, spongy and attractive leaf, violet flowers within yellow strips on the banner petals. The spongy leaf stem tissue helps to keep it afloat on the water surface. It has an oval round leaf that is arranged in a rosette form. The common water hyacinth (*Eichhornia crassipes*) is vigorous growers; one plant may be able to produce enough growth to cover 600 square meters in one year (Dereje, 2015; Friehun, 2017; Sewnet & Habtamu, 2023). Infestations break up in to "rafts" that drift wherever the winds and currents take them, rapidly infesting entire aquatic ecosystems.

In Africa around 39 countries are colonized by water hyacinth weed including Ethiopia (EPPO, 2008). Water hyacinth, a non-native plant, is often grown in lentic water bodies to Ethiopia that introduced around the mid-20$^{th}$ Century with recently exacerbated devastating ecological and economic consequences (Bekele *et al*., 2017). *Eichhornia crassipes* (Mart.) Solms that may be free-floating or rooted in mud to establish in water bodies (Kassu *et al*., 2022). It is a well-known and fastest growing invasive aquatic weed in most lakes of the country that reproduces both sexually and clonally. The seeds of the weed remain viable from 20 to 30 years and mats can double in area size in two weeks (Opeyemi *et al.*, 2020). Water hyacinth body content about 90% is water (Innocent, 2008; Friehun, 2017; Weiping *et al*., 2018). This is causes for more water evapotranspiration through plant leaves stomata and thick mats of the weed cause disruption to water transport, water circulation, light penetration, oxygen depletion, clogging of river channel, impede access to fishing areas, landing beaches and destroy fish traps and nets. So it affects negatively water ecology and over dominancy through formation of mat on the surface of water bodies undertaken. Water hyacinth highly affects Lake Tana. An image satellite reported to BETin in July 2023 indicated that the biomass coverage increased from 409.7 hectares in October 2022 to 766.0 hectares in November 2023 after one year interval. In Lake Tana area coverage of water hyacinth around 2% cause the fish production potential to be reduced by 92% (Nagassa and Belay, 2020).

According to FAO (1995) the absence of natural enemies contributes to the rapid growth creating mats. The other consequence of this weed is high nutrient computation from other macrophyte that leads to high explosive growth rate in a large extent and cause to eutrophication in water bodies. Hence looking for controlling mechanisms of water hyacinth is better solution through physical, biological, mechanical and chemical way. Physical and chemical controls are effective for short-term result. But it has its own drawbacks and limited scale to clear the weed. To the contrary biological control method is regarded as the most preferred form of control and can provide a long-term solution (Samson *et al*., 2021) especially Neochetina weevils'. Neochetina Weevils' species are insects that enemies water hyacinth through common feed adaptation, and it originates from South America. It is two in number Weevil beetles (*Neochetina eichhorniae* and *Neochetina bruchi*) that environmental eco-friendly biological control agent for *Eicchornia crassipes*. The adults feed WH plant leafs and stems, whereas larvae life cycle feed petioles inside the WH tissue. The adult females and males within the same species mate then later lay eggs on the petioles for as long as they survive. Other life stage did not play a role affect the weed through feeding( Firiehun2017; Getachew and Wassie, 2021; Stephen,2004). It affects only water hyacinth population, no influence to other Aquatic plants after the introduction of several years (Pratiwi *et al.*, 2018). The intention of this theses was to collect data on the adaptability/survival of weevils , to investigate the effect of weevils on the WH/weed**,** to convey information and to decision makers as weevils' are alternative controlling agents to the manage of WH that draw important conclusion and forward sound initiatives required for management aquatic resource from the impacts of this invasive weed via effect of WH parts in quantified scale.

### 1.2. Statement of the problem

Water hyacinth is one of the world's worst invasive weed (Aklilu *et al*., 2017). It is among the 100 worst invasive plants and ranked as the $11^{th}$ worst invasive species in Europe, being a threat to aquatic biodiversity and water provision (Goular *et al*., 2019). *Eicchornia crassipes* introduced as an ornamental species to decorate the water bodies of

Ethiopia (Negassa and Belay, 2020). But it was officially reported in 1956 at Koka Dam and Awash River and considered as a constraint to the development of the country (Abule *et al*., 2017). In Ethiopia at this time rapid invasion of WH weed, causing adverse effect on aquatic ecosystem and human benefits. It is directly and indirectly affects fish, crop and livestock productions, electric power generation, irrigation, waterway transportation, tourism and human health.

Current water hyacinth management in Lake Tana intervention is only the application of human labor and mechanical removal but the problem remains unsolved. Among control methods being considered, biological control agent stands out to be a major component and a globally acceptable tool for sustainable management of this exotic and noxious weed (Stephen, 2004). One of the reasons for the rapid proliferation of WH is lack of natural enemies in this Lake, which is not center of origin are a biological agent that helps to control its spread. The government of Ethiopia encouraged this controlling method based on long lasting effect and environmental friendly (Negassa and Belay, 2020; Getachew, 2020). But before this time biological controlling agent( weevils') did not apply on this Lake since decision makers required sufficient information about weevils' Neochetina species (*Neochetina eichhorniae* and *Neochetina bruchi*) ablitiy to reduce plant petiole length, and above/below surface bio-mass through feeding (Jones *et al*., 2018). Through this reason the two weevils' are presently being considered as candidates for impacting of different parts of water hyacinth in Ethiopian water bodies' especially in Lake Tana. Prior to the introduction of weevils' directly to Lake Tana, sufficient research data was collected locally in a controlled environment to convenience stakeholders, policy makers and professionals. With this understanding, the current research work has been conducted by collecting sufficient data about the effect of weevils' on water hyacinth using control and experimental treatment ponds constructed in Peda campus near Maritime center. The effect clearly observed on water hyacinth plant parts with the reference local control water hyacinth plants. The presence of weevils' made scars on the leaf of the weed that were directly related to the number of weevils', which had a positive effect on water quality and weevils' survival.

## 1.3. Objectives

### 1.3.1. General objective

To assess the effect of weevils' on growth and biology of water hyacinth in Earthen pond.

### 1.3.2. Specific objectives

i. To investigate temporal environmental variability's on the survival and development of the weevils.

ii. To determine the abundance of weevils population in the experimental ponds and quantify damage parts of *E. crassipes* caused by weevils

iii. To evaluate the impact of weevils on the growth and proliferation of water hyacinth compared to the controlled ponds**.**

### 1.4. Research question

i. Is there any effect of temporal environmental variability's on the survival and development of the weevils' as compare to other studies?

ii. what is the abundance of weevils' population in the experimental ponds and amount of damage on part of *E. crassipes* caused by weevils'?

iii. What is the effect of weevils' on the growth and proliferation of water hyacinth?

### 1.5. Hypothesis

### 1.5.1. Null Hypothesis ($H_0$)

i. Temporal environmental variability did not affect the survival and development of weevils'.

ii. The abundance of the weevils' population had direct relation to quantified damage parts (number of feeding scars) in the experimental ponds.

iii. The presence and absenceof Neochetina weevils in earthen ponds with water hyacinth plants showed distinct differences in growth and proliferation.

### 1.5.2. Alternative Hypothesis (Ha)

i. Temporal environmental variability did affect the survival and development of weevils.

ii. The abundance of the weevils' population had not direct relation to quantified damage parts (number of feeding scars) in the experimental ponds.

iii.The presence and absenceof Neochetina weevils' in earthen ponds with water hyacinth plants showed had not distinct differences in growth and proliferation.

### 1.6. Significant of the study

This study was provide relevant information mainly for management of aquatic ecosystems through biological control of water hyacinth by quantifying the impacted part of water hyacinth plant that could not been studied by others before this research was conducted. The research was informative on how much the water hyacinth plant parts affected by Neochetina weevils' species and the difference between presence and absence of weevils' on water hyacinth that determine the water quality parameters. It is important for policy makers, water body managers, Fisheries expert and managers and NGO workers in quantified manner for the introduction of weevils' Neochetina species on the water hyacinth invaded aquatic ecosystems, especially Lakes, reservoirs, rivers and wetlands of Ethiopia.

### 1.7. Scope of the study

The study would be incorporated(limited) effective number of Neochetina weevils' species and quantified effect of Neochetina weevils' species on given area of water hyacinth planted of sampling in earthen pond. The Neochetina weevils' species control water hyacinth would be studied in three treated and three controlled of total six ponds at Peda campus.

# 2. Literature Review

## 2.1. Impact of water hyacinth on water quality and survival of weevils'

Water hyacinth once established that has a strong water quality impacts in the vicinity. The infestation of weeds in the form of floating dense mat leads to drastic deterioration of water quality such as decline in the amount of dissolved nutrients, temperature, pH and dissolved oxygen in the water column leading to mass destruction of the fish fauna and decline in net primary production of the system (Chapungu *et al*., 2018; Dersseh *et al*., 2020; Enyew *et al*., 2020). It affects native macrophyte and algae classes such as Cyanophyceae, Bacillariophyceae, Chlorophyceae, Euglenophyceae, Cryptophyceae and Dinophyceae that has significant role for water quality balance in water (Habtamu *et al*., 2021). In turn aquatic organisms including fish without quality water is difficult. Due to affecting of fishing, high accumulation of organic matter and higher biological oxygen demand, less phytoplankton abundance and diversity through competition of other native aquatic vegetation. Neochetina weevils' can control the weed which survive and reproduce in Ethiopian water environment on both highland (Getachew and Wassie, 2021 and lowland (Feriehun, 2017) areas.

### 2.1.1. Water temperature

Temperature refers to degree of hotness or coldness that measured in degree Celsius. Water temperature needs to be monitored regularly as outside tolerable temperature range, disease and stress will become more prevalent. Among the consequences of temperature changes are; photosynthetic activity and rate of dissolved of oxygen in water. The most favorable conditions for the optimum growth of water hyacinth are nutrient-rich water within temperature ranges from 28°C to 30°C (Minychl *et al*., 2019). But mats of water hyacinth infestation on water bodies significantly affect water temperature. The growth make presence of canopy covered in which heat and light can't pass away that water temperature become decline. According to Flipos (2020) Maximum temperature measured at both infested and non-infested in Lake Tana at Gorgora site was in normal environmental temperature range of 21-27 °C that suitable for growth of aquatic plants. But relative lower temperature measured at the infested site could be attributed to the canopy cover of the water hyacinth which form a dens mat. His water temperature on infested site was 23.6 to 23.9°C whereas none infected site 25.2 to 26.7 °C that indicate numerical difference. In Ethiopia on Koka reservoir also the absence of significant spatial variation in water temperature at the infested and non-infested sites critical indicator for temperature difference but the polymictic nature of the reservoir, which mixes with strong turbulence every day that make it insignificance difference( Habtamu *et al.*, 2021). Similarly in Uganda in Lake Victoria; the water temperature in water hyacinth covered environments was slightly higher (27°C) than that of open lake water (26°C). But the water hyacinth mat and open water temperature the difference were not statistically significant (Hussein *et al*., 2023).

Neochetina weevils' can reproduce and survive with the ambient temperature of 17.1°C up to 33.7°C in rift valley of Ethiopia (Tatek *et al*., 2022). The temperature does not have significant effect on survival for adult but for reproduction cause delay in Ethiopian atmospheric condition that change seasonally. The temperature in winter and fall temperature treatments ranged from 2.6 to 14.5 °C and 11.2 to 28.4 °C daily for rearing in good condition respectively (Angelica *et al*., 2018). In Lake Victoria for control of water hyacinth that rear weevils recorded mean weekly ambient temperature range 21.44ºC to 23.78°C under these range the weevils' survived , adapted and reproduced (Stephen *et al*., 2006). The *Neochetina brunchi* egg can't hatch below 15 **º**C in seven days whereas *Neochetina eichhorniae* below 20 **º**C in 10 days(George and Joseph,2015). These indicate that temperature can affect the life cycle and the weevil's species required different temperature limit.

### 2.1.2. Dissolved oxygen

Dissolved oxygen is essential for sustaining aquatic organisms with variation in tolerances of oxygen concentrations existing among species and life stages that fluctuate temporally. One of the deleterious effects of aquatic organism is lowest DO concentration in water that water hyacinths mat cause for decline. Anoxic waters are defined as those with 0 mg $L^{-1}$ DO and hypoxic waters are less than 2 mg $L^{-1}$ and aquatic organism are aerobic which can't survive in anoxic condition and in hypoxic condition reduce feeding later make difficult to survive (USEPA,2000). Survivorship of Neochetina weevils depend health water hyacinth plant (Shephen, 2004 and Feriehun, 2017) but environmental parameter can affect its life cycle.

The water hyacinth infestation water bodies cause for DO exchange decline (atmosphere to water environment). Critical indicator for this in Lake Tana Water hyacinth infected part of dissolved oxygen reduced by 3.31  to 4.55mg/L whereas none infected increased (7.9 to 8.4mg/L) (Flipos ,2020). In Lake Koka water hyacinth was infested in 1965(Abule *et al*., 2017). Due to that study was conducted; dissolved oxygen concentration exhibited a statistically significant spatial variation between the non-infested and infested sites). The dissolved oxygen concentration of the non-infested sites (6.86±0.725 mg/L) is higher than those of infested in site (3.77±0.375). The highest value of dissolved oxygen (DO) concentration is recorded at the non-infested sites (8.67 mg/L) while the minimum is observed at the high infested site (1.10 mg/L) (Habtamu *et al*., 2021).

### 2.1.3. pH

The term pH derived from a French word, "pouvoir hydrogéne", which means "hydrogen power". This parameter shows the quantity of hydrogen ions (H+) in the water. The scale for measuring the degree of acidity is called the pH scale, which ranges from 1 to 14. At 25 $^{0}$ C, pH of 7.0 will be considered neutral (neither acidic nor basic). But values below 7.0 are considered acidic, and above 7.0 are basic. The pH concentration can affect the aquatic organism survivals. According to CWQGs (2019) the aquatic invertebrate in good survival of pH ion concentrated interpolated 5.8 to 8.4. Water hyacinth has impact on the hydrogen ion concentration. According to Flipos (2020) the pH concentration of infected part of the Lake Tana was 8.28 to 8.42 but none infected water 8.61 to 8.7.  A slightly alkaline pH range of 8.2 to 8.7 is measured in both infested and non-infested sites and but value is in limit of guidelines for livestock watering (WHO, 2011; USEPA, 2011). Even though the pH insignificant on water quality it shows difference between infected weed mat and none infested water of the Lake. This is due to strong usage of phosphates and carbonates of the water. Ecologically, the infestation of floating dense mat leads to drastic deterioration of water quality such as amount of dissolved nutrients, temperature, pH and DO of water column leading to mass destruction of fish fauna and decline in net primary production (Chapungu *et al*., 2018; Dersseh *et al*., 2020; Enyew *et al*., 2020). Even though statistically not significant, the pH concentration of Koka Ethiopia reservoir had difference between infested and none infested site that the presence of mixing the reservoir daily. The mean values of pH recorded are 8.34 for the non-infested sites and 8.32 for the weed-infested sites (Habtamu *et al*., 2021).

### 2.1.4. Electrical conductivity of water

One of advantages of water hyacinth plant is treated the polluted and metalloid waters. Electrical conductivity of water hyacinth infested water bodies are lower than none infested due to absorption of metals by water hyacinth mat (Flipos, 2020). Though not statistically significant, mean of electrical conductivity showed variations between the infested and non-infested sites with higher values of electrical conductivity occurring at the weed infested sites (210.7 μS/cm ) than non-infested sites (139.8μS/cm )(Habtamu *et al.*,2021). In Lake Victoria Uganda Electrical conductivity of Murchison Bay on both water hyacinth-infested and open lake sites differ slightly. However, the results indicated that water depth significantly affected the electrical conductivity of water. The results signify that water EC is significantly altered by water depth rather than by water hyacinth infestation (Hussein *et al.*, 2023). Due to the presence of mat formation on the water surface that absorbed by water hyacinth plant. Even though water hyacinth have significant effect on EC but that reversed the effect by water depth, water current and environment.

High conductivity value is a sign of water pollution. Conductivity is the result of high concentration of salt that made worst of aquatic life in water (Hamadamin *et al.*, 2018). The aquatic life electrical conductivity benchmark was developed for good condition waters 300 μ S/cm 95% aquatic invertebrate occurrence in year round (US EPA, 2010). In this rage of conductivity of water for aquatic life is good conditioned but the above and below this limit organismic dependent that can survival.

## 2.2. Controlling mechanisms of water hyacinth

Water hyacinth (*Eichhornia crassipes*) invaded of water bodies poses challenges to communities. There is number of weed management strategies such as physical removal, chemical methods and biological control agents are being used to control it. But various environmental and financial challenges are associated with these controlling methods (Sharma *et al.*, 2016). According to Honlah *et al*. (2022) it is important to control through cost minimizing and environmental smart approach strategy. Manual control of the plant's proliferation could complement to the effect of the biological control. But it's cost high so that it is better to use biological control or integrated biological and physical is the most sustainable and cost- effective approach(Karouach *et al*.,2022). In Lake Tana from 2012 to 2018 huge human labor dedicated which 800,000 for manual removal and above one million USD spent for machine harvester procurement (Dereje, 2015). In spite of the devotion of huge labor and spending of a lot of money, the expansion of the weed has not controlled. Poor coordination of controlling efforts, dumping of harvested dense mats of the weed in the lakeshore, lack of genuine participation of the local people and none use of bio-agents are principal factors for the failure of the controlling efforts (Getnet *et al*., 2020). So that using biological control will be the best method for the problem. Due to the financial and environmental costs associated with herbicidal (chemical) control measures and their limited effectiveness have also led to a growing interest in the use of biological control. Biological control of the weeds using natural enemies is cheap, sustainable but comparatively slow. Bio-agents once established are self-sustaining. *Neochetina bruchi* and *Neochetina eichhorinae* whose entire life cycle depends on water hyacinth has been used to control this aquatic weed in 30 and 27 countries, respectively (Feriehun *et al*., 2017).

### 2.2.1. Biological control of water hyacinth

Biological control of water hyacinth by pathogens and biological agents.The use of weevils can be supplemented with artificial inoculation of fungal pathogens through mass production of fungal spores. Among the most promising pathogens are *Uredo eichhorniae*, suitable as a classical biocontrol agent, and *Acremonium zonatum*, *Alternaria eichhorniae*, *Cercospora piaropi*, *Myrothecium roridum*, and *Rhizoctonia solani*, which are widely distributed in different continents, as bioherbicides(Charudattan,2001). Biological control agents of water hyacinth have been introduced across the globe, resulting in a significant reduction of water hyacinth cover and biomass in many localities but not all (Winston *et al*., 2014). Out of the nine bio control agents released worldwide, the most widely utilized and effective species are the weevils *Neochetina bruchi* Hustache and *Neochetina eichhorniae* Warrener (Coleoptera (order): Curculionidae (family)), and the moth *Niphograpta albiguttalis* (Lepidoptera: Pyralidae) (Hill *et al*., 2011). Releases of *N. bruchi* and *N. eichhorniae* from their native in South America began in the early 1970s, with releases solely in 30 and 32 countries respectively (Stephen, 2004). These weevils have had ‘medium’ to ‘heavy’ impacts on water hyacinth populations in at least 18 countries, but ‘variable’ to ‘slight’ impacts in others (Winston *et al*., 2014). All of the regions where biological control of water hyacinth has been implemented, the main factors that are known to limit the effectiveness of biological control include: cooler temperatures, intense flooding or drought periods that remove both the weed and the natural enemies, heavy use of chemical pesticides and herbicides, and highly eutrophic conditions that alter host plant nutrient quality and can propagate rapid plant growth beyond the population growth rates of the natural enemies ( Coetzee and Hill, 2008 ; Winston *et al*., 2014). The weevils’ couldn’t control water hyacinth in all localities; Sacramento-San Joaquin River Delta in California is one of the localities where biological control of water hyacinth has underperformed (Hopper *et al*., 2017). Biological control using weevils’ is environmentally friendly and has successfully reduced infestations in many African countries. But there no complete control even in highest inoculation loads; weevils definitely slowed down plant growth and reduced water hyacinth density (Yasotha & Lekeshmanaswamy, 2012). These weevils were released in Benin, Burkina Fasso, Congo, Cote d’Ivoire, Egypt, Ghana, Kenya, Malawi, Mali, Mozambique, Niger, Nigeria, Rwanda, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, and Zimbabwe ( Mbati and Neuenschwander, 2005).

For instance, a significant level of water hyacinth control was achieved in Lake Victoria between1996 and 1998 (Stephen, 2004). This was largely attributed to biological control using weevils *Neochetina eichhorina* and *Neochetina bruchi* along with manual and mechanical control that are limited to site of strategic importance. In Ethiopia the biological controlled of water hyacinth method was practiced on the laboratory (lath house adaptability and rearing experiments) level at Wonji Sugar Estate and BDU. Bahir Dar University department of Biology model for controlling of water hyacinth in lath house reared the weevils (figure-1).

**Figure 1:** BDU biology department of lath house of Neochetina weevils' spp. adaptability and rearing experiments site(Source: direct photo capture).

**2.2.2. Neochetina weevils' species**

Neochetina weevil species are an insect of weevils' that host specified on water hyacinth. Sometimes referred to as the mottled water hyacinth weevil, *Neochetina eichhorniae* Warner and *Neochetina bruchi* hostache are weevils' that attack the invasive aquatic plant, water hyacinth (*Eichhornia crassipes*) (Mart.) Solms. *Neochetina eichhorniae* and *Neochetina bruchi* is host specific and causes substantial damage to water hyacinth, making it a valuable biological control agent for this invasive weed. The insect was first introduced into the United States from Argentina in 1972 when scientists released the insect in Broward County, Florida, to manage water hyacinth. The insect has been introduced in more than three dozen countries worldwide (Winston *et al*., 2014). Post-introduction studies indicate the insect suppresses the growth of water hyacinth, significantly reducing biomass and flower production (Tipping *et al*., 2014).

According to Stephen (2004), adults of *Neochetina eichhorniae* and *Neochetina bruchi* distinguished by the color and pattern of the scales covering the elytra. Both species have two shiny dark lines on the elytra on either side of the mid-line. This short line is actually a tubercle or ridge and its position varies between the two species. *N. eichhorniae* never has the tan band and is usually grey mottled with brown. The color pattern is associated with scales and specimens may be difficult to identify if the scales are missing or the specimens are dirty or wet; the tubercles are situated in front of mid-length and lines are relatively coarse and longer. Whereas *N. bruchi* ranges in color from uniform tan or brown with no distinct markings to brown with a broad crescent-shaped or chevron-like tan band across the elytra; tubercles are situated very near mid-length and lines are relatively fine and shorter.

### 2.2.3. Biology of Neochetina weevils'

*Neochetina* is a genus of weevils' known as water hyacinth weevils' .There are at least two species: *N. eichhorniae* or mottled water hyacinth weevils' which gets its name from the plant it feeds on and *N. bruchi* or chevroned water hyacinth weevils' which is characterized by a chevron shaped marking on its back. The adults produce characteristic feeding scars on the leaves and petioles. Scarring always give a response for adult weevils' feeding since other life stage did not made ascar(Moran,2004). In larval stage, tunnels into the petioles and the crown of the plant. This feeding results in biotic stress, reduced flowers and seeds, and less vigorous growth. Other life cycle inactive in feeding the water hyacinth such as eggs and pupual stage.

The total life cycle took about 92 days for completion in India (Parmeshwar *et al*., 2020). Whereas in Ethiopia , it takes 98 to 112 days in Rift valley(Friehun *et al*., 2017). The mean fecundity of the two weevils was recorded as 290 and 237 eggs per female laid over a period of 16 weeks. A two-way analysis of variance showed there was significant difference between the egg laying capacities of the two weevil species. The survival rate of the two species was significantly (Stephen,2004).

### 2.2.4. Abundance of Neochetina weevils' water hyacinth plant

The Neochetina weevil number increase that the water hyacinth plant growth suppressed. The relative establishment of the weevils' density depends on plant, nutrient, and herbivores interaction. The larval population was affected only by the interaction effect of Neochetina weevils' and the nutrient levels. The mean number of emerged adult density of the weevils' increased with increasing nutrient levels. The nutrients and weevils' exhibited a significant interaction effect on *E. crassipes* leaf scarring and petiole tunnel. Leaf scarring at the highest weevils' density and nutrient level is six-fold greater than that at the lower nutrient level and weevil density. The tunnel length of the weed is threefold higher at the highest nutrient level regardless of the weevils' density (Tatek *et al*., 2022). The Neochetina weevils' in USA released on water hyacinth plant in 10 $m^2$

mats area coverage at two sites for a year that had initial weevils' abundant from 0 to 4000 weevils' in South and North site at North site 1000 weevils' increment was done that could affect the plant growth by 19cm (70cm for control and 1000 increment 51cm) . The mat coverage increment also affected but in mid summer there was no difference in case of seasonal environmental changes. Densities (larvae and adult weevils' per destructively sampled plant) varied spatially and temporally. Atypical example of temporal and spatial variation in USA, peak mean densities (averaged across August-November) decreased with increasing distance from the original release area. Peak mean densities ranged from 0.31 to 6.31 weevils' per plant. Densities averaged across sites were the lowest in June 2015 (0.54 weevils'), increasing in August to 5.35 weevils', and peaking in November at 6.22 weevils' (Hopper *et al*., 2017). The proportion of damaged leaf area from weevils' feeding increased directly with weevils' densities and number of feeding scars is more on small growth stage of water hyacinth as compared to equal number of weevils' released on middle or large growth stage proving the preferential feeding of the weevils' on younger leaves (Puja *et al*., 2009). Feeding scar correlated to adult weevils' abundance but all life stage of weevils' density or larvae gallery density not associated to scaring (Patrick, 2004). The abundance of an adult increase after adult regeneration date reaches. In rift valley Ethiopia *Neochetina bruchi* and *Neochetina eicchorniae* can reach in 80 up to130 (mean = 116 ± 7.3) and 90 up to 160((mean = 133 ± 9.2) days respectively (Firehun , 2017 ).

The effect level is different based on the weevil inoculation load and stage of water hyacinth plant growth. The weevils could affect the early stage of water hyacinth plant in short time within high percentage damage. The old water hyacinth plant percent of damage is low as compare to medium and early stage. Small growth stage of water hyacinth is an increase in damage percentage corresponding to the increase in weevils' load as compare to medium and large water hyacinth plant. Similar in fresh water hyacinth plant biomass and number of leaves damage depends on inoculation load of weevils' and stage of water hyacinth plant (Puja *et al*., 2009).

Effect of weevils' in different country variable due to environment and inoculation load that take time to affect the weed. Fore stance in Uganda Lake Victoria weevils' release in population (17-25 weevils' per plant), that reduced the weed biomass about 80% for five years (Ogwang and Molo, 2004). whereas in Benin, 100 up to 5% reduction in area coverage for 8 years (Ajuonu *et al*., 2003) and in Egypt from August 2000 up to July 2002 in Lake Edko coverage reduced by 90% (Cillers *et al*., 2003). Where as in Mexico 20-80% reduction of the water hyacinth population occurred within 2-3 year after release (Aguilar *et al*., 2003). This indicates that water hyacinth weevils are being used in different parts of the world with variable success. The first reason for this variability is spatial and seasonal variation in each area. Moreover, success is achieved with the use of both species where *N. eichhorniae* establishment was relatively higher ( Ajuonu *et al*., 2003). The combined usage of the two weevils has better herbivores impacts on water hyacinth than does alone. In addition, it is a synergy potential between the two weevils and other bio agents (insects or pathogens) in the management of water hyacinth (Feriehun *et al*., 2017).

### 2.2.5. Current status of biological control using Neochetina weevils'

Biological controlling methods involve introducing biological control agents on water hyacinth mat. It is one of the best methods for reducing water hyacinth populations through biological control agents. There are eight species of biological control agents have been released throughout the world (Coetzee and Hill, 2012). Searching of biological control agents began in the early 1960s and continues today. Six arthropod species have been released around the world. They are: two weevils, *Neochetina bruchi* and *Neochetina eichhorniae*; two months, *Niphograpta albiguttalis* and *Xubida infusellus*; a mite *Orthogalumna terebrantis*; and a bug, *Eccritotarsus catarinensis*. The mite and *X. infusellus* have not contributed to control and the bug is under evaluation following recent releases in Africa. The two weevils and the moth *N. albiguttalis* have been released in numerous infestations since the 1970s and have contributed to successful control of the weed in many locations (GBICWH, 2011). The use of biological control agents in various parts of the world has had various levels of success. This method was successfully in Australia through the regular release of the weevils Neochetina eichhorniae and *Neochetina bruchi*. Reproduction and biological control goes side by side meaning the number of weevils' increase the water hyacinth growth is affected since per population consumption. *N. bruchi* and *N. eichhorniae* population determine the growth of water hyacinth (Tatek *et al*., 2022). Acoording to Stephen (2004) in Lake victoria the biological agent is effective that had fecundity of the two weevils was recorded as 290 and 237 eggs per female laid over a period of 16 weeks, with an adult longevity of 98 and 112 days for *Neochetina bruchi* and *Neochetina eichhorniae* respectively. An adult initial feeding start in 24 hours after emergence and egg produced six days later. Over a lifetime, 200-400 eggs can be oviposit (laid) but egg production is dependent upon an abundance of healthy plants.

Physico-chemical parameter play great role on reproduction of the Neochitena weevils species. Generational time for *N. eichhorniae* is 70-140 days and *N. bruchi* is 56-94 days depending on temperature (Allie *et al*., 2001). Life cycle and development of Neochetina weevils had shorter generation time in Ethiopia than in Argentina but relatively similar to Kenya and Uganda (Getachew, 2020). In Ethiopia, the two weevils produced four generations per year indicating their successful establishment (Getachew and Wassie 2021). Feeding by adult weevils and tunneling by larvae significantly impacted the vigour and reproduction of water hyacinth plants. A herbivory loads of three pairs of *N. bruchi* and two pairs of *N. eichhorniae* showed the highest level of leaf damage and defoliated petioles (Firehun *et al*., 2017). Environmental condition affect the reproduction of weevils and the reproduction cycle delay the protection status of weevils.

### 2.5. Water hyacinth

#### 2.5.1. Historical perspective of water hyacinths

Water hyacinth (*Eichhornia crassipes*), a native weed to South America specially in Amazonian Brazil first described by Von Martius in 1823 under the family of Pontederiaceae plants (Jones *et al.*, 2018). It has been introduced into tropical and subtropical parts of the world since the 1800s where it has become a serious aquatic weed (Minichel *et al*., 2018). It is devastating weed grows in water bodies either naturally or as a result of human interference, is considered as threat to environment due to its negative effects on aquatic ecosystems (Begum *et al*.,2021). Water hyacinth has been considered as an invasive aquatic plant in the United States since 1984, in Africa since early 1900s, in Asia since 1902, and in Europe since 1930s. In China it was introduced in the 1930s and in the 1950s and 1960s, it was promoted as a livestock feed mostly for pigs. However, due to the popularization of formulated feeds, the utilization rate was reduced, and it has gradually become wild, especially in urban rivers and eutrophic waters in inner lakes of China (Ndimele *et al*., 2011). Even though the exact place and time introduce to East Africa still debated, botanists and gardeners take role for distribution in their travels for ornamental garden ponds since 1980s (Dereje ,2014). In South Africa it introduce in 1908(Kendall, 2015). Egypt was first introduced from Africa in 1880 where as in Ethiopia, water hyacinth was officially reported in 1956 in Koka Lake and the Awash River (Ebro, 2019). In Lake Tana, it has positively identified since 2011, a challenge to the ecosystem services (Minychl *et al*., 2019) and it was officially recognized in September 2011 (Ayalew *et al*., 2012).

### 2.5.2. Biology of water hyacinth

According to Abera (2019) nutrients and temperature are considered the strongest determinants for water hyacinth growth and reproduction. Under favorable conditions, water hyacinths can double its mass every 5 days and it also grows and form seed, which can remain viable for 20 years. The weed dispersal occurs by water-borne seeds through water current, Migratory birds stick fit feather, boat cushions, active transport by people who ignorant of its impacts or seek to propagate it in other ponds and lakes. Due to its extremely fast growth, floating nature on water and absence of natural enemies made it quickly becomes invasive, colonizing from the water bodies. Especially the water bodies slow moving results in thick and extensive mats which degrade aquatic ecosystems and limit their utilization. These mats affect fisheries and related commercial activities, functioning of irrigation canals, navigation, hydroelectric powers and tourism. The impact is not only loss of biodiversity in aquatic ecosystems but also economic development and human wellbeing.

The reproduction systems of water hyacinth are both sexual and clonal reproduction. The sexual reproduction is by producing seeds through self-fertilizing. According to Stephen (2004) in one thin walled fruit capsule contains 450 seeds which sink into the water upon getting good condition to re-infestation that can keep for up to 30 years.

On the other hand vegetative reproduction is a common form of propagation and is largely responsible for the rapid increase and spread of water hyacinth into new areas. The daughter plants produced from the horizontal stolon develop roots and eventually separate from the mother plant following breakage of the connecting stolon. Water currents, winds, fishing nets and watercraft are distributer vegetated piece. According to Minychl (2019) A single plant can develop and double itself in short time in 6-15 days. Three water hyacinth plant produce 3000 new plant shoot in 50 days and in one year 140 million ramants with fresh weight 28000 tons can produce (Weiping *et al.*, 2018). The water hyacinth classification biology in shot is explained in figure 2 below.

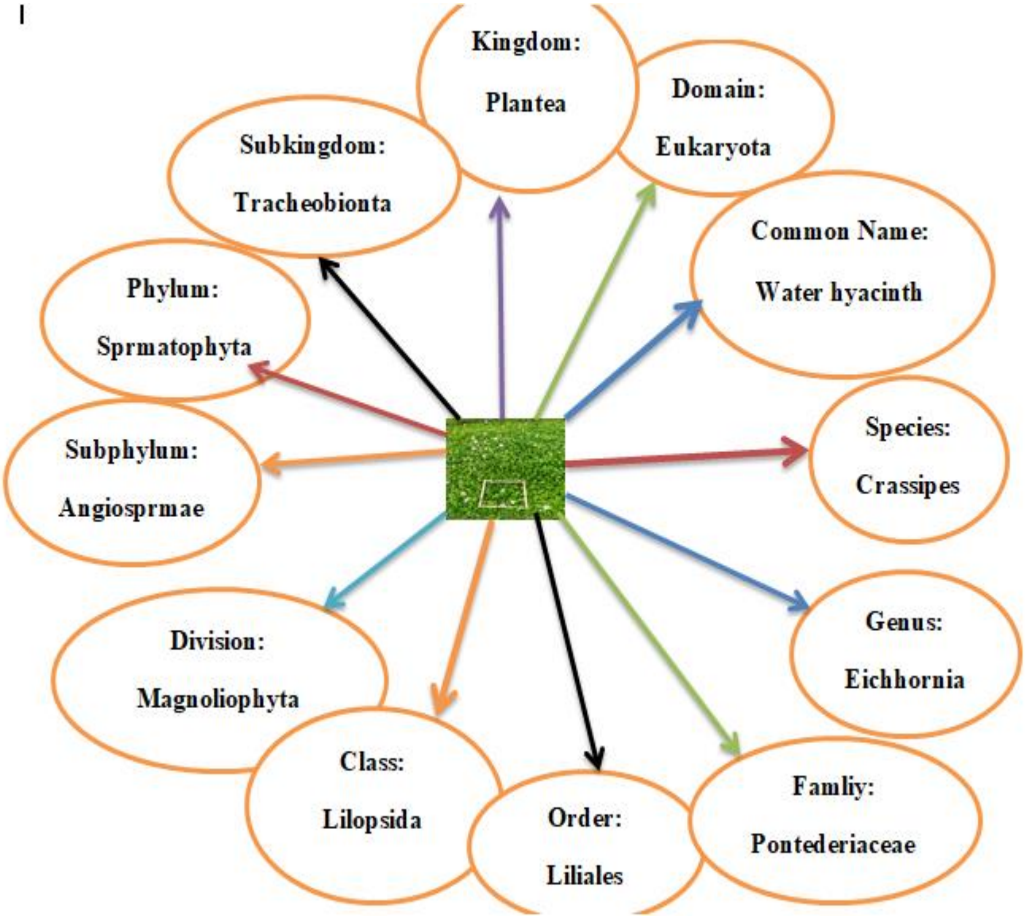



**Figure 2:** Classification biology of water hyacinth plant (source: Ghadir *et al*., 2022).

### 2.6. Water hyacinth plant and effect of weevils' feeding

#### 2.6.1. Leaves

Water hyacinth plant leaf differentiates from other aquatic weeds by its heart shape leaves. The leaf consist 3 parts. These are petiole end, isthmus and blade parts (Mahmood *et al.*, 2005). The densely veined leaves ovate or elliptic shape. The leaf blade has smooth edges, glossy, circular to heart-shaped and up to 30 cm in diameter. Two types of leaves occur those with petioles that are bulbous (swollen) and those that are non-bulbous .They are thick, glossy and waxy measuring 2 to 15 cm long and 2 to 10 cm wide respectively. The erect petioles are thick and spongy up to 50 cm long (SEEPPC, 2019). Near to the leaf spongy petioles swollen in the middle and tapering towards the blade or they may form a bulbous float. Water hyacinth plant leaves have furled and unfurled leafs. The furled leaf highly damaged by weevils due to nocturnal behavior of insects (Patrick, 2004). The Water hyacinth plant leaves affected by adult Neochetina Weevils is the herbivores insect that host specified its feeding habits on this weed that forming scars. Different scholars report that numbers of feeding scars per day were different. According to Getachew and Wassie (2021) one weevil could made scars raged 0 up to 6.53 feeding scar per day on leaves and petioles by forming rectangular and circular shapes. The insect affect the present leaf by feed and get ready to feed the new shoot leaf raised. These affect the leaf surface diameter enlarged and minimized the water evapotranspiration through decreasing number of stomata on leaf surface. The lowest leaf surface area is correlated with number of stomata and transpiration rates in the individual measured plants (Maylani *et al*., 2020).

### 2.6.2. Water hyacinth plant shoots

The shoot length of water hyacinth measured from root starting up to upward peaks of water hyacinth plant above the water. The shoot of water hyacinth plant could affect by directly feed the leaf by adult via making spots and larvae feed the petiole tissue through scrolling towards the roots (Friehun, 2017; Getachew and Wassie, 2022). Water hyacinth plant growth stage have great role on affecting by weevils' of shoot damage. The weevils could affect the early stage of water hyacinth plant shoot in short time within high percentage damage.

According to Puja *et al*. (2009), in small tubs water hyacinth planting, 4 and 8 weevils could control small growth stage water hyacinth in 25 and 15 days, while 12, 16 and 20 weevils could drown the weed mat in 20, 15 and 10 days, respectively. The number of feeding scars is more on small growth stage of water hyacinth as compared to equal number of weevils release on middle or large growth stage proving the preferential feeding of the weevils on younger shoots. So that there is no chance to growth extend. Firehun (2017) reports were comparing of infested petiole length by larvae to non-infested one effect between the two Neochetina weevil species in lath house. He was conducting on *Neochetina burchi* and *Neochetina eicchorniae* larvae affected petiole length at an average tunnel length was 8.2 cm, and the average length of the affected petiole was about 42% less than that of the non-affected petiole and 5.5cm and the average length of affected petioles was about 27% less than the non-affected petioles respectively.

### 2.6.3. Water hyacinth plant roots

Water hyacinth plant root float on water that wards to ground or attached to the mud. Water hyacinth is a perennial, herbaceous, free-floating aquatic plant in open water but it is rooted in moist mud along the banks of rivers, lakes, and impoundments (Admas *et al*., 2017; Dersseh *et al*., 2019). Its roots are totally submerged and have some adaptations associated with growth in a hydric environment. Such traits are called Hydromorphic. It has long fibrous adventitious roots mostly floating, sometimes rooting muds. The floated water hyacinth roots have a plastic like covered bundle caps which is show in Appendences fig. 15. The lateral roots affect by third instars larvae stage through cut off small lateral rootlets and form a cocoon around it. The fully developed larvae burrow out of the stem and move to the upper root zone just under the surface of the water. They cut off small lateral rootlets and form a cocoon around it (Stephen, 2004). This cocoon is attached to one of the roots and form pupae that root zone is living habitat of it. During the rainy seasons, increased nutrient concentrations, humidity, and especially water level can promote the formation of extensive water hyacinth mats and the roots part also increase (Cai *et al*., 2023).

### 2.6.4. Fresh water hyacinth plant biomass

The whole water hyacinth plant that measured by sensitive balance as is fresh water hyacinth plant biomass. The plant biomass affected by adult Neochetina weevils' and it's larvae by feeding and reproduction for regenerate itself. According to Puja *et al*. (2009), research in tank water hyacinth plating by inoculation load in small, Medium and large size plant the percent damage of water hyacinth plant depends on weevils' inoculation load and water hyacinth plant size that show below table1. Small growth stage of water hyacinth was controlled in high percentage damage corresponding to the increase in weevil load as compare to medium and large size water hyacinth plant of fresh biomass.

**Table1:** The damage percent of WH plant in a time based on size and inoculation load of weevils' (Source: Puja *et al*., 2009).

| Size | Days | Inoculation load | % Dage |
|---|---|---|---|
| Small | 10 | 4 | 11.7 |
| Small | 10 | 8 | 47 |
| Small | 10 | 12 | 96 |
| Small | 10 | 16 | 96 |
| Small | 10 | 20 | 95 |
| Small | 20 | 16 | 100 |
| Small | 20 | 20 | 100 |
| Small | 30 | 12 | 100 |
| Small | 40 | 8 | 100 |
| Small | 50 | 4 | 100 |
| Medium | 70 | 4 | 100 |
| Medium | 60 | 8 | 100 |
| Medium | 50 | 12 | 100 |
| Medium | 40 | 16 | 100 |
| Medium | 20 | 20 | 100 |
| Large | 10 | 20 | 100 |

The combination treatment of two weevils (*Neochetina eichhorniae* and *Neochetiniae bruchi*) are effective than solely treated. According to Firehun (2016) report that plant biomass (fresh weight) was highly significantly affected by different densities of the two weevils and their interaction at eight weeks after release of the herbivores treatments. The three pairs of *N. bruchi* (109.16grm) gave the lowest plant weight affected, two pair (66.49grm) or three (64.37grm) pairs of *N. eichhorniae* indicating that it has a significant suppressive effect on plant weight. So that *Neochetina bruchi* high damage effect than *Neochetina eichhorniae*; but it is better to use the combination of the two weevils'. Center *et al*. (2005) reported that herbivores of the two weevils' combination decreased water hyacinth's competitive performance by 98% at a density of 4 weevils per plant. The water hyacinth plant parts show by arrows below on figure 3.

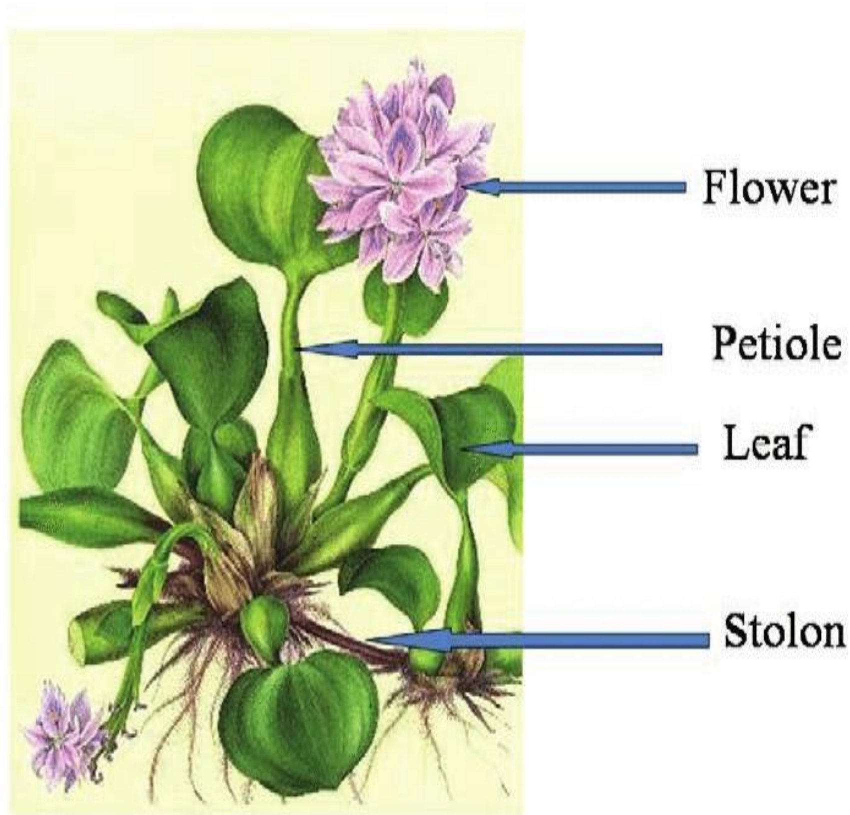



**Figure 3:** Water hyacinth plant morphology (Source: Stephen, 2004).

# 3. Materials and Methods

## 3.1. Study area

The research was conducted at Peda Campus; Bahir Dar University in Bahir Dar town, which is Amhara National Regional State of Ethiopia. It was conducted in six earthen ponds located between latitude 11°33’1’’ to 11°38'1"North and longitude 37°20'0" to 37°27'0" East near the Blue Nile River out let from Lake Tana. Specifically the ponds were found at the back of BDU Martine academy. The area was selected due to the seasonal water load area that helps easy construction of the pond construction and is adaptable to water hyacinth plants which is similar to Lake Tana.

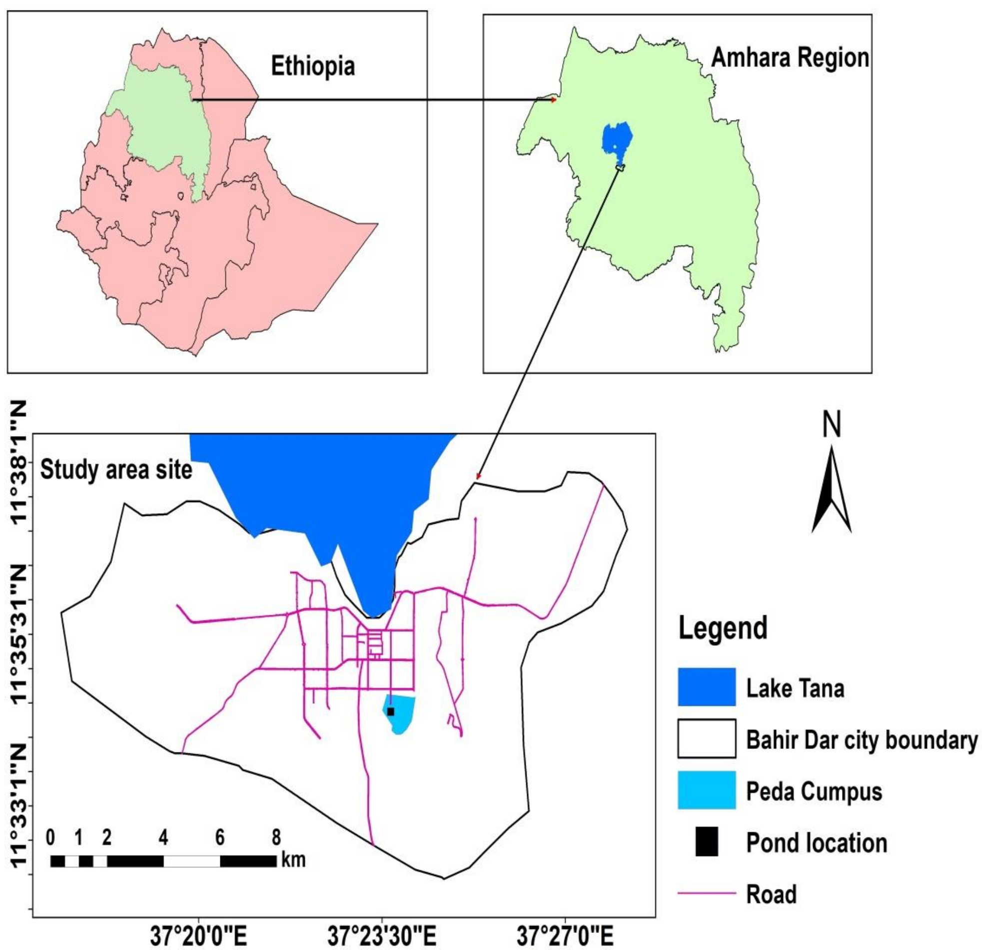



**Figure 4:** The study pond location in BDU peda Campus.

## 3.2. Experimental Setup and Design

### 3.2.1. Experimental setup

The assessment of the impact of Neochetina weevils' species on water hyacinth plant trials was conducted in constructed earthen ponds with a dimension of 4x4x0.75m for a period of 12 weeks from January to July 2023. The ponds were first installed and arranged randomly in a position with considering manipulation during the experimental period. The ponds were randomly assigned for each treatment and control group. The ponds were similar with respect to depth, basin configuration, and pattern including water supply facilities. The ponds had got water via plastic pipes from Bahir Dar University Neochetina weevils' species rearing research lath house to maintain the water level. The experimental ponds with weevils' were labeled as treatment ponds 1-3(TP 1-3), and the control ponds were labeled by control ponds1-3(CP 1-3) with 35 water hyacinth plants. The setup is shown in figure 5 below.

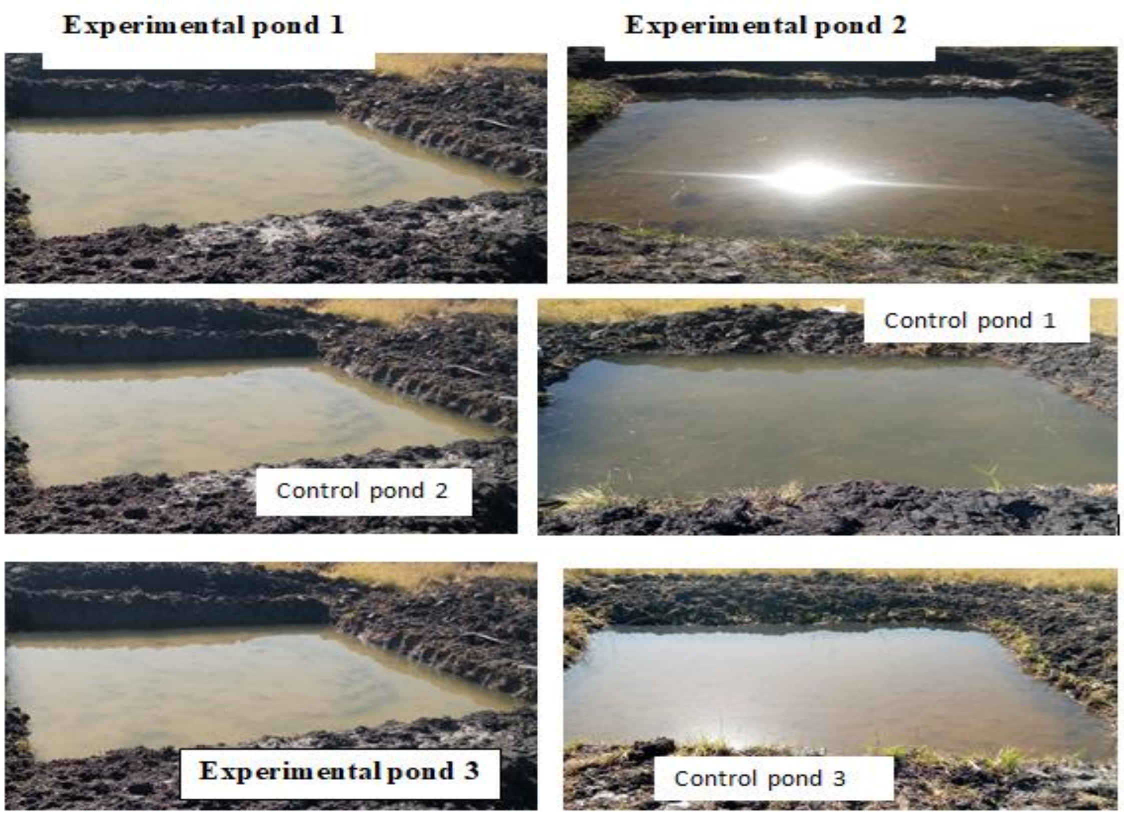



**Figure 5:** Treatment and controlled ponds filled with ground water before the start of the experiment.  (Direct photo captured in February, 2023).

### 3.2.2. Experimental design

The study was designed one treatment and control ponds of equal size that triplicated for each of the ponds. The six ponds had 4x4x0.75 m cube volume was dug and prepared for each of them. All the ponds were grouped into two blocks and signed as control and treatment ponds using a simple random method. All the ponds were filled by water from ground water up to 80% holding capacity. A total of 210 water hyacinth plants were present throughout all the ponds, with 35 plants in each pond and then water hyacinth plant leaf at first planting had bright green, waxy, smooth and fleshy. After a week of being introduced to the ponds, it became yellowish due to a lack of nutrients. 18 kg animal dung was added to all ponds equally. Then the color changed to green after a week till acclimatized, and then Neochetina weevils' species were introduced in treatment ponds. In tripilicated experimental treatment ponds, 525 adult *Neochetina eichhornia* and *Neochetina bruchi* weevils' species were introduced without segregation in equal divisions for three ponds of the weevils that came from BDU experimental biology department lath house (figure-1). The weevils naturally co-existed on water-hyacinth under field conditions (Ray *et al*., 2009). The design randomly signed the blocks into two, as shown below table 2. Thus, the design has three Expermental treated ponds (TP) and three controlled ponds(CP).

**Table 2:** Experimental design and layout of the research pond configuration in blocks was as follows.

| Experimental ponds | Blocks | Pond size(metric cube) | Number of WH plants | Introduced Neochetinia weevil number |
|---|---|---|---|---|
| TP1 | A | 12 | 35 | 175 |
| CP1 | B | 12 | 35 | 0 |
| TP2 | B | 12 | 35 | 175 |
| CP2 | A | 12 | 35 | 0 |
| TP3 | A | 12 | 35 | 175 |
| CP3 | B | 12 | 35 | 0 |

### 3.3. Sampling techniques

The ponds were constructed from January, 16, 2023 to February, 13, 2023 with a volume of 4x4x0.75 cubic meter for each pond, and then the water was filled. From each pond 35 water hyacinth plants were planted in equal distribution and 18 kg Cattle dug were added equally for all ponds which helped to enhance the water-hyacinth plant growth as well as weevil density. For each three ponds 175 adult Neochetina weevil species were inoculated. During April, 04, 2023 to July, 05, 2023 samples were taken using 0.5x0.5m quadrat in simple random method. Both the water hyacinth plant and the Neochetina weevils' specie were measured and counted respectively. From each pond, three quadrat samples were taken randomly for three months in a biweekly gaps repetitively. The water hyacinth plant maximum and minimum leaf diameter, shoot and root length were measured using a Rollo-meter and plastic Ruler in centimeter with 0.01 cm precision and the number of feeding scars count using marking pens to protect recount, adult weevils' and larvae were counted in the quadrat sample through visual observation. Fresh water hyacinth pant biomass was measured by using three digits sensitive balances in gram within a precision of 0.01gram( Faulkner,2011). The shoot length of water hyacinth plant measured from the root starting point to the longest leaf peaks of WH plant leaf in centimeter. The water quality parameter sample was measured using an automatic portable probe Multi-meter randomly for all ponds by changing cables in biweekly gaps, which help to determine the water quality and survival environmental parameters of Neochetina weevils' species.

### 3.4. Data collection

This research data were collected in six excavated earthen ponds, of which three ponds would be experimental treatment, and the other three were control ponds. In each pond, three quadrat (0.5*0.5 meter wooden quadrat) sample data were taken on biweekly gaps for three months. From each pond, the quadrat representative sample was taken at random sampling, which helps to give an equal chance of sampling the pond coverage. Both in the experimental treated and controlled ponds, 108 sample data were taken for each of the seven study parameters (variables) that are number of weevils, number of feeding scars, maximum leaf diameter, minimum leaf diameter, shoot length, root length and fresh WH plant biomass. Data on these study parameters were recorded from each plant in a quadrat, and one quadrat could incorporated 3 to 7 WH plants.

### 3.4.1. Water quality parameter data collection

Water quality parameter also measured randomly for each pond using multi meter probe in the 15$^{th}$ day's term for three months from April 2$^{nd}$ 2023 up to July 1$^{st}$ 2023. This helps to compare and contrast control and treatment groups of the ponds that helps to determine water hyacinth mat impacts.

The randomly data collection sample taking method was used due to homogeneity of the ponds in terms of the water type, the water hyacinth plant and the treated Neochetina weevil species as well as similar back ground habitat presented in the ponds. Measurements of physicochemical parameters of water quality variable data was collected from experimental and control ponds via on site based through probe insert. The water quality parameters of water such as typical water temperature (Temp), pH, dissolved oxygen (DO) and electrical conductivity (EC) would be measured in each treatment and control ponds. The data from the various experiments would be compiled in appropriate data sheets and analyses separately.

### 3.4.2. Adult, larvae Neochetina weevils' and number feeding scars data

The introduced adult Neochetina weevils', generated larvae and the number of feeding scars on WH plant leaf and petioles were counted in each quadrat sample for three months in biweekly intervals at triplication random quadrat. The adult and larvae *Neochetina eichhorniae* and *Neochetina bruchi* were counted through visual observation, carefully in each WH plant by pulling out the plant from the pond that was randomly incorporated in a quadrat. The adult counting was difficult since the natural behavior of the weevils' that sets it in the secured part of the plant (furl), such as the calyx of the stem, flower, and root and shoots part. The adult weevil was counted after the water hyacinth plants were pulled out from the quadrat since insects are movable by their nature from one WH plant to another plant on the plastic plate. The larvae were also counted by observing on the stem of the water hyacinth plant main and branch shoots turn by turn that created a tunnel which helps to observe them easily with naked eye. The larvae were counted through visual observation based on bore petioles in which water logged and made a line on the stem that caused the ultimate death of the plant. After counting weevils, the scars were also counted through observation from the leaf surface and petioles of the plant. Compound scars were separated into component scars by noting any apparent discontinuities in the normally regular scar borders or on the differential depth of feeding. Feeding scars were counted by marking each counted scar using a marker pen. Marking of each scar prevented accidental recounting. So that careful counting was done in each plant and then the plants were returned immediately to the quadrat in the pond which helped to protect the damage on the plant as well as on an adult and larvae weevil. All the data for both the larvae and adult weevils' count were recorded on paper and then coped in an excel sheet.

### 3.4.3. Water hyacinth data collection

Impacted water hyacinth plant data would be collected on WH plant populations through measured of the WH plant growth change such as maximum leaf diameter, minimum leaf diameter, shoot length, root length and fresh(wet) plant biomass data would be measured from neochetina weevil treated ponds that were sampled from the quadrat. Non- impacted water hyacinth plant data were collected from control ponds through measured the water hyacinth plant parts such as maximum leaf diameter, minimum leaf diameter, shoot length and root length using Rollo meter within the precision 0.1cm. The fresh weights of water hyacinth plant were measured by three digit sensitive balance within the precision 0.1gram. The WH plant data would be collected through visual observation via supporting photographic data which helps to compare and contrast the control and treatment ponds water hyacinth weed biological controlling effectiveness in specified adult weevils inoculation load based on the color change. The impacted part of water hyacinth weed would be quantified by measured and counted values. Data was recorded chronological order on the hard and soft paper excel sheet within two weeks round for three months.

## 3.5. Data analysis

Water hyacinth shoot length, root length, maximum and minimum leaf diameter, plant biomass, number of feeding scars, number of adult Neochetina weevils' species, number of larvae, and water quality data were subjected to multivariate analysis of variance (MANOVA) to test the effects of weevil on the growth performance of Water hyacinth. Multivariate analysis was used to quantify the effects of the independent variable

(Neochetina weevils) on the related response variables (water quality variables and WH plant within Neochetina weevils' species and without Neochetina weevils' species character). Analysis for Weevils' impact on water hyacinth maximum leaf diameter, minimum leaf diameter, shoot length, root length, and fresh water hyacinth plant biomass change were done using multivariate general linear model procedure (SPSS). The relationship between weevils' and number of feeding scars was determined using linear regression statistical analysis. All the statistical analyses were analyzed using SPSS Statistical software Package Version 23.

### 3.6. Data quality control

Data reliability would be checked through experimental treatment and control ponds direct observation by compare and contrast via change photograph support. Triplicate is also one of the treatment and control group and instrument standardization is also another data quality control means. The statistical significance difference was also the data quality controlled method for this research. The validity of data was checked through a parametrical test, which helps to determine weather the data is normality distributed or not. Similar observation rates in each sampling unit at time, space, and observations somehow unrelated were used for sample taking, which helps the quality of the data accuracy. The test is significant or $p < 0.05$, the distribution is non-normal at 95% confidence interval or $\alpha = 0.05$. The value of $P \geq 0.05$, the distribution is normal. Normality and other assumptions should be taken during analysis seriously. When these assumptions do not hold, it is impossible to draw accurate and reliable conclusions about reality in the research finding. The assumption of normality needs to be checked for many statistical procedures, namely parametric tests, because their validity depends on it. "α" is the symbol of significance level. It is indication of how close your estimate is likely to be to the parametric ("true") estimate.

# 4. Results

## 4. 1. Effect of water hyacinth on water quality and survival of weevils’

**Table 3:** The multivariate tests of water quality parameter result.

| Effect | Value | F | Hypothesis df | Error df | Sig. | Partial Eta Square | Observed power |
|---|---|---|---|---|---|---|---|
| Level of weevil Wilks’ Lambda | .047 | 2.282 | 44.000 | 82.295 | .001 | .534 | .999 |

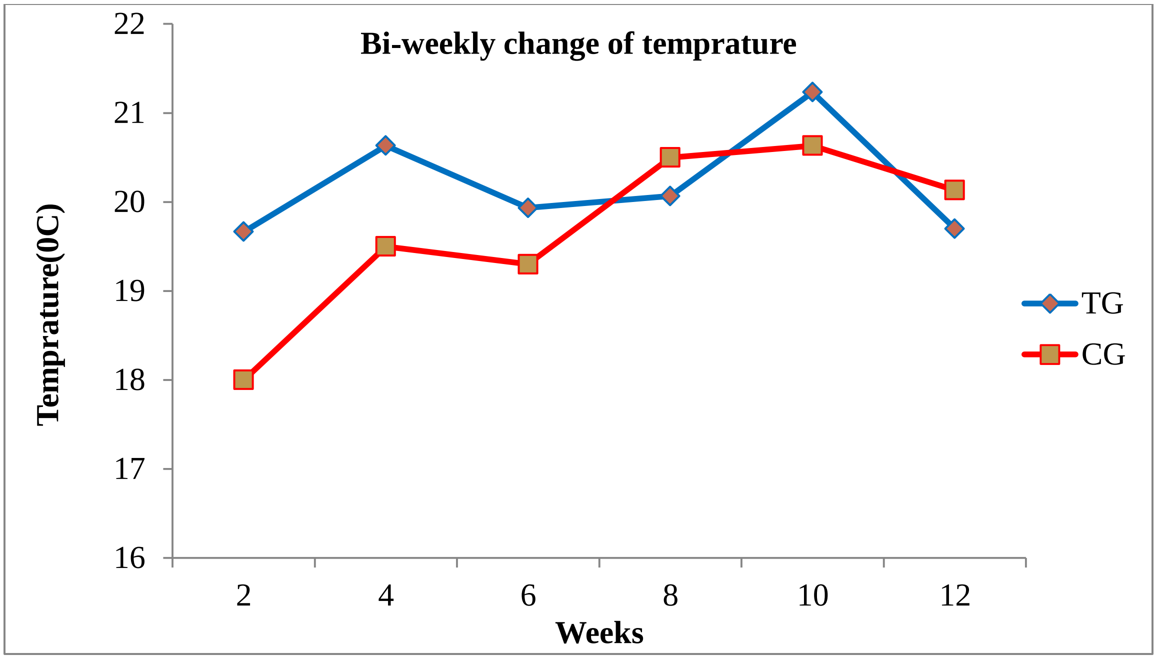
The strength of relationship between Temperature, DO, pH and EC was weak which account 53.4% of the variance.The observed power of 0.999, indicate that there was a 99.9 % chance that the results could not have come out for all other results. Since the observed power is less than 1 the effect size is low.

### 4. 1.1. Temperature (°C)

The measured temprature values in both treatment and control ponds are summarized in Table 4.

**Table 4:** Statical description of result tests of temprature in °C.

| **Bi-weeks** | **Means(℃) ± SE** | | **95% confidence interval** | | | |
|---|---|---|---|---|---|---|
| | | | **lower bound** | | **upper bound** | |
| | treated | controlled | treated | controlled | treated | controlled |
| 2 | 19.6 ± 0.5 | 18 ± 0.5 | 18.7 | 17.1 | 20.6 | 18.9 |
| 4 | 20.6 ± 0.5 | 19.5 ± 0.5 | 19.7 | 18.6 | 21.5 | 20.4 |
| 6 | 19.9 ± 0.5 | 19.3 ± 0.5 | 19 | 18.4 | 20.9 | 20.2 |
| 8 | 20.1 ± 0.5 | 20.5 ± 0.5 | 19.1 | 19.6 | 21 | 21.4 |
| 10 | 21.2 ± 0.5 | 20.6 ± 0.5 | 20.3 | 19.7 | 22.2 | 21.6 |
| 12 | 19.7 ± 0.5 | 20.2 ± 0.5 | 18.8 | 19.2 | 20.6 | 21.1 |




TG: Treatment groups of water temprature and CG : control groups of water temperature of water hyacinth planted ponds line trend graph

**Figure 6:** Water temperature comparisons water hyacinth planted ponds with weevil present and absence time series line grap

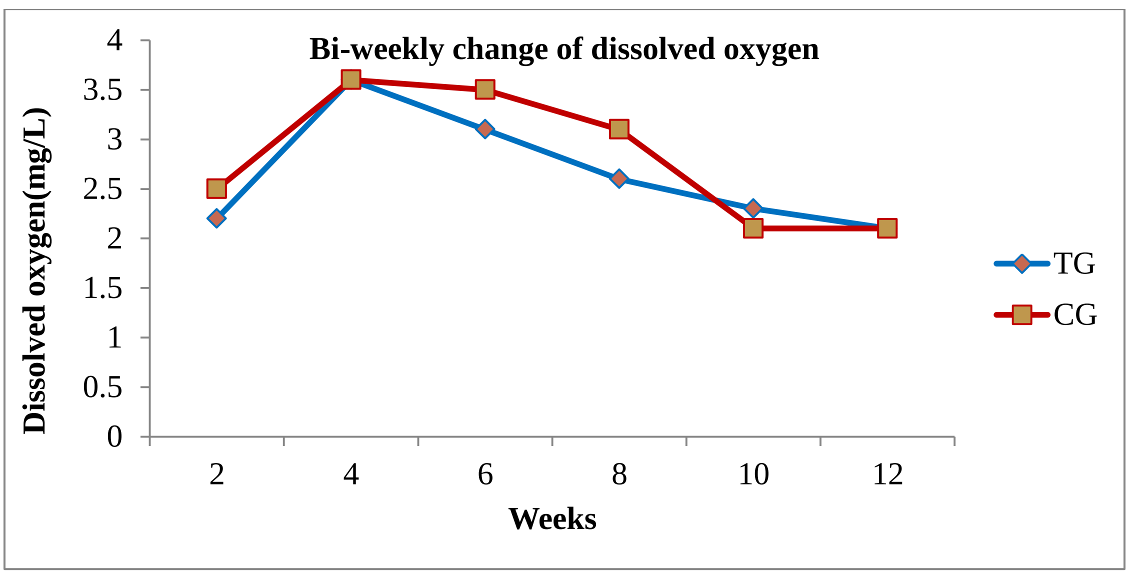
Final to initial difference of weevil treated(0.1± 0.5) and control(2.2± 0.5) of pond mean water temperature were differ . Even though statisticaly insignificant that the temperature difference was there between treated and local controlled ponds water. Statistical result of water temperature, (F (11, 24) = 3.33, p=0.007, partial eta square ($\eta^2$) = 0.604, observed power =0.951). The effect size was not large for water temperature MANOVA. The strength of relationship between the temperature and dissolved oxygen, pH and Electrical conductivity was not strong that accounting for 60.4 % of the variance.

#### 4. 1.2. Dissolved oxygen

The measured DO values in both treatment and control ponds are summarized in Table 5.

**Table 5:** Statical description results of tests of DO in mg/L.

| **Bi-weeks** | **Means(mg/L) ± SE** | | **95% confidence interval** | | | |
|---|---|---|---|---|---|---|
| | treated | controlled | **lower bound** | | **upper bound** | |
| | | | treated | controlled | treated | controlled |
| 2 | 2.2 ± 0.3 | 2.5 ± 0.3 | 1.4 | 1.8 | 2.9 | 3.3 |
| 4 | 3.6 ± 0.3 | 3.6 ± 0.3 | 2.8 | 2.8 | 4.3 | 4.3 |
| 6 | 3.1 ± 0.3 | 3.5 ± 0.3 | 2.3 | 2.8 | 3.8 | 4.3 |
| 8 | 2.6 ± 0.3 | 3.1 ± 0.3 | 1.8 | 2.4 | 3.4 | 3.8 |
| 10 | 2.7 ± 0.3 | 2.6 ± 0.3 | 1.9 | 1.8 | 3.4 | 3.4 |
| 12 | 2.3 ± 0.3 | 2.1 ± 0.3 | 1.5 | 1.4 | 3.1 | 2.9 |




TG: Treatment groups of dissolved oxygen and CG : control groups of dissolved oxygen of water hyacinth planted ponds line trend graph

**Figure 7:** Graphical comparision of DO ponds water weevils' present and absence.

During the experimental period of water hyacinth plant treated ponds by Neochetina weevils' species and controlled of DO concentration (mg/L) registered were varied. The treated and controlled water hyacinth ponds mean minimum to maximum concentrations of DO ranged from 2.2 to 3.6 mg/L and 2.1 to 3.6 mg/L respectively. Final to initial mean difference of treated and controlled DO concentration were differ (0.1 ± 0.3 mg/L ) and (0.4 ± 0.3 mg/L ) respectively. The mean concentration of dissolved oxygen comparison in treatment and control ponds water were set for each biweekly base in Table 5 above. The highest mean concentration of DO was registered (3.6 ± 0.3 mg/L) in treated and controlled (3.6 ± 0.3 mg/L). The least mean concentration of DO was registered (2.2 ± 0.3 mg/L) in first weeks and (2.1 ± 0.3 mg/L) in last weeks in treatment and control water hyacinth planted ponds respectively.

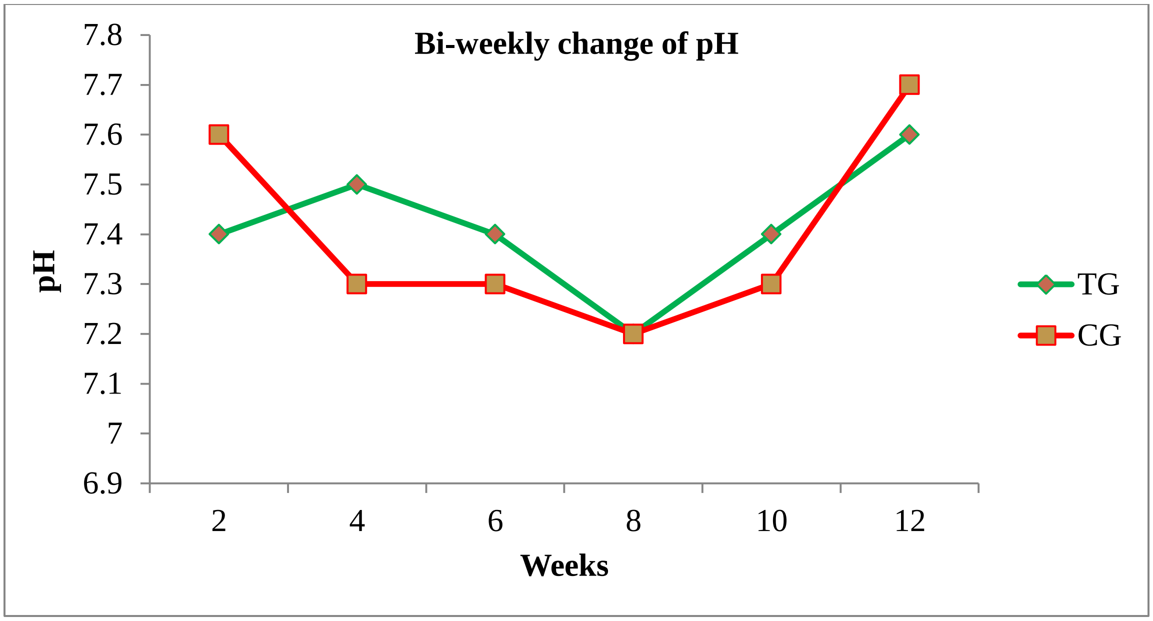
The dissolved oxygen concentration of statistical result is, (F (11, 24) =1.73. p = 0.125, partial eta square ($\eta^2$) = 0.443, observed power =0.675). The effect size was not large for dissolved oxygen MANOVA. The strength of relationship between the dissolved oxygen and Temperature, pH and Electrical conductivity was not strong with the type group accounting for 44.3 % of variance the dependent variable. The mean concentration of dissolved oxygen in the treatment and control ponds water was not statistically significant difference (MANOVA) p>0.05. So alternative hypothesis were accepted that shows difference. Based on statistical insignificance the null hypothesis is rejected ($H_0$ # 0).

**4. 1.3. pH**

During the study period the values of pH as environmental variable were recorded in both the treatment and controlled ponds are summarized below on Table 6.

**Table 6:** Statical description results of tests of pH.

| **Bi-weeks** | **Means ± SE** | | **95% confidence interval** | | | |
|---|---|---|---|---|---|---|
| | treated | controlled | **lower bound** | | **upper bound** | |
| | | | treated | controlled | treated | controlled |
| 2 | 7.4 ± 0.1 | 7.6 ± 0.1 | 7.2 | 7.5 | 7.6 | 7 .8 |
| 4 | 7.5 ± 0.1 | 7.3 ± 0.1 | 7.3 | 7.1 | 7.6 | 7.5 |
| 6 | 7.3 ± 0.1 | 7 .2 ± 0.1 | 7.2 | 7.1 | 7.6 | 7.4 |
| 8 | 7.2 ± 0.1 | 7.1 ± 0.1 | 7.1 | 6.9 | 7.4 | 7.3 |
| 10 | 7.4 ± 0.1 | 7.3 ± 0.1 | 7.2 | 7.1 | 7.6 | 7.4 |
| 12 | 7.6 ± 0.1 | 7.7 ± 0.1 | 7.4 | 7.5 | 7.7 | 7.8 |




TG: Treatment groups of pH and CG : control groups of pH of water hyacinth planted ponds line trend graph

**Figure 8:** Pond water of pH comparisons weevil present and absence time series line graph**.**

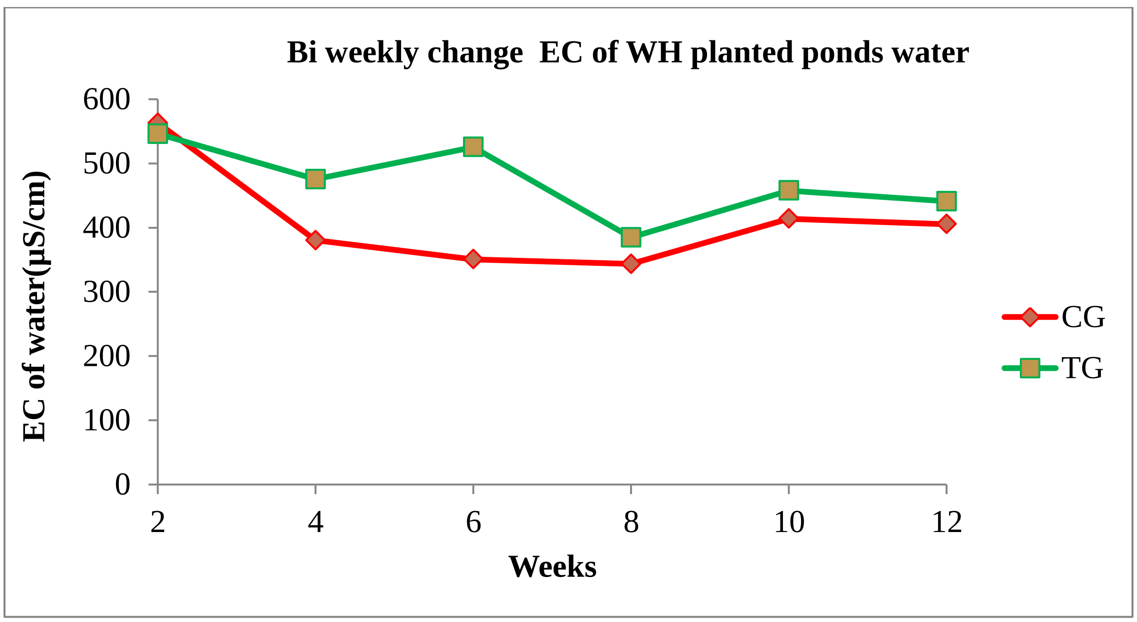
The pH of treated and controlled WH plant range 7.1 to 7.9 and 7.1 to 7.8 respectively. Final to initial difference of weevil treated and controlled ponds of water mean hydrogen ion concentration difference each other (0.2±0.1) and (0.1±0.1) respectively. The pH result is, (F (11, 24) =4.09. p = 0.02, partial eta square ($\eta^2$) = 0.652, observed power =0.983). The effect size was slightly large for pH MANOVA. The strength of relationship between the pH and Temperature, dissolved oxygen concentration and Electrical conductivity was strong with the type group accounting for 65.2 % . The observed power of 0.983, indicate that there was not 98.3 % chance that the results could have come out significant for all other result. The mean concentration difference of pH in the treated and controlled ponds water was not statistically significant difference (MANOVA) p>0.05. So alternative hypothesis were accepted that shows difference. Based on statistical insignificance the null hypothesis is rejected ($H_0$ # 0).

**4 .1.4. Electrical conductivity (µS/cm)**

During the study period the values of EC as environmental variable were recorded in both the treatment and controlled ponds are summarized below on Table 7.

**Table 7: :** Statically description of result of tests Electrical conductivity in µS/cm.

| Bi-weeks | Means(µS/cm) ± SE | | 95% confidence interval | | | |
|---|---|---|---|---|---|---|
| | treated | controlled | **lower bound** | | **upper bound** | |
| | | | treated | controlled | treated | controlled |
| 2 | 563 ± 62 | 546 ± 62 | 435 | 418 | 690 | 673 |
| 4 | 380 ± 62 | 475 ± 62 | 252 | 347 | 508 | 603 |
| 6 | 350 ± 62 | 525 ± 62 | 222 | 397 | 478 | 653 |
| 8 | 343 ± 62 | 384 ± 62 | 215 | 256 | 471 | 512 |
| 10 | 741± 62 | 457 ± 62 | 286 | 329 | 541 | 585 |
| 12 | 405 ± 62 | 441 ± 62 | 277 | 313 | 533 | 568 |




**TG:** Electrical conductivity of the treatment group and **CG:** Control group of water hyacinth planted ponds water

**Figure 9:** The electrical conductivity of pond water comparisons of weevil present and absence time series line graph.

During the experimental period of treated and controlled WH planted water, the electrical conductivity recorded ranges (304µS/cm) to (713 µS/cm) and (317µS/cm) to (657µS/cm) respectively. Final to initial mean difference of treated and controlled of electrical conductivity of water were (158 ± 62µS/cm ) and (105 ± 62µS/cm ) respectively. The mean electrical conductivity for treated and controlled WH planted pond water in weeks showed in table 7.

Electrical conductivity water statistically result were, ($F$ (11, 24) =1.443. $p$ = 0.218, partial eta square ($\eta^2$) = 0.398, observed power =0.576). The EC of effect size was small of MANOVA result. The strength of relationship between the electrical conductivity and Temperature, dissolved oxygen concentration and pH was not strong with the type group accounting for 39.8 % of the variance the dependent variable. The observed power of 0.567, indicate that there was not 56.7 % chance that the results could have come out significant for all other result. The mean electrical conductivity in the treatment and control ponds water was not statistically significant difference (MANOVA) $p>0.05$. So alternative hypothesis were accepted that shows difference and the null hypothesis is rejected ($H_0$ # 0). The season impact were showed up and down difference in graphical trend lines.

### 4.2. Abundance of Neochetina weevils' (adults and larvae)

In this study the abundance of weevil population and the larvae produced are summarized below on Table 8 and Figure 9.

**Table 8:** Bi-weekly mean abundance of adult and regenerate larvae

| Bi-weeks | Adult Weevils | Larvae |
|---|---|---|
| 0 | 5 | 0 |
| 2 | 7 | 0.3 |
| 4 | 8 | 3.8 |
| 6 | 9 | 5.3 |
| 8 | 5 | 2.5 |
| 10 | 2 | 1.7 |
| 12 | 0.2 | 0.06 |

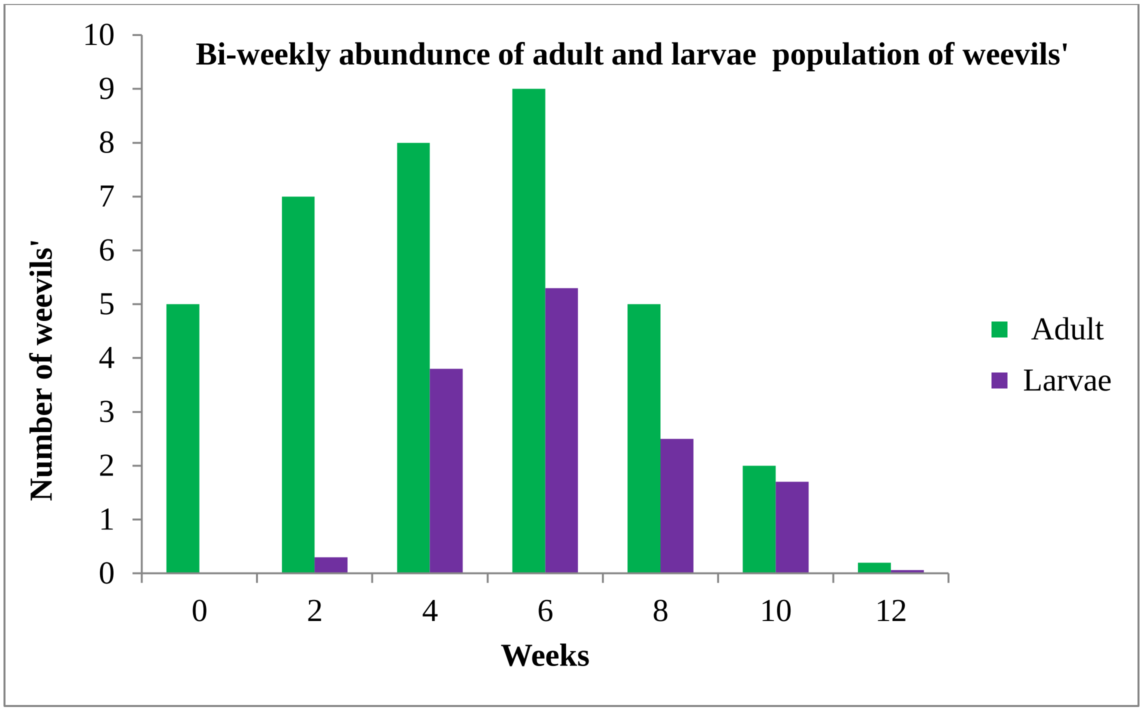



**Figure 10:** Biweekly weevils (adult and larvae) abundance in earthen water hyacinth planted ponds.

In this study the weevils' were able to survive and regenerate larvae increasing and decreasing in number through time due to short life span in their life cycle as indicated in Figure 10.

The highest number of water hyacinth plant (448) was recorded in local control ponds. The maximum adult weevils' number abundance (14 per plant) was recorded in the first six week after inoculation. The minimum adult weevil 0 per plant mostly recorded in 12$^{th}$ week. But new adult didn't reached till 84(till the data collection end) days. 5 weevils' per plant could affect one water hyacinth plant in 3 months. In 0.25m square area mat contain 3 up to 7 plants so that required 15 to 35 adult weevils' that could control the growth and reproduction of the weed. The adult generate larvae from 2$^{nd}$ weeks (after 14day) 0.3 in means up to 5.3 in 6$^{th}$ $^{(}$after 56 days) week's.

**4. 3. The relationship between Neochetina weevils' and number of feeding scars**

**Table 9:** The regression model summary[b] table

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .784[a] | 0.615 | 0.607 | 36.088 |

a. Predictors: (Constant), Number of weevils

b. Dependent variable: Number of feeding scar

The adjusted r-square is a standardized indicator of r-square, adjusting for the number of weevils'. This shows the standardized variance of the weevils on the number of feeding scars. The values of Pearson's r (0.784), $R^2$ (.615), adjusted $R^2$ (.607), and the standard error of estimate (36.088). Pearson's r is measure of association betweennumber of feeding scars and number of weevils. But in this model required the relationship rather association. $R^2$ showed that the model fit by comparing the value of closeness to adjusted $R^2$ value. Means the adult weevil explains 61.5% of the related to the feeding scars. Adjusted $R^2$ is a more conservative estimate of $R^2$.

**Table 10:** The ANOVA table in regression model analysis.

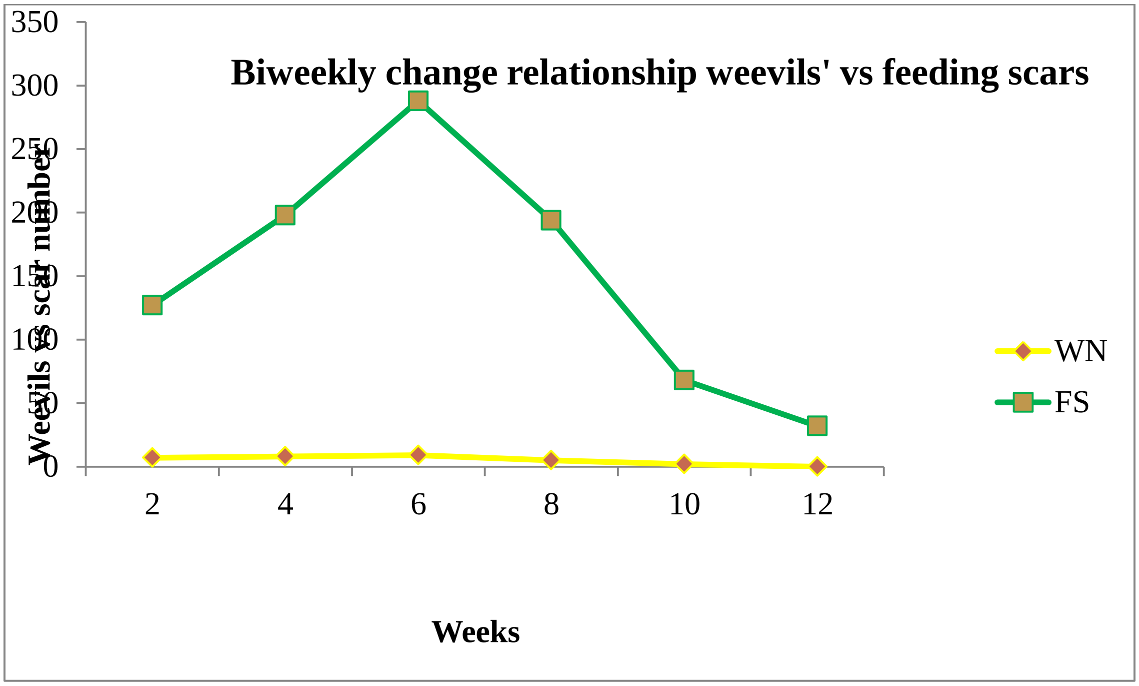
| Model | Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Regression | 110042.4 | 1 | 110042.4 | 84.5 | .000 |
| Residua | 69025.7 | 53 | 1302.4 | | |
| Total | 179068.1 | 54 | | | |

Weevils are significantly related to the scar numbers. Because the p value (significance level) is less than 0.05, then "the model" is statistically significant (F (1, 53) = 84.5. p<0.001). Based on statistical significance the null hypothesis is accepted ($H_0$ =0).

**Table 11:** The regression output of coefficients table

| Model | Unstandardized Coefficients | | Standardized Coefficients | T | Sig. |
|---|---|---|---|---|---|
| | B | Std. Error | | | |
| (Constant) | 26.84 | 5.700 | | 4.709 | .000 |
| Number of Weevils | 16.86 | 1.835 | 0.784 | 9.192 | .000 |


**Figure 11:** Direct photo ( May, 2023) of effect of weevils' on water hyacinth leaf and petioles forming of feeding scar




**WN:** number of Weevils' and **FS:** number of feeding scars trend line graph

**Figure 12:** The relationship between number of feeding scars and number of adult weevils in time series line graph.

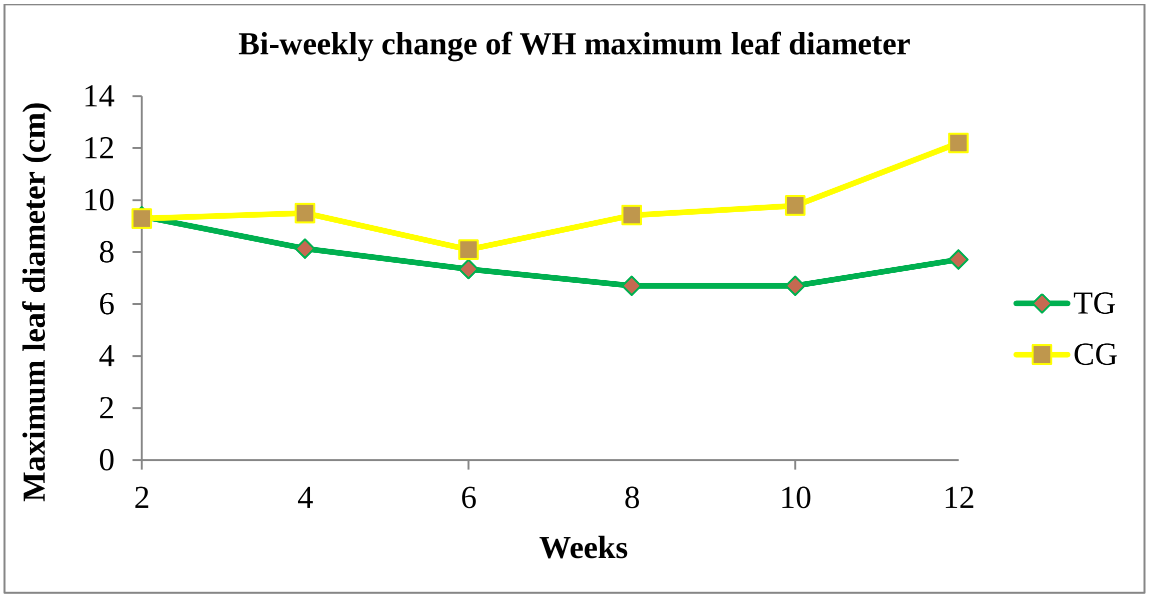
The general interpretation for this result; there is a statistically significant relationship between number of weevils' and number of feeding scar. This is a positive relationship: As number weevils' increases, so does number of feeding scars increase. The nature of the relationship is described mathematically in the regression equation based on models: NFS = 26.8 + 16.9 NW. For every weevils' increase in number, number of feeding scars (NFS) increases by 16.9 or, for every weevils' 1,000 increase, number of feeding scar increases by 16900 in two weeks (on average).

## 4.4. Effect of Weevils’ on Water hyacinth plant parts

### 4.4.1. Maximum leaf diameter

**Table 12:** The maximum leaf diameter means and confidence interval result of WH plant comparison on treatment and control ponds.

| Bi-weeks | Means(cm) ± SE | | 95% confidence interval | | | |
|---|---|---|---|---|---|---|
| | | | lower bound | | upper bound | |
| | treated | controlled | treated | controlled | treated | controlled |
| 2 | 9.4 ± 0.3 | 9.3 ± 0.3 | 8.7 | 8.9 | 10.1 | 9.9 |
| 4 | 8.1 ± 0.3 | 9.5 ± 0.3 | 7.4 | 8.8 | 8.8 | 10.2 |
| 6 | 7.3 ± 0.3 | 8.1 ± 0.3 | 6.7 | 7.4 | 8.1 | 8.8 |
| 8 | 6.7 ± 0.3 | 9.4 ± 0.3 | 6.1 | 8.7 | 7.4 | 10.1 |
| 10 | 6.7 ± 0.3 | 9.8 ± 0.3 | 6.1 | 9.1 | 7.4 | 10.5 |
| 12 | 7.7 ± 0.3 | 12.2 ± 0.3 | 7.0 | 11.5 | 8.4 | 12.8 |




**TG:** Treatment groups and **CG :** control groups water hyacinth planted ponds line trend graph

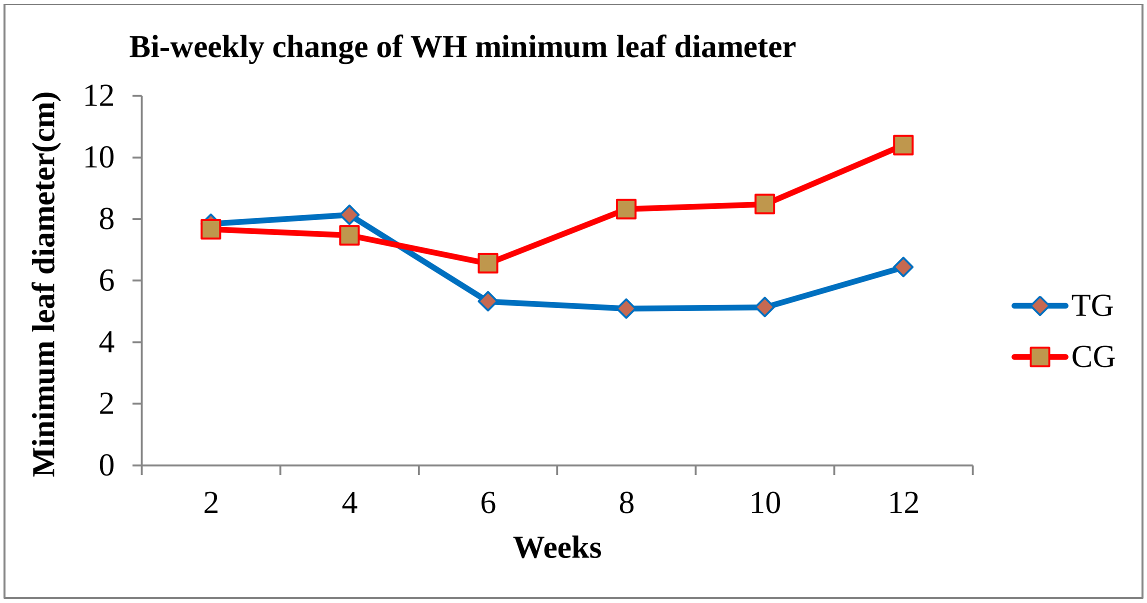
**Figure 13:** The maximum leaf diameter Biweekly change comparsion of weevils’ presence and weevils’ absence of line trend.

The nature of leaf structure of water hyacinth is oval shape and some a little bet circular in that case the measurement was cross-sectional of the leaf. The *Neochetina eichhorniae* and *Neochetina bruchi* that affect WH plant maximum leaf diameter of the upper and lower bound range value 8 .7 to 10.1 and 8.9 to 9.9cm at the first two weeks after weevil inclusion with the mean value 9.4 ± 0.3 and 9.3 ± 0.3 cm experimental treated by WH weevil and controlled WH planted pond, respectively.The last 12$^{th}$ weeks were recorded 7 to 8.4cm and 11.5 to 12.9cm with mean value 7.7 ± 0.3cm and 12.2 ± 0.3cm, respectively. The final to initial mean difference of maximum leaf diameter in weevil treated WH plant decreased by 1.7 ± 0.3cm whereas controlled WH plant increased by 2.9 ± 0.3cm. The middle weeks brief set in table 12 below. Maximum leaf diameter, F (11, 96) =20.046. p<0.001, partial eta square ($\eta^2$) = 0.697, observed power =1. The effect size was large for maximum leaf diameter MANOVA. The relationship between the maximum leaf diameter and other dependent variable (minimum leaf diameter, shoot length, root length and fresh plant biomass) were strong with the type group accounting for 69.7 % of the variance the dependent variable. The observed power of 1.00, indicate that there was a 100% chance that the results could have come out significant for all other result. P<0.05 the result statistically significant the null hypothesis is accepted ($H_0$ =0).

### 4.4.2. Minimum leaf diameter

**Table 13:** The minimum leaf diameter (means and confidence interval) of WH plant comparison on treated and controlled ponds.

| **Bi-weeks** | **Means(cm) ± SE** | | **95% confidence interval** | | | |
|---|---|---|---|---|---|---|
| | treated | controlled | **lower bound** | | **upper bound** | |
| | | | treated | controlled | treated | controlled |
| 2 | 7. 8 ± 0.3 | 7.7 ± 0.3 | 7.2 | 7.1 | 8.4 | 8.3 |
| 4 | 6.1 ± 0.3 | 7.5 ± 0.3 | 5.5 | 6.8 | 6.8 | 8.1 |
| 6 | 5.3 ± 0.3 | 6.6 ± 0.3 | 4.7 | 5.9 | 5.9 | 7.2 |
| 8 | 5.1 ± 0.3 | 8.3 ± 0.3 | 4.5 | 7.7 | 5.8 | 8.9 |
| 10 | 6.7 ± 0.3 | 8.5 ± 0.3 | 4.5 | 7.8 | 5.7 | 9.1 |
| 12 | 6.4 ± 0.3 | 10.4 ± 0.3 | 5.3 | 9.8 | 7.1 | 11.1 |




**TG:** Teatment group of water hyacinth planted ponds and **CG:** Control group of minimum leaf diameter of water hyacinth planted ponds line trend graph.

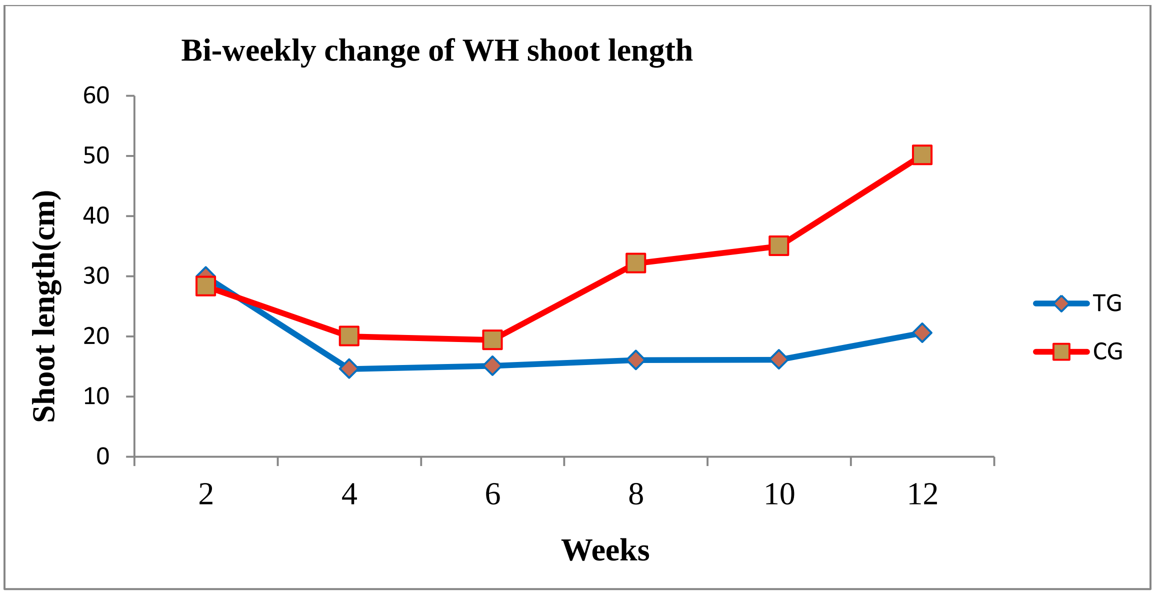
**Figure 14:** The minimum leaf diameter comparisons of weevil present and absence in time series.

The water hyacinth minimum leaf diameter change value in two weeks change by comparisons Neochetina weevils' species inclusion and exclusion range from lower to upper bound with mean value of water hyacinth minimum leaf diameter change comparisons expressed below table 13.The final to initial difference of weevils' treated WH plant decreased by 1.4 ± 0.3cm whereas controlled WH plant increased by 2.7 ± 0.3cm from its mean value. Minimum leaf diameter, $F(11, 96) = 24.996$. $p<0.001$, partial eta square ($\eta^2$) = 0.741, observed power =1). The effect size was large for minimum leaf diameter MANOVA since effect size is 1. The strength of relationship between the minimum leaf diameter and maximum leaf diameter, shoot length, root length and fresh plant biomass were strong with the type group accounting for 74.1% of the variance the dependent variable. The observed power of 1.00, indicate that there was a 100% chance that the results could have come out significant for all other result. The trend line graph showed increasing and decreasing WH plant by comparison leaf diameter of treated and controlled plant. $P<0.05$ then statistically significant the null hypothesis is accepted ($H_0 = 0$).

### 4.4.3. Shoot length

**Table 14:** Shoot length of means and confidence interval result of WH plant comparison on treatment and control ponds.

| Bi-weeks | Means(cm) ± SE | | 95% confidence interval | | | |
|---|---|---|---|---|---|---|
| | | | lower bound | | upper bound | |
| | treated | controlled | treated | controlled | treated | controlled |
| 2 | 29.8 ± 1.7 | 28.3 ± 1.7 | 26.4 | 19.8 | 33.3 | 30.7 |
| 4 | 14.5 ± 1.7 | 20 ± 1.7 | 11.1 | 16.6 | 17.9 | 23.4 |
| 6 | 15.1 ± 1.7 | 19.4 ± 1.7 | 11.6 | 15.9 | 18.5 | 22.8 |
| 8 | 16 .1 ± 0.3 | 32.1 ± 1.7 | 12.6 | 28.6 | 19.5 | 35.5 |
| 10 | 16.1 ± 1.7 | 35 ± 1.7 | 12.6 | 31.5 | 19.5 | 38.4 |
| 12 | 20.5 ± 1.7 | 50.1 ± 1.7 | 17.1 | 46.6 | 23.9 | 53.3 |




**TG:** Treatment groups and **CG:** control groups of water hyacinth plant shoot change in line trend graph.

**Figure 15:** Shoot length comparisons of water hyacinth planted ponds of weevil present and absence time series line graph

Biweekly shoot length comparison change of Neochetina weevils' species inclusion and exclusion mean value within lower and upper bound showed in table 14. The final to initial difference of weevil treated and controlled WH plant decreased by 9.3 ± 1.7cm and increased by 21 ± 1.7 cm respectively. Shoot length of WH plant, (F (11, 96) = 37.683.

p<0.001, partial eta square ($\eta^2$) = 0.812, observed power =1) the effect size was large for shoot length MANOVA based on. The strength of relationship between the shoot length and maximum leaf diameter, minimum leaf diameter, root length and fresh plant biomass were strong with the type group accounting for 81.2% of the variance the dependent variable. The observed power of 1.00, indicate that there was a 100% chance that the results could have come out significant for all other result. Based on statistical significance the null hypothesis is accepted ($H_0$ =0).

The physical observation result of water hyacinth plant with weevils' inclusion and exclusion compared from planted, middle time and at the end of data collected showed below on direct photographical figure 16a, 16b and 16c.


**Figure 16 a:** The experimental conducted ponds at period of water hyacinth planting.


**Figure 16 b:** Comparisons of Neochetina weevils' inclusion and exclusion after 6th weeks (42 days).

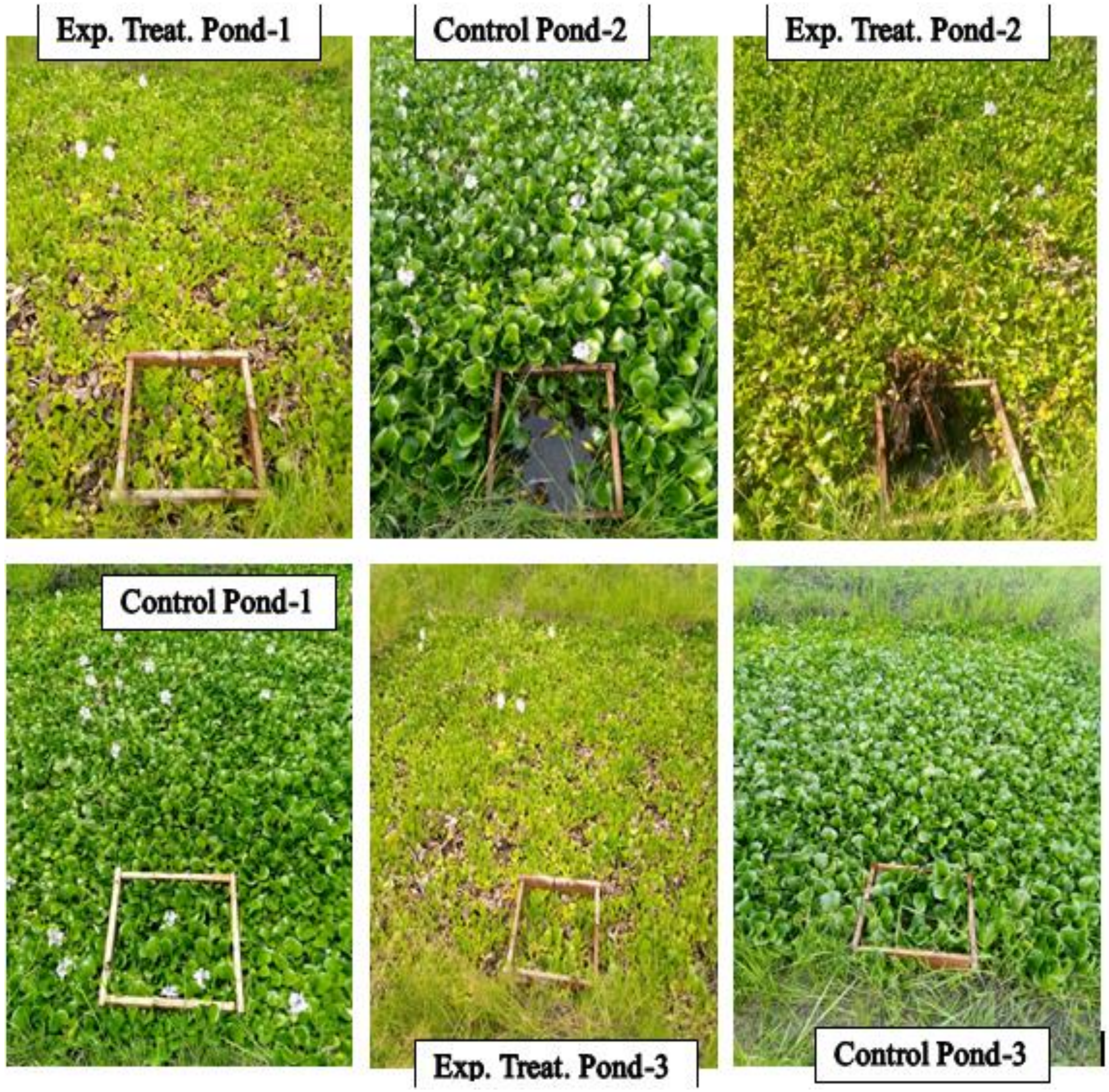
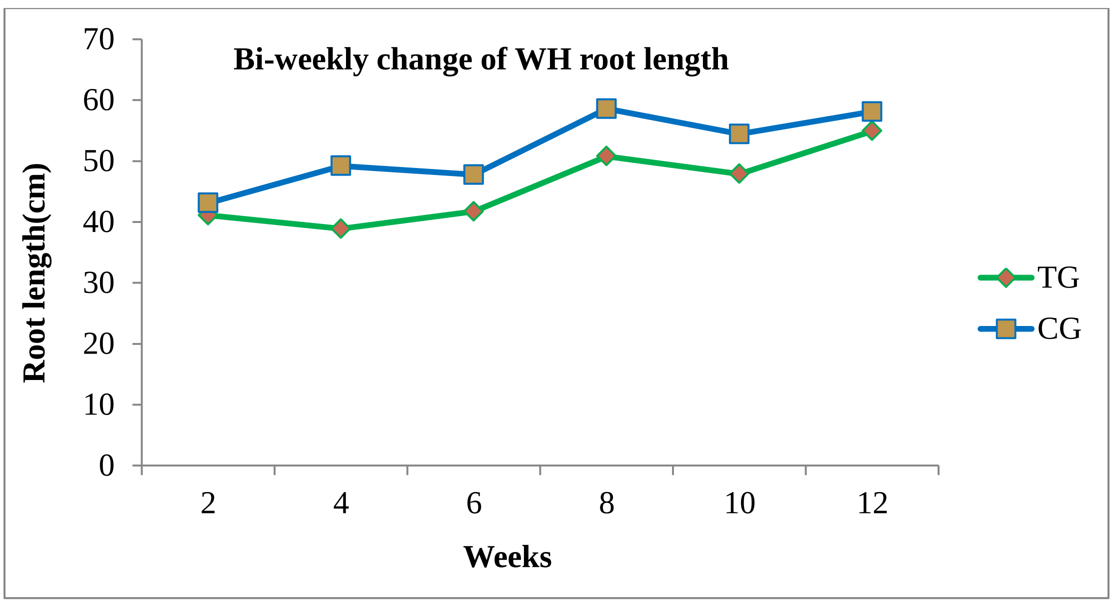



**Figure 16c:** Comparisons of Neochetina weevils' inclusion and exclusion of water hyacinth after 12$^{th}$ weeks (84 days).

### 4.4.6. Root length

**Table 15:** Root length result comparison of means and confidence interval on treated and controlled WH planted ponds.

| Bi-weeks | Means(cm) ± SE | | 95% confidence interval | | | |
|---|---|---|---|---|---|---|
| | treatment | control | lower bound | | upper bound | |
| | | | treatment | control | treatment | control |
| 2 | 41.1 ± 1.8 | 43.1 ± 1.8 | 39.5 | 37.5 | 46.7 | 44.7 |
| 4 | 38.8 ± 1.8 | 49.2 ± 1.8 | 35.3 | 45.6 | 42.5 | 52.8 |
| 6 | 41.7 ± 1.8 | 47.7 ± 1.8 | 38.1 | 44.2 | 45.3 | 51.3 |
| 8 | 50.7 ± 1.8 | 58.6 ± 1.8 | 47.1 | 54.9 | 54.3 | 62.2 |
| 10 | 47.8 ± 1.8 | 54.4 ± 1.8 | 44.3 | 50.8 | 51.45 | 58.1 |
| 12 | 54.9 ± 1.8 | 58.1 ± 1.8 | 51.3 | 54.5 | 58.5 | 61.7 |




**TG:** Treatment groups and **CG:** control groups of WH planted ponds line trend graph.

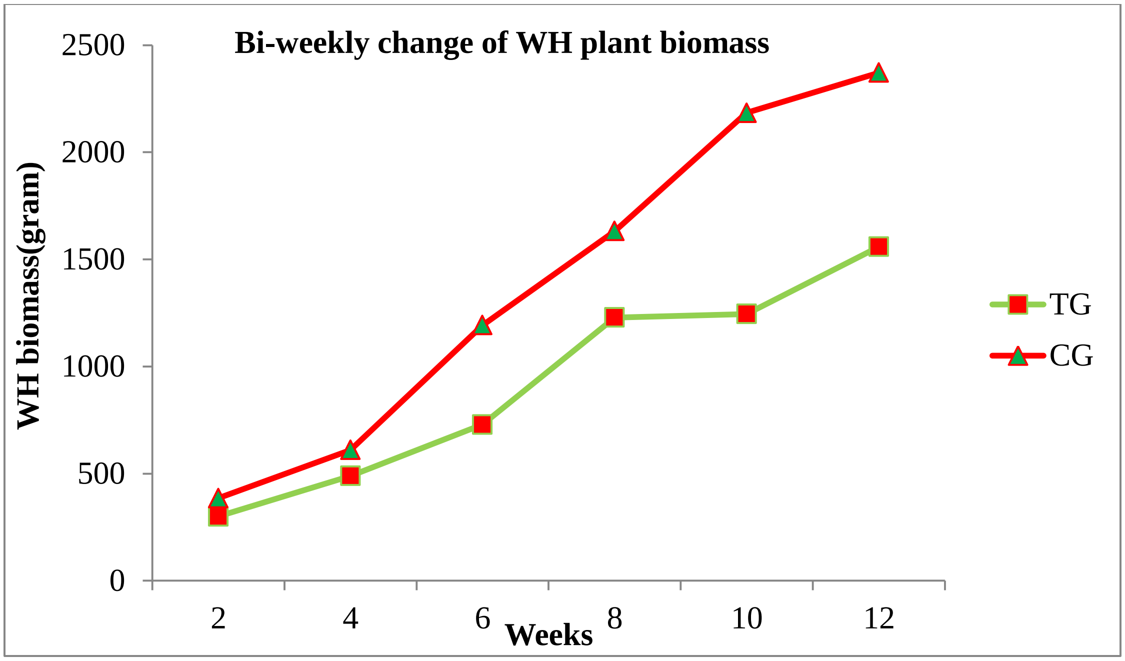
**Figure 17:** Root length of water hyacinth plant comparisons of weevil present and absence time series line graph.

The root length of water hyacinth plant measured from the end of water hyacinth stem to conspicuous root cap end. The root length biweekly change comparisons of Neochetina weevils' species inclusion and exclusion value lower and upper bound with means of water hyacinth root length in table 15. The mean difference of weevil treated and controlled WH plant increased by 13.8 ± 1.8cm and increased by 15 ± 1.8cm respectively. Even though both have been increased but the rate of increasing had been different. Root length of WH plant, (F (11, 96) = 13.643. p<0.001, partial eta square ($\eta^2$) = 0.610, observed power =1) the effect size was large for root length MANOVA based. The strength of relationship between the root length and maximum leaf diameter, minimum leaf diameter, shoot length and fresh plant biomass were strong with the type group accounting for 61.0% of the variance the dependent variable. The observed power of 1.00, indicate that there was a 100% chance that the results could have come out significant for all other result. Based on statistical significance the null hypothesis is accepted ($H_0$ =0). The root length comparison of weevils' inclusion and exclusion trend graph changes in biweekly series in figure 17.

**4.4.7. Fresh water hyacinth plant biomass**

**Table 16:** Statically description result of tests between fresh WH plant biomass of treatment and control groups.

| **Bi-weeks** | **Means(grm) ± SE** | | **95% confidence interval** | | | |
|---|---|---|---|---|---|---|
| | treated | controlled | **lower bound** | | **upper bound** | |
| | | | treated | controlled | treated | controlled |
| 2 | 300.6 ± 37.8 | 385.6 ± 37.8 | 225.6 | 310.6 | 375.7 | 460.7 |
| 4 | 489.4 ± 37.8 | 610 .6 ± 37.8 | 414.3 | 535.6 | 564.4 | 685.7 |
| 6 | 729 ± 37.8 | 1182.7 ± 37.8 | 653.9 | 1117.7 | 804 | 1267.8 |
| 8 | 1228.8 ± 37.8 | 1631.8 ± 37.8 | 1153.8 | 1556.8 | 1706.9 | 1303.9 |
| 10 | 1245.4 ± 37.8 | 2184.2 ± 37.8 | 1170.3 | 2109.2 | 1320.4 | 2259.2 |
| 12 | 1558.8 ± 37.8 | 2371.5 ± 37.8 | 1483.8 | 2296.5 | 1633.9 | 2446.6 |




**TG:** Treatment groups and **CG:** control groups fresh water hyacinth plant biomass in ponds trend line graph.

**Figure 18:** Fresh water hyacinth plant biomass comparison of weevil present and absence time series line graph.

The fresh water hyacinth plant biomass of water hyacinth plant measured value of fresh WH plant mass in grams. The fresh water hyacinth plant biomass value in biweekly change comparisons Neochetina weevils' species inclusion and exclusion of lower and upper bound with mean value in table 16. The mean difference final to initial of weevil treated and controlled WH plant increased by 1258.2 ± 37.8grm and 1985.9 ± 37.8grm respectively. In both cause mean difference increased but the rate of increasing had been different. Fresh water hyacinth plant biomass, ($F$ (11, 96) = 329.904. $p<0.001$, partial eta square ($\eta^2$) = 0.974, observed power =1) the effect size was large for fresh water hyacinth plant biomass of MANOVA. Based on statistical significance the null hypothesis is accepted ($H_0$ =0).The strength of relationship between the Fresh water hyacinth plant biomass and maximum leaf diameter, minimum leaf diameter, shoot length and root length were strong with the type group accounting for 97.4% of the variance the dependent variable. This means that the maximum leaf diameter, minimum leaf diameter, shoot and root length the summation diminished caused for fresh water hyacinth plant biomass diminished by 97.4%. The observed power of 1.00, indicate that there was a 100% chance that the results could have come out significant for all other results.

# 5. Discussion

## 5.1. Effect of water hyacinth on water quality and survival of weevils'

Physicochemical parameters help to determined quality of water both in experimental treated and controlled WH planted ponds that determine living organisms. At the three months both Neochetina weevils' inclusion and exclusion pond water quality was different. The temperature, dissolved oxygen, hydrogen ion concentration and electrical conductivity levels are reduced due to beneath of floating mat by decreasing the natural transfer and weed aggressively usage affected and made layer in water. This caused for the difference result recorded. All ponds of these factor lead to a decrease in water quality at the end of research weeks as showed on result statistical description Tables.

Neochetina weevils' had required healthy water hyacinth plant and health water environment for survival. Based on the result the weevils' could control the water hyacinth growth that could survive and generate larvae within measured result of water quality parameters, such as temperature, dissolved oxygen, pH and electrical conductivities.

### 5. 1.1. Temperature (°C)

The mean water temperature recorded variation treated and control value up and down with seasonal change in consideration so that the highest and lowest mean value recorded in similar weeks. The observed power was 0.951; indicate that there was a 95.1 % chance that the results could have come out insignificant for all other result(DO, pH and EC). But the Water hyacinth weevils' exclusion was showed increasing linear trend and only decreased in seasonal change due to plant growth increase the mat was dense whereas the weevils' inclusion water hyacinth ponds water temperature varies up and dawn trend (figure 5). Because of in addition seasonal change the weevil impact on water hyacinth plant leaf diameter, shoot length and biomass helped to reduce the mat covered which directed to sun heated and the temperature increase whereas weevils' impact decrease the WH plant canopy formed which protected sun heat. Habtamu *et al.* (2021) in Ethiopia on Koka reservoir reported that supported to this thesis. They report that absence of significant spatial variation in water temperature at the infested and non-infested sites may be attributable to the polymictic nature of the reservoir, which mixes with strong turbulence every day but that show difference. In weed-infested site of the reservoir affected heat transfer between surface water and the atmosphere, minimizing temperature variation in that area. Similar results were also reported by Flipos (2020) in Lake Tana. In Uganda in Lake Victoria also similar results were recorded; the water temperature in water hyacinth covered environments was slightly higher than that of open lake water (Hussein *et al*., 2023).

The Neochetina weevils' could survive, reproduce and control the water hyacinth growth within mean water temperature 19.6 ± 0.5 up to 21.2 ± 0.5 °C in three months. Similar literatures support this report even though special difference is there; Neochetina weevils' can reproduced in rift valley of Ethiopia (Tatek *et al*., 2022). The temperature does not significant effect on survival for adult but for reproduction cause delay in Ethiopian atmospheric condition through seasonally changed ( Friehun *et al.*, 2017 ). Similarly in Lake Victoria for control of water hyacinth that rear weevils' survive, adapt and reproduced in a similar temperature range (Stephen *et al*., 2006).

**5. 1.2. Dissolved oxygen**

The present study showed a concentration of dissolved oxygen in the pond water WH plant affected by dead water hyacinth plant for weevil inclusion ponds and the water temperature (canopy cover). The level of dissolved oxygen concentration decrease with increasing shoot length and mat formation dense (canopy formed). The lowest concentration of dissolved oxygen was observed in first week in treated WH planted water. Whereas in controlled WH planted water pond lowest dissolved concentration was recorded in the 12$^{th}$ weeks because of longest shoot length, high biomass (mat formation was condensed), low temperature (layer formation no water mixing below mat) recorded. The observed power of 0.675, indicate that there was a 67.5 % not chance that the results could have come out significant for all temperature, pH and electrical conductivity.Toft (2003) supports these findings. He was reported on his studies ; the water hyacinth mat increase that make difficult for life existence inside the water bodies especially depth increase(Lakes, reservoirs and ponds) layer is formed because of stratification (no wind effect due to cover and water density- temperature relationship upraising) lead to occur. The water hyacinth eventually covers the surface of the water body therefore decreasing the amount of light penetration. This, in turn, will decrease algal growth which ultimately decreases the amount of dissolved oxygen available in the water for aquatic fish and other organisms to use the harsh conditions create an anoxic environment making it extremely difficult for organisms to survive. Habtamu *et al*. (2021) at Koka Ethiopia reservoir support this finding.

Dissolved oxygen is essential for sustaining aquatic organisms with variation in tolerances of oxygen concentrations existing among species. The mean dissolved oxygen of this finding indicated that good condition DO level for Neochetina weevils' survival and reproduction($2.2 \pm 0.3$ up to $3.6 \pm 0.3$mg/L) that supported by (USEPA,2000). Even though didn't measured DO level to survival ship in Ethiopian water under lath house can survive and reproduce by the finding of; similarly Even though survivorship of Neochetina weevils depend health water hyacinth plant (Shephen, 2004; Feriehun *et al.*, 2017 and Getachew and Wassie, 2021).

**5.1.3. pH**

The highest pH for both treated and controlled at 12$^{th}$ weeks was 7.6 and 7.7 respectively. Whereas the least pH for treated and controlled registered at8th weeks 7.2 and 7.1 respectively. However, the mean pH in all of the treatments and controlled was not statistically significant difference (MANOVA $p>0.05$) between treatments and controlled WH plant pond because the mean range of the pH values of the ponds in all ponds showed in the result was within the permissible optimum range of 7.1-7.7 for living organisms in water since it is not challenged for organisms that could survive and regenerate larvae. But there impact of mat that showed on result on the table 6 and graphical figure 7. Water hyacinth mat has impacted on the pH. This is due to water hyacinth usage carbonates and phosphate for nutrition that couldn't be reacts to water. Flipos (2020) support this finding in Lake Tana in Lake Tana water hyacinth infected and non-infected. Many scholars support these findings that the mats affect pH (Chapungu *et al*., 2018; Dersseh *et al*., 2020; Enyew *et al*., 2020 and Habtamu *et al* 2021).

The pH can affect the aquatic organism survivals. The pH ion concentration on weevils' treated water hyacinth ponds that interpolated $7.2 \pm 0.1$ up to $7.6 \pm 0.1$ that could survive and regenerate larvae. These finding is supported by CWQGs 2019 that interpolated.

**5.1.4. Electrical conductivity (μS/cm)**

At the 12$^{th}$ weeks the electrical conductivity final to initial difference decreased by 157.7 and 105 μS/cm on experimental treated and local controlled ponds respectively. These showed that even statically insignificance there was difference. This is due to highly usage of water hyacinth plant mat the electrical conducted materials such as carbonate and phosphate and other ionized salts charge metalloids in addition to seasonal impacts. Flipos (2020) on Lake Tana Ethiopia; support this finding. He was reported that electrical conductivity of water hyacinth infested water bodies are lower than none infested due to absorption of metals by water hyacinth mat. Habtamu *et al*. (2021) on Koka Ethiopian reservoir; also support this finding. They reported that even though not statistically significant infested and non-infested site of reservoir, mean of electrical conductivity showed variations with higher values of electrical conductivity occurring at the weed infested sites (210.7 μS/cm) than at the non-infested sites (139.8μS/cm). Hussein *et al*. (2023) supported this reports in Lake Victoria Uganda at Murchison Bay; on both water hyacinth-infested areas and open lake sites differ slightly. However, the results indicated that water depth significantly affected the electrical conductivity of water. They report that water EC is significantly altered by water depth rather than by water hyacinth infestation. Due to the presence of mat formation on the water surface that absorbed by water hyacinth plant. Even though water hyacinth have significant effect on EC but that reversed the effect by water depth, water current and environment. Neochetina weevils could survive and reproduce within this electrical conductivity rage. Even though the EC result of this finding out of US EPA (2010) favorable aquatic life EC limit the Neochetina weevils' was survive and generate larvae that could affect the water hyacinth growth.

### 5.2. Abundance of Neochetina weevils'

The study were conducted 5 weevils per plant proportion that could affect the plant growth and reproduction. Even though the adult abundance decrease from 5th to 8th weeks the plant growth also decreased that affected by regenerated larvae and then changed to pupae that could not feed in turn weeds growth was increased this situation is observed only till first cycle generated adult. The minimum adult weevil 0 per plant mostly recorded in $12^{th}$ weeks due to aging of weevils and the new adult could not reach till 84(till the data collection end) days. The final number of larvae became decrease due to duration pass away in $12^{th}$ weeks larvae in Figure 10. This is important to expect how much Ethiopian water bodies covered by water hyacinth mat and per planned the reared weevils' numbers.These results similar from friehun *et al*. (2017) but the only differ in spatial that delay new adult regenerated. This is the temperature difference since his research conducted on rift valley that differs to this theses area. Similarly Hopper *et al.* (2017) in USA similar report discharged.

**5.3. The relationship between number of feeding scars and Neochetina weevils'**

The first actions of adult Neochetina weevils are feeding in the form of pits called feeding scars on water hyacinth plant leaves and petioles. This help to survivals and reproduction that were regenerate itself and form natural enemies on water hyacinth plant for long times. The relationship weevils' to feeding scars was direct relationship. After week 6$^{th}$ the number of weevils' decreases that was presence of death which indicates age difference between weevils' when introduced in water hyacinth because of randomly taken the weevil from lath house to planted water hyacinth ponds. Even though the number of adult number decreased the WH plant damage increase due to the larvae increment. The relationship between weevils' number to feeding scar illustrate by equations that derivate from data generated regression model that also future expectation of increasing and decreasing weevils' based on Y= 26.8 + 16.9X. This means that Neochetina weevils' increase by x; number of feeding scar (NFS) also increases by 26.8 + 16.9x. Even if you had count 0 a weevil number, number of feeding scar would be 26.84, on average since the weevils' is natural behavior that is feed movement to other unfeed weed plants.

Where Y= number of feeding scar and X = number of adult weevils'. As the number of feeding scar increased the plant growth was affected. Firehu *et al*. (2017) support this idea; the perforation causes significant loss of functional leaf surface and also may allow entry of pathogens which ultimately slows down plant growth and eventually leads to its death. Tatek *et al*. (2022) also support this thesis; number of weevils' increase the water hyacinth growth is affected since per population consumption. Getachew and Wassie (2021) also support this finding.

**5.4. Effect of Weevils' on Water hyacinth plant parts**

**5.4.1. Maximum leaf diameter**

Unfortunately, no adequate scientifically published information on the weevils' effect on maximum leaf diameter quantified specifically and, therefore, already available values from the literature are reported for maximum leaf diameter of WH plant in earthen ponds was used to compare with the present finding. Firehun *et al*. (2017) reports that, Compared the effect of infested larvae petiole length to non- infested one between the two Neochetina weevil species in lath house. He was conducting his research on Neochetina burchi and Neochetina eicchorniae larvae affected petiole length. His research supports this finding.

The water hyacinth plant leaf diameter affected by adults directly and larvae indirectly of Neochetina weevil species. This means that the adult feed directly the leaf and made leaf scare shrink since it partially or fully dried that decrease the size of the leaf as showed on figure 11. Whereas larvae fed first within the petiole tunneling aggressively on plant tissue and develop inside the petiole and undergo three instars or stages through moving down ward (Firehun, 2017; Stephen, 2004). After damage to the water hyacinth plant petioles tissue ultimately leading to the death of the plant and side by side through stolon sister new shoots were raised. This made a chance to decrease the leaf diameter. Stephen studies also support this finding.

**5.4.2. Minimum leaf diameter**

Similarly, there was no adequate published information on the weevil impact on minimum leaf diameter quantified specifically and, therefore, already available values from the literature are reported for minimum leaf diameter of WH plant in earthen ponds conducted one was used to compare with the present finding. According to Firehun *et al*. (2017), Comparative of infested petiole length by larvae to non- infested one effect between the two Neochetina weevil species in lath house. He was conducting his research on *Neochetina burchi* and *Neochetina eicchorniae* larvae affected petiole length. He supports this finding.

In the present study, the minimum leaf diameter the treated and controlled WH plant showed clear difference from initial to final study time. The Neochetina weevils' treated minimum leaf diameter diminished by 4.6 ± 0.3cm. Whereas the local controlled water hyacinth plant minimum leaf diameter increased by 2.7 ± 0.3cm.

The water hyacinth plant leaf diameter affected by adults directly and larvae indirectly of Neochetina weevil species. This means that the adult feed directly the leaf and made leaf scare shrink since it partially or fully dried that decrease the size of the leaf. Larvae fed first within the petiole tunneling aggressively on plant tissue and develop inside the petiole and undergo three instars or stages through moving downward (Firehun *et al*., 2017; Stephen, 2004). After damage to the water hyacinth plant petioles tissue ultimately leading to the death of the plant and side by side through stolon sister new shoots were raised. This made a chance to decrease the leaf diameter.

**5.4.3. Shoot length**

Shoot length of water hyacinth plant start from root initial to pick of a rosette that may free float or a stoloni-ferous that consist stems, leaves and flowers make up the shoot system. The shoot length growth suppressed by water hyacinth weevils through feed heavily on plant tissue. Larvae feed internally on the plant tissues (petioles) and adults feed externally on the leaf. Feeding damage by both life stages suppress the growth of the plant often inhibiting flowering (figure 15b and 15c).

In this study the final mean difference to initial of shoot length treated and controlled was -9.8 ± 1.7 and 21.8 ± 1.7 cm after 12$^{th}$ weeks respectively. This was the impact of weevils that decreased by 9.8cm. The new introduced adult weevil feed many feeding scars were recorded since they were new introduce with the non-infected new shoot and the broken shoot tissue already dead due to planting period every WH plant mostly couldn't been erected. This was plantation on water no support was there (figure 15a). That was why the controlled also decrease in shoot length in 4$^{th}$ weeks measured. Side by side the new shoot was release through stolon so that showed little bit some increment in a treated WH plant but in case of controlled WH plant highly increased since no thing were affected. The 12$^{th}$ week increase treated WH plant mean increase as compare to 8$^{th}$, 10$^{th}$ weeks mean due to rain that initiated growth.  During the rainy seasons, increased nutrient concentrations, humidity, and especially water level can promote the formation of extensive water hyacinth mats (Cai *et al*., 2023).  Finally the treated WH plant was decreased by 9.8 ± 1.7 cm whereas the controlled WH plant was increased by 26.8± 1.7 in the mean values. Aguilar *et al*. (2003) reporte support this finding that 6 weevils' per plant based could control in both field and cage trial but they did not study plant sized but only damaged. In this study 5 weevils per plant in earthen pond could control within the diminished shoot sized decreased in quantified way.

Ray *et al*.(2009) reported that water hyacinth reduce the in medium size plant and damaged in 4,8,12,16,and20 inoculation load of the weevils on 70,60,50,40 and 20 day damage respectively that reduced of fresh biomass, number of leaves and ramifications. All the scholars that made similarity to this research but the only difference is that there were keeping of water hyacinth plants in limited space which might have restricted the growth and proliferation of water hyacinth and also they could not measure a specific shoot length that were diminished and weevil inoculation load were also differ the above cited scholars from this finding other ways similar result observed. Final observation of this result showed after the $12^{th}$ week an insect exclusion WH plants were form arranged leaves in a rosette and a dense impenetrable floating mats formation as compare to insect inclusion pond which forms short new shoot produced but as soon as feed by larvae and adult ultimately dried damage shoots (figure 15b and 15c).

**5.4.4. Root length**

Water hyacinth has feathery roots that remain submerged. The root morphology is highly plastic and the plasticity is related to nutrient, particularly phosphorus (P), availability in the water. Lateral roots are generally longer and denser at low P levels than at high P levels (Yonghong and Dan, 2003). The root length growth also suppressed by water hyacinth weevils indirectly when adult feed the leaf and larvae feed petioles that cause nutritional transfer system collapse. The color of the weevil inclusion was black including shorten the length of the root whereas weevil exclusion water hyacinth (local control) root color whitish within root hanging in figure 19 . The initial mean root length treated and controlled WH plant was 41.1 ± 1.8 cm and 43.1 ± 1.8 cm, then decreased by 2.3 ± 1.8 cm and increased by 5.9 ± 1.8 after $4^{th}$ weeks respectively. Due to the impact of introduced adult weevil feeding the leaves through spot like scar were recorded that affect nutritional transfer tissue. Larvae also direct affect the lateral root line in order to out to the root zone for processing the pupae stage. That was why the controlled increased the root length whereas the treated decreased. There were significant difference between treated and controlled WH plant roots but the graphical biweekly line series showed similar up and down mode in figure 16. Due to seasonal change and inactive life cycle stage made advantages to root growth. These research supported by (Cai *et al*., 2023; Friehun *et al*., 2017; Stephen, 2004). Normally when compared to shoot length growth impact change not that much based on the result reported. Weevils' stress in water hyacinth leaf growth more rapidly than root growth.

Final to initial difference the treated and controlled WH plant root was increased by 13.8 ± 1.8 cm and 15 ± 1.8 cm respectively. Even though both had increased there was change of increasing rate. Aguilar *et al*. (2003) report support this finding but he didn't measured the root sized. But they were conducted in 6 weevil per plant based could controlled in both field and cage trial that affect above and below ground water hyacinth mass. Whereas in this study 5 weevils per plant in earthen pond could controlled within the diminished shoot sized above and the root length specified. Ray *et al*.(2009) reported that water hyacinth damaged in different sized plant stage within different inoculation load of the weevils that reduced of fresh biomass, number of leaves and ramifications which cause for root damage. But they did not quantified scale the root damage. All the scholars that made similarity to this research but the only difference is that they were done in tube or green glass of water hyacinth plants in limited space which might have restricted the growth and proliferation of water hyacinth root and also they could not measure a specific root length that were diminished.

### 5.4.5. Fresh water hyacinth plant biomass

Impact of the Neochetina weevils' species on WH plant can be quantified based on changes in plant parameter is production of biomass. The WH treated by weevils decreased in fresh biomass as compared to WH without treated table 16. But as general trend both controlled and treated increased from week two to week twelfth figure 17. This indicate that the growth and reproduction of WH plant could suppressed and the change required time to diminished since controlling method required long time within less cost.

Firehun *et al.* (2017) report similar to this finding the only difference he compare the two Neochetina weevils' species biomass damaged comparison individually and longtime data collection that show up and down trend, life cycle and the other season cause for decreased and increased. His report, the WH damage caused by N. eichhorniae showed that the highest biomass was observed in December in all his study periods while the highest biomass reduction he was observed in October 2012 and April 2013. He was reported linear decrease recorded from January to April 2012 and then there was a slight increase during May. Even though, this thesis result showed increasing trend both treated and controlled result. Increasing rate different treated and controlled graph. Fresh water hyacinth plant biomass of Neochetina weevils' species experimental treatment group result was highly significant effect as compare to fresh water hyacinth plant biomass of insect exclusion (controlled) groups. This was due to the nature of plants that is sponginess stems that fully or partially dried plant part that cause for holding water capacity and water could not lose through evapotranspiration due to the plant cell dried. This was the reason that the fresh water hyacinth plant biomass increase on the insect inclusion (experimental treated) groups on time series increase. Stephen, (2004); Ray *et al*. (2009) reported similar finding to this finding.

# 6. Conclusion and Recommendations

## 6.1. Conclusion

In this result we have been able to describe water quality parameter impacted by water hyacinth mat but that could not affect the survival of Neochetina weevils', the water hyacinth plant part growth impacted by Neochetina weevils' species presence and with feeding scars to weevils' direct relationship. Water hyacinth plant affected by those weevils' in which the leaf diameters, shoot length, root length and plant biomass suppressed and new shoot regeneration reduced as well as flowering were reduced. The leaf diameter of the water hyacinth plant was directly affected by adult weevils' through partial feeding by forming spot, which is called scar, that caused the leaf to shrink. Ultimately the water hyacinth leaf diameter diminished and the plant died. The larvae affect the inside tissue of water hyacinth plant petioles, which caused for the whole plant death. In turn new shoot was formed with a small leaf, as well as decreased shoot length, root length and fresh water hyacinth plant biomass from the first to the last weeks.

The Neochetina weevils' could survive and regenerate itself within the ambient environment. But the local controlled water hyacinth plant increased the leaf diameter, shoot length, root length and plant biomass due to insect exclusion from the initial two weeks to the twelve weeks within condensed mat formation and long shoot with a green rosette leaves. Even though attractive for greenness, it affects the water quality parameters such as temperature, dissolved oxygen, hydrogen concentration and water conductivity through mat formation above the water. The mat causes the layer formation between water and atmospheric round. Even though statistically insignificant, the local control water hyacinth planted pond water temperature, dissolved oxygen; pH and electrical conductivity were differing from weevils' inclusions. Neochtina weevils' species (*N. eichhorniea* and *N. burnchi*) was decrease the mat of water hyacinth plant that helps to mixed the atmosphere air to water of the srounding environmental parameters through densed mat barrar decreasing.

### 6.2. Recommendations

Water hyacinth (*Eichhornia crassipes*) is an invasive weed and causes environmental and social menace in Ethiopia. Due to their prolific growth rate, enormous biomass and larger surface cover of natural water ecosystems, it blocks dissolved oxygen and temperature that come from atmosphere (sun) to water environments. This is degrading the water quality in water bodies that affect living organisms. So that it shall be better to protect aquatic bodies from water hyacinth invasion, by means of introduction of the use of the Neochetina weevils' to resolve this invasive weed that could survive and regenerate itself.

Number of weevils' had direct relationship to feeding scars which means as the number of weevils' increase impact rate also increase. The larvae regeneration is direct relation to number of adult. These are good opportunity to control the weed in mass through the number of weevils' increase that affect quickly the water hyacinth plant growth and invasion. So that shall better to introduce number of adult weevils' considering the water hyacinth plant area coverage and growth stage of water hyacinth plant.

Based on this study 5 weevils' per plant could suppressed the water hyacinth plant growth and reproduction. The water hyacinth plant growth affected the leaves, shoot and root length and fresh water hyacinth plant biomass on earthen ponds. In Ethiopia water bodies (lakes and reservoir) are highly dominated by this invasive weed. In this case manual removal through Campaign and machinery removal through machine bought takes place. But that was short period of solution within high cost that could not stop invasion from time to time whereas the weevils' could suppress the growth and reproduction through forming natural enemies. So that shall better to amply weevils' for creating natural enemies for this exotic invasive weed to Ethiopian water bodies. This research was conducted on earthen ponds through adult weevils' introduction . In this cause adult damage and larvae damage quantification specifically in two stage could not done yet. It is open to do for other researchers or by my self to the future.

# 7. Reference

***Abule E., Kahsay B ., Yasin G., Zewdie A., Nigatu A., Yismashawal F. & Azage T. (2017).*** *Water hyacinth (Eichhornia crassipes (Mart.): Land use/land cover changes and community-based management in east Shoa zone, Ethiopia. International Journal of Environmental and Agriculture Research, 3(5), 01–11. https://doi.org/10.25125/agriculture-journal-ijoear-apr-2017-2*

***Admas A., Sahle S., Belete E. Agidie A. & Alebachew M****. (2017). Controlling of Water Hyacinth in Lake Tana Using Biological Method at Green House and Pond Level. European J. Exp. Biol. 7(5): 29*

***Aguilar J., Camarena O., Center T. and Bojorquez G.*** *(2003). Biological control of water hyacinth in Sinaloa, Mexico with weevils Neochetina eichhorniae and N. bruchi. BioControl, 48:595-608.*

***Ajuonu O., Schade V., Veltman B., Sedjro K. & Neuenschwander P.*** *(2003). Impact of the exotic weevils Neochetina spp. (Coleoptera: Crculionidae) on water hyacinth, Eichhornia crassipes (Lil: Pontenderiaceae) in Benin, West Africa. African Entomology, 11:153-161*

***Aklilu A., Samuel S., Adugnaw A. & Maheri A.*** *(2017). Controlling Water Hyacinth, Eichhorni acrassipes (Mart.) Solms Using Some Selected Eco-Friendly Chemicals. Journal of Aquaculture Research & Development, 09(01), 9–11. https://doi.org/10.4172/2155-9546.1000521*

***Allie C., Sebe B. & Rodri D.*** *(2001). The Water Hyacinth Weevils. November, 8524623.*

***Angelica M.,Paul D., Julie B., Ximena C.,Goillermo C.& Fernando M.****(2018). Variation in cool temperature performance between populations of Neochetina eichhorniae (Coleoptera: Curculionidae) and implications for the biological control of water hyacinth, Eichhornia crassipes, in a temperate climate.http://www.sciencedirect.com/science/pii/S1049964418304493.*

***Begum S. , Himaya S. & Afreen S.*** *(2021). Potential of Water Hyacinth (Eichhornia crassipes) as Compost and its Effect on Soil and Plant Properties: A Review. Agricultural Reviews, 43(Of), 20–28. https://doi.org/10.18805/ag.r-184*

***Bekele M., Unbushe D. & Abebe E. (2017).*** *Invasion of Water Hyacinth ( Eichhornia crassipes ) Is Associated with Decline in Macrophyte Biodiversity in an Ethiopian.*

*667–681. https://doi.org/10.4236/oje.2017.713046*

***Bwelachew G., Worie W. & Ayanew G.*** *(2020). Socioeconomic effects of water hyacinth ( Echhornia Crassipes ) in Lake Tana , North. 1–21. https://doi.org/10.1371/journal.pone.0237668*

***Cai J., Jiao C., Mulat M., Solomon A. , Ishikawa K., Ayalew W. & Shinjiro S.*** *(2023). Water hyacinth infestation in Lake Tana, Ethiopia: a review of population dynamics. Limnology, 24(1), 51–60. https://doi.org/10.1007/s10201-022-00706-1*

***Cilliers C., Hill M., Ogwang J. & Ajuonu O.*** *(2003). Aquatic weeds in Africa and their control. In: Neuenschwander, P., C. Borgemeister, and J. Langewald (Eds), Biological control in IPM systems in Africa. CABI Publishing, Wallingford, UK, pp. 161-178.*

***Chapungu L., Mudyazhezha O. & Mudzengi B.*** *(2018). Socio-ecological Impacts of Water Hyacinth (Eichhornia Crassipes) Under Dry Climatic Conditions: The Case of Shagashe River in Masvingo, Zimbabwe. J. Environ. Sci. and Public Health 2: 36-52r*

***Charudattan R.*** *(2001). Biological Control of Water Hyacinth by Using Pathogens : Opportunities , Challenges , and Recent Developments. Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth, 9-12 Octob, 21–28.*

***Coetzee J. & Hill M.*** *(2012). The role of eutrophication in the biological control of water hyacinth (Eichhornia crassipes), in South Africa. Bio Control, 57(2): 247–261.*

***CWQGs.*** *(2019). Canadian water quality guidelines for the protection of aquatic life: manganese. Canadian Environmental Quality Guidelines, 1299, 10.*

***Dereje T.*** *(2015). Preliminary Survey of Water Hyacinth in Lake Tana, Ethiopia . Review Article January 2015. https://doi.org/10.17352/2455-8141.000003*

***Dersseh M., Kibret A., Tilahun S., Worqlul A., Moges M., Dagnew D., Abebe W. & Melesse A.*** *(2019). Potential of Water Hyacinth Infestation on Lake Tana, Ethiopia: A Prediction Using a GIS-Based Multi-Criteria Technique. Water. 11: 1921*

***Ebro A., Berhe K., Getahun Y., Adane Z., Alemayehu N., Fayisa Y. & Tegegne A.*** *(2017). Water hyacinth (Eichhornia crassipes (Mart.): Land use/land cover changes* *and community-based management in east Shoa zone, Ethiopia. International Journal of Environmental and Agriculture Research, 3(5), 01–11. https://doi.org/10.25125/agriculture-journal-ijoear-apr-2017-2*

***Enyew B., Assefa W. & Gezie A.*** *(2020). Socioeconomic effects of water hyacinth (Echhornia Crassipes) in Lake Tana, North Western Ethiopia. PLoS ONE 15(9): e0237668*

***EPPO.*** *(2008). Eichhornia crassipes.* Data sheet on quarantine pests fiches informatives sur less organisms de quarantaine. *1884, 441–449.*

***FAO.*** *(1995). Food and Agriculture Organization of the United Nations (FAO). 1469–1472. https://doi.org/10.18356/d6ce0776-en*

***Firehun Y., Struik P. Lantinga E., & Taye T.*** *(2016). Pre-Release Evaluation of Neochetina Weevils Potential for the Management of Pre-Release Evaluation of Neochetina Weevils Potential for the Management of Eichhornia Crassipes [ Mart .] Solm . In The Rift Valley of Ethiopia . July. https://doi.org/10.15413/ajar.2016.0163*

***Firehun Y.*** *(2017). Management of water hyacinth ( Eichhornia crassipes [ Mart .] Solms ) using bioagents in the Rift Valley of Ethiopia.*

***Flipos E.*** *(2020). Socio-Ecological impacts of Water Hyacinth , Eichhornia crassipes ( MART .) in Lake Tana , Gulf of Gorgora , Ethiopia.*

***GBICWH (****2011). Biological and Integrated Control of Water Hyacinth, Eichhornia crassipes Proceedings of the Second Meeting of the Global Working Group for the Biological and Integrated Control of Water Hyacinth, Beijing, China, 9–12 October 2000. AgEcon Search .*

***Getachew B.*** *(2020). Implementation guideline on use of Neochetina weevils for Dar University and Global Coalition for Lake Tana Restoration. September.*

***Getachew B. & Wassie A.*** *(2021). Establishment of Neochetina spp . ( Coleoptra : Curculionidae ) for the control of water hyacinth ( Eichhornia crassipes ) infestation in Lake Tana , Ethiopia. iMedPub Journals 1–4.* Vol.11 No.5:420

***Ghadir A. , Muhammad A., Sayed R. & Murthy C.*** *(2022). A review on potential uses of invasive aquatic weed; water hyacinth. 26(1), 457–467.*

***George M. and Joseph N.*** *(2015). This document is discoverable and free to researchers across the globe due to the work of AgEcon Search . Help ensure our sustainability .*

*Actor influencing price of Agricultural products and stability counte. AgEcon Search, 18.*

**Goulart M., Pedro F., Cordeiro F. Figueiredo D. & Rodrigues M.** *(2019). Modeling of the potential distribution of Eichhornia crassipes on a global scale: risks and threats to water ecosystems. Ambiente and Agua- an International Journal of Applied Science, 15. https://doi.org/10.4136/1980-993X*

**Hailu A.** *(2019). Water Hyacinth (Eichhornia crassipes) Biology and Its Impacts on Ecosystem, Biodiversity, Economy and Human Well-being. Journal of Natural Sciences Research, 9(12), 24–30. https://doi.org/10.7176/jnsr/9-12-04*

**Hamadamin R. & Jawad N.** *(2018). Koya River Water Quality Assessment with a Focus on Physiochemical Properties and Heavy Metals. February, 206–212.*

**Honlah E., Segbefia A. , Appiah D. & Mensah M.** *(2022). Responses of institutions and communities to environmental problems of water hyacinth invasion in Jomoro Municipality, Ghana. Social Sciences & Humanities Open, 6(1), 100289. https://doi.org/10.1016/j.ssaho.2022.100289*

**Hoppera J., Prattb P., McCuec K., Pitcairnd M., Moranb P. & Madsene J.***(2017). Spatial and temporal variation of biological control agents associated with Eichhornia crassipes in Sacramento-San Joaquin River Delta, California.https:www.elsevier.com/open access/userlicense/1.0/*

**Hussein K., Bernard B., Joyfred A., Paul M. & Getrude A.** *(2023). Water Hyacinth's Extent and Its Implication on Water Quality in Lake Victoria, Uganda. Scientific World Journal, 2023. https://doi.org/10.1155/2023/4947272*

**Innocent A. , Lawrence O. & Ayub N.** *(2008). Dewatering and Drying Characteristics of Water Hyacinth (Eichhornia crassipes) Petiole. Part I. Dewatering Characteristics. Agricultural Engineering International: CIGR Ejournal, X, 1–11.*

**Jones Roy W., Hill J. , Coetzee J. & Hill M.** *(2018). The contributions of biological control to reduced plant size and biomass of water hyacinth populations. Hydrobiologia, 807(1), 377–388. https://doi.org/10.1007/s10750-017-3413-y*

**Karouach F., Ben B., Ezzariai A., Sobeh M., Kibret M., Yasri A., Hafidi M. & Kouisni L.** *(2022). A Comprehensive Evaluation of the Existing Approaches for Controlling and Managing the Proliferation of Water Hyacinth (Eichhornia crassipes): Review.*

*Frontiers in Environmental Science, 9(February), 1–22. https://doi.org/10.3389/fenvs.2021.767871*

***Kendall A.*** *(2015). A model for water hyacinth biological control.*

***Mahmood Q., Zheng P., Siddiqi M. , Islam E. , Azim M. & Hayat Y.*** *(2005). Anatomical studies on water hyacinth (Eichhornia crassipes (Mart.) Solms) under the influence of textile wastewater. Journal of Zhejiang University: Science, 6 B(10), 991–998. https://doi.org/10.1631/jzus.2005.B0991*

***Maylani D., Yuniati R. & Wardhana W****. (2020). The Effect of leaf surface character on the ability of water hyacinth, Eichhornia crassipes (Mart.) Solms. To transpire water. IOP Conference Series: Materials Science and Engineering, 902(1). https://doi.org/10.1088/1757-899X/902/1/012070*

***Mengistu B., Unbushe D. & Abebe E.*** *(2017). Invasion of Water Hyacinth ( Eichhornia crassipes ) Is Associated with Decline in Macrophyte Biodiversity in an Ethiopian. 667–681. https://doi.org/10.4236/oje.2017.713046*

***Mnichl G., Abeyou W., Saifu T. & Mamaru A.****(2019). Potential of water hyacinth infestation on Lake Tana, Ethiopia: A prediction using a GIS-based multi-criteria technique. Water (Switzerland), 11(9). https://doi.org/10.3390/w11091921*

***Moran P.*** *(2004). Feeding by Waterhyacinth Weevils (Neochetina spp.) (Coleoptera: Curculionidae) in Relation to Site, Plant Biomass, and Biochemical Factors. Environmental Entomology, 33(2), 346–355.*

***Negassa D. & Belay A.*** *(2020). Current Status of Water Hyacinth (Eichhornia crassipes) in Ethiopia: Achievements, Challenges and Prospects: A Review. Journal of Environment and Earth Science, January. https://doi.org/10.7176/jees/10-12-03*

***Ndimele P., Kumolu-Johnson C. & Anetekhai M.(2011).*** *The invasive aquatic macrophyte, water hyacinth {Eichhornia crassipes (Mart.) Solm-Laubach: Pontedericeae}: Problems and prospects. Res. J. Environ. Sci. 5, 509–520. [CrossRef]*

***Ogwang J. & Molo R.*** *(2004). Threat of water hyacinth resurgence after a successful biological control. Biocontrol Science and Technology, 14(6):623-626.*

***Opeyemi I. , Tolulope A. & Femi P.*** *(2020). Eichhornia crassipes (Mart.) Solms: Uses, Challenges, Threats, and Prospects. Scientific World Journal, 2020.*

*https://doi.org/10.1155/2020/3452172*

***Parmeshwar G., Jayaxmi G. & Rashmi G.*** *(2020). Studies on the biology of the water hyacinth weevil , Neochetina eichhorniae hustache ( Coleoptera : curculionidae ) at Raipur , Chhattisgarh. 8(2), 915–919.*

**Patrick J.** (2004). *Feeding by Waterhyacinth Weevils ( Neochetina spp .) ( Coleoptera : Curculionidae ) in Relation to Site , Plant Biomass , and Biochemical Factors*.

***Pratiwi F., Zainuri M. & Purnomo P.*** *(2018). Evaluation of weevils ( Neochetina spp .) existence in Rawa Pening Lake ( abundance and impact on target and non-target plant ). 11(3), 823–832.*

***Puja R., Sushilkumar & Akhilesh K.*** *(2009). Impact evaluation of Neochetina spp. on different growth stages of waterhyacinth. Journal of Plant Protection Research, 49(1), 7–13. https://doi.org/10.2478/v10045-009-0002-8*

***Roy William J.*** *(2009). The impact on biodiversity, and integrated control, of water hyacinth, Eichhornia crassipes (Martius) Solms-Laubach (Pontederiaceae) on the Lake Nsezi-Nseleni River System. January.*

***Samson M., Dagmawit S., Firmaye B., Yosef G., Mamuye H. & Taye T.****(2021). What do research evidence tell us about : Water hyacinth control methods ? Rapid Evidence Review Included : 1–22.*

***SEEPPC*** *(2019). Management of invasive exotic plants in natural areas of the Southeast America. Center for Invasive Species and Ecosystem Health University of Georgia.www.se-eppc.org*

***Sewnet G. & Habtamu K.*** *(2023). Problem of Water Hyacinth (Eichhornia crassipes (Mart.)) in Lake Tana (Ethiopia): Ecological, Economic, and Social Implications and Management Options. International Journal of Ecology, 2023. https://doi.org/10.1155/2023/4618069*

***Sharma A., Aggarwal N. , Saini A. & Yadav A.*** *(2016). Beyond Biocontrol : Water Hyacinth-Opportunities and Challenges. Journal of Environmental Science and Technology, 9(1), 26–48. https://doi.org/10.3923/jest.2016.26.48*

***Stephen W.*** *(2004). The Biology and Impact of Neochetina Weevils on Water Hyacinth , Thesis submitted to the School of Graduate Studies at Moi University in partial fulfilment for the degree of Doctor of Philosophy in Environmental Studies (*

*Biological Sciences ) Declaration. January.*

***Stephen W., Gerald R., Manyalar J. , & Okeyo-Owuow J.*** *(2006). The life history and survival of Neochetina in Lake Victoria basin: basis for biological weed control. In: Proceedings of the 11th World Lakes Conference: Vol. 2. Nairobi, Kenya, 2, 593–599.*

***Tatek K., Emana G., & Diriba M****. (2022). Optimization of Neochetina eichhorniae Warner and Neochetina bruchi Hustache for the management of water hyacinth , Eichhornia crassipes ( Mart .) Solms in the Central Rift Valley lakes through the use of different nutrient levels in Ethiopia. 45(2), 205–223.*

***Tipping P., Sosa A., Pokomy E., Foley J., Schmitz D., Lane J., Rodgers L., McCloud L., Livingston-Way P. & Nicholas G.*** *(2014). Release and establishment of Megamelus scutellaris (Hemiptera: Delphacidae) on water hyacinth. Florida Entomologist, 97(2):804-806.*

***US EPA****. United Stated Environmental Protection Agency (2011). National Primary Drinking Water Regulations. http://water.epa.gov/drink/contami nants/index.cfm*

***US EPA.*** *(2010). A field-based aquatic life benchmark for conductivity in central Appalachian streams. National Center for Environmental Assessment, March, 193.*

***US EPA .*** *United Stated Environmental Protection Agency (2000)**.** Ambient Aquatic Life water quality criteria for dissolved oxygen (salt water): Cape Cod to cape hatteras.*

***Weiping S., Qingping S., Meisheng X., Zhengshun W. & Zhitong Y.*** *(2018). The resource utilization of water hyacinth (Eichhornia crassipes [Mart.] Solms) and its challenges. Resources, 7(3). https://doi.org/10.3390/resources7030046*

***WHO****. World Health Organization (2011). Guidelines for drinking water quality (4th Ed). Geneva, Switzerland.*

***Yasotha D. & Lekeshmanaswamy M.*** *(2012). Impact of Neochetina eichhorniae Warner. on Biological Control of Water Hyacinth (Eichhornia crassipes (Mart.) Solms.) of Singanallur pond, Coimbatore, Tamil Nadu, India. Indian Journal of Natural Sciences, 2(10), 721–726.*

***Yonghong X. & Dan Y.*** (2003). The significance of lateral roots in phosphorus (P) acquisition of water hyacinth (Eichhornia crassipes). *Aquatic Botany*, *75*(4), 311–321. https://doi.org/10.1016/S0304-3770(03)00003-2

# Appendix

## Appendix 1, Tables

**Table 17:** The upper and lower bound interval and mean value of comparisons 2 weeks change of weevils' inclusion and exclusion WH plant parts

**Level of weevils**

| Dependent Variable | Level of weevils | Mean | Std. Error | 95% Confidence Interval Lower Bound | 95% Confidence Interval Upper Bound |
|---|---|---|---|---|---|
| Maximum leaf diameters | Treated maximum leaf diameter in 2nd weeks | 9.378 | .349 | 8.684 | 10.071 |
| | Controlled maximum leaf diameter in 2nd weeks | 9.289 | .349 | 8.595 | 9.982 |
| | Treated maximum leaf diameter in 4th weeks | 8.133 | .349 | 7.440 | 8.827 |
| | Controlled maximum leaf diameter in 4th weeks | 9.500 | .349 | 8.807 | 10.193 |
| | Treated maximum leaf diameter in 6th weeks | 7.344 | .349 | 6.651 | 8.038 |
| | Controlled maximum leaf diameter in 6th weeks | 8.089 | .349 | 7.395 | 8.782 |
| | Treated maximum leaf diameter in 8th weeks | 6.700 | .349 | 6.007 | 7.393 |

| | | | | | |
|---|---|---|---|---|---|
| | Controlled maximum leaf diameter in 8th weeks | 9.422 | .349 | 8.729 | 10.116 |
| | Treated maximum leaf diameter in 10th weeks | 6.700 | .349 | 6.007 | 7.393 |
| | Controlled maximum leaf diameter in 10th weeks | 9.789 | .349 | 9.095 | 10.482 |
| | Treated maximum leaf diameter in 12th weeks | 7.711 | .349 | 7.018 | 8.405 |
| | Controlled maximum leaf diameter in 12th weeks | 12.200 | .349 | 11.507 | 12.893 |
| Minimum leaf diameters | Treated minimum leaf diameter in 2nd weeks | 7.844 | .319 | 7.211 | 8.478 |
| | Controlled minimum leaf diameter in 2nd weeks | 7.667 | .319 | 7.033 | 8.300 |
| | Treated minimum leaf diameter in 4th weeks | 6.133 | .319 | 5.500 | 6.767 |
| | Controlled minimum leaf diameter in 4th weeks | 7.467 | .319 | 6.833 | 8.100 |
| | Treated minimum leaf diameter in 6th weeks | 5.322 | .319 | 4.688 | 5.956 |
| | Controlled minimum leaf diameter in 6th weeks | 6.556 | .319 | 5.922 | 7.189 |
| | Treated minimum leaf diameter in 8th weeks | 5.089 | .319 | 4.455 | 5.723 |

| | | | | | |
|---|---|---|---|---|---|
| | Controlled minimum leaf diameter in 8th weeks | 8.322 | .319 | 7.688 | 8.956 |
| | Treated minimum leaf diameter in 10th weeks | 5.133 | .319 | 4.500 | 5.767 |
| | Controlled minimum leaf diameter in 10th weeks | 8.478 | .319 | 7.844 | 9.112 |
| | Treated minimum leaf diameter in 12th weeks | 6.433 | .319 | 5.800 | 7.067 |
| | Controlled minimum leaf diameter in 12th weeks | 10.400 | .319 | 9.766 | 11.034 |
| Shoot length | Treated shoot length in 2nd weeks | 29.889 | 1.734 | 26.447 | 33.331 |
| | Controlled shoot length in 2nd weeks | 23.289 | 1.734 | 19.847 | 26.731 |
| | Treated shoot length in 4th weeks | 14.556 | 1.734 | 11.114 | 17.997 |
| | Controlled shoot length ponds in 4th weeks | 20.000 | 1.734 | 16.558 | 23.442 |
| | Treated shoot length in 6th weeks | 15.067 | 1.734 | 11.625 | 18.508 |
| | Controlled shoot length in 6th weeks | 19.378 | 1.734 | 15.936 | 22.819 |
| | Treated shoot length in 8th weeks | 16.044 | 1.734 | 12.603 | 19.486 |
| | Controlled shoot length in 8th weeks | 32.111 | 1.734 | 28.669 | 35.553 |

| | | | | | |
|---|---|---|---|---|---|
| | Treated shoot length in 10th weeks | 16.111 | 1.734 | 12.669 | 19.553 |
| | Controlled shoot length in 10th weeks | 35.000 | 1.734 | 31.558 | 38.442 |
| | Treated shoot length in 12th weeks | 20.556 | 1.734 | 17.114 | 23.997 |
| | Controlled shoot length in 12th weeks | 50.111 | 1.734 | 46.669 | 53.553 |
| Root length | Treated root length in 2nd weeks | 41.100 | 1.822 | 37.484 | 44.716 |
| | Controlled root length in 2nd weeks | 43.111 | 1.822 | 39.495 | 46.727 |
| | Treated root length in 4th weeks | 38.889 | 1.822 | 35.273 | 42.505 |
| | Controlled root length in 4th weeks | 49.222 | 1.822 | 45.606 | 52.838 |
| | Treated root length in 6th weeks | 41.722 | 1.822 | 38.106 | 45.338 |
| | Controlled root length in 6th weeks | 47.778 | 1.822 | 44.162 | 51.394 |
| | Treated root length in 8th weeks | 50.778 | 1.822 | 47.162 | 54.394 |
| | Controlled root length in 8th weeks | 58.600 | 1.822 | 54.984 | 62.216 |
| | Treated root length in 10th weeks | 47.889 | 1.822 | 44.273 | 51.505 |
| | Controlled root length in 10th weeks | 54.444 | 1.822 | 50.828 | 58.061 |
| | Treated root length in 12th weeks | 54.933 | 1.822 | 51.317 | 58.550 |

| | | | | | |
|---|---|---|---|---|---|
| | Controlled root length in 12th weeks | 58.111 | 1.822 | 54.495 | 61.727 |
| Wet water hyacinth plant biomass | Treated WWHP biomass in 2nd weeks | 300.667 | 37.807 | 225.621 | 375.712 |
| | Controlled WWHP biomass in 2nd weeks | 385.667 | 37.807 | 310.621 | 460.712 |
| | Treated WWHP biomass in 4th weeks | 489.444 | 37.807 | 414.399 | 564.490 |
| | Controlled WWWHP biomass in 4th weeks | 610.667 | 37.807 | 535.621 | 685.712 |
| | Treated WWWHP biomass in 6th weeks | 729.000 | 37.807 | 653.954 | 804.046 |
| | Controlled WWHP biomass in 6th weeks | 1192.778 | 37.807 | 1117.732 | 1267.824 |
| | Treated WWHP biomass in 8th weeks | 1228.889 | 37.807 | 1153.843 | 1303.935 |
| | Controlled WWHP biomass in 8th weeks | 1631.889 | 37.807 | 1556.843 | 1706.935 |
| | Treated WWHP biomass in 10th weeks | 1245.444 | 37.807 | 1170.399 | 1320.490 |
| | Controlled WWHP biomass in 10th weeks | 2184.222 | 37.807 | 2109.176 | 2259.268 |
| | Treated WWHP biomass in 12th weeks | 1558.889 | 37.807 | 1483.843 | 1633.935 |
| | Controlled WWHP biomass in 12th weeks | 2371.556 | 37.807 | 2296.510 | 2446.601 |

**Table 18:** The upper and lower bound interval and mean value of comparisons of bi weekly change of weevils' inclusion and insect exclusion water quality parameters.

**Level of weevil**

| Dependent Variable | Level of weevil | Mean | Std. Error | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | Lower Bound | Upper Bound |
| Temperature | In two weeks weevil inclusion ponds | 19.667 | .452 | 18.733 | 20.600 |
| | In fourth weeks weevil inclusion ponds | 20.633 | .452 | 19.700 | 21.567 |
| | In sixth weeks weevil inclusion ponds | 19.933 | .452 | 19.000 | 20.867 |
| | In eighth weeks weevil inclusion ponds | 20.067 | .452 | 19.133 | 21.000 |
| | In tenth weeks weevil inclusion ponds | 21.233 | .452 | 20.300 | 22.167 |
| | In twelfth weeks weevil inclusion ponds | 19.700 | .452 | 18.767 | 20.633 |
| | In two weeks weevil exclusion ponds | 18.000 | .452 | 17.067 | 18.933 |
| | In fourth weeks weevil exclusion ponds | 19.500 | .452 | 18.567 | 20.433 |
| | In sixth weeks weevil exclusion ponds | 19.300 | .452 | 18.367 | 20.233 |

| | | | | | |
|---|---|---|---|---|---|
| | In eighth weeks weevil exclusion ponds | 20.500 | .452 | 19.567 | 21.433 |
| | In tenth weeks weevil exclusion ponds | 20.633 | .452 | 19.700 | 21.567 |
| | In twelfth weeks weevil exclusion ponds | 20.133 | .452 | 19.200 | 21.067 |
| Dissolved oxygen | In two weeks weevil inclusion ponds | 2.190 | .370 | 1.427 | 2.953 |
| | In fourth weeks weevil inclusion ponds | 3.570 | .370 | 2.807 | 4.333 |
| | In sixth weeks weevil inclusion ponds | 3.060 | .370 | 2.297 | 3.823 |
| | In eighth weeks weevil inclusion ponds | 2.590 | .370 | 1.827 | 3.353 |
| | In tenth weeks weevil inclusion ponds | 2.703 | .370 | 1.940 | 3.466 |
| | In twelfth weeks weevil inclusion ponds | 2.283 | .370 | 1.520 | 3.046 |
| | In two weeks weevil exclusion ponds | 2.543 | .370 | 1.780 | 3.306 |
| | In fourth weeks weevil exclusion ponds | 3.570 | .370 | 2.807 | 4.333 |
| | In sixth weeks weevil exclusion ponds | 3.543 | .370 | 2.780 | 4.306 |
| | In eighth weeks weevil exclusion ponds | 3.127 | .370 | 2.364 | 3.890 |
| | In tenth weeks weevil exclusion ponds | 2.643 | .370 | 1.880 | 3.406 |
| | In twelfth weeks weevil exclusion ponds | 2.147 | .370 | 1.384 | 2.910 |

| | | | | | |
|---|---|---|---|---|---|
| Hydrogenion concentration | In two weeks weevil inclusion ponds | 7.413 | .092 | 7.224 | 7.603 |
| | In fourth weeks weevil inclusion ponds | 7.457 | .092 | 7.267 | 7.646 |
| | In sixth weeks weevil inclusion ponds | 7.373 | .092 | 7.184 | 7.563 |
| | In eighth weeks weevil inclusion ponds | 7.227 | .092 | 7.037 | 7.416 |
| | In tenth weeks weevil inclusion ponds | 7.437 | .092 | 7.247 | 7.626 |
| | In twelfth weeks weevil inclusion ponds | 7.557 | .092 | 7.367 | 7.746 |
| | In two weeks weevil exclusion ponds | 7.643 | .092 | 7.454 | 7.833 |
| | In fourth weeks weevil exclusion ponds | 7.327 | .092 | 7.137 | 7.516 |
| | In sixth weeks weevil exclusion ponds | 7.277 | .092 | 7.087 | 7.466 |
| | In eighth weeks weevil exclusion ponds | 7.170 | .092 | 6.981 | 7.359 |
| | In tenth weeks weevil exclusion ponds | 7.283 | .092 | 7.094 | 7.473 |
| | In twelfth weeks weevil exclusion ponds | 7.660 | .092 | 7.471 | 7.849 |
| Conductivity | In two weeks weevil inclusion ponds | 563.000 | 62.012 | 435.014 | 690.986 |
| | In fourth weeks weevil inclusion ponds | 380.333 | 62.012 | 252.348 | 508.319 |
| | In sixth weeks weevil inclusion ponds | 350.667 | 62.012 | 222.681 | 478.652 |

| | | | | | |
|---|---|---|---|---|---|
| | In eighth weeks weevil inclusion ponds | 343.333 | 62.012 | 215.348 | 471.319 |
| | In tenth weeks weevil inclusion ponds | 414.000 | 62.012 | 286.014 | 541.986 |
| | In twelfth weeks weevil inclusion ponds | 405.333 | 62.012 | 277.348 | 533.319 |
| | In two weeks weevil exclusion ponds | 546.000 | 62.012 | 418.014 | 673.986 |
| | In fourth weeks weevil exclusion ponds | 475.333 | 62.012 | 347.348 | 603.319 |
| | In sixth weeks weevil exclusion ponds | 525.333 | 62.012 | 397.348 | 653.319 |
| | In eighth weeks weevil exclusion ponds | 384.667 | 62.012 | 256.681 | 512.652 |
| | In tenth weeks weevil exclusion ponds | 457.667 | 62.012 | 329.681 | 585.652 |
| | In twelfth weeks weevil exclusion ponds | 441.000 | 62.012 | 313.014 | 568.986 |

**Appendix 2 , Plates**

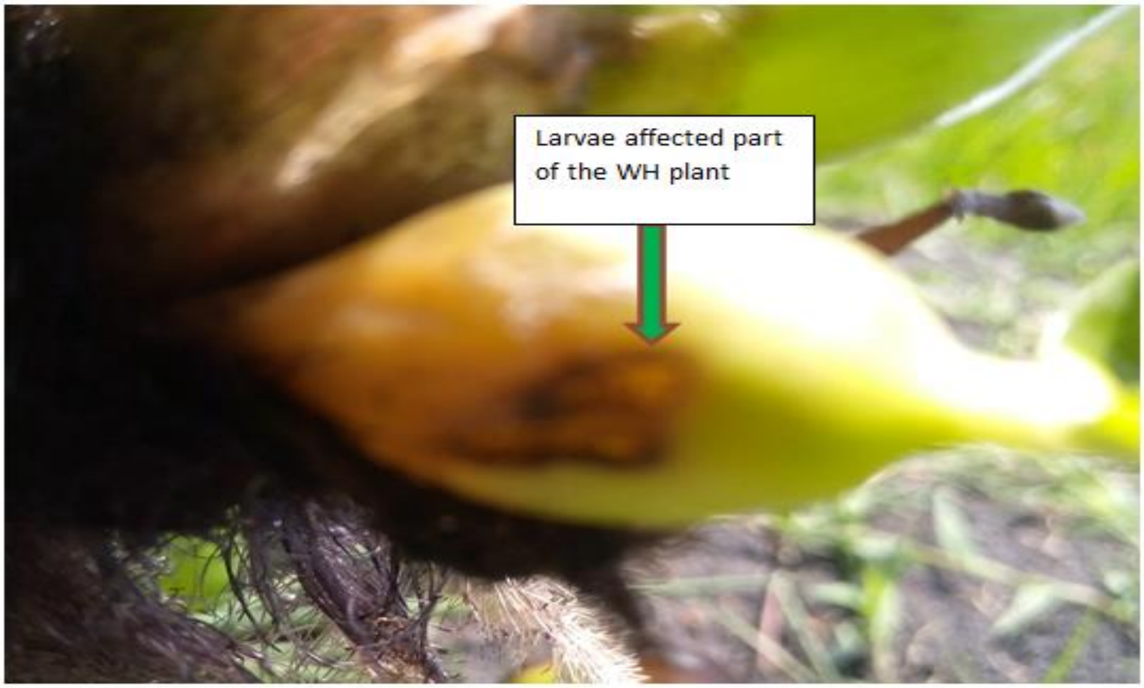



**Plate 1:** Photograph taken from atreament pond demonstrates how weevils larvae contribute to the death of water hyacinth plants.


**Plate 2:** Photo of water hyacinth root showing how the inclusion and exclusion treatments of weevils differ in terms of root srcture