EVALUATION OF LEAD NITRATE AND CADMIUM CHLORIDE TREATMENT ON JUTE MALLOW (*Corchorus olitorius* L .) GROWTH USING SPECTRAL INDICES

BY

Phoebe Udhedheoghene IDEJI (Miss)

LSC2007215

DEPARTMENT OF PLANT BIOLOGY AND BIOTECHNOLOGY

FACULTY OF LIFE SCIENCES

UNIVERSITY OF BENIN

BENIN CITY

FEBRUARY, 2025.

EVALUATION OF LEAD NITRATE AND CADMIUM CHLORIDE TREATMENT ON JUTE MALLOW (*Corchorus olitorius* L .) GROWTH USING SPECTRAL INDICES

BY

Phoebe Udhedheoghene IDEJI (Miss)

LSC2007215

A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF PLANT BIOLOGY AND BIOTECHNOLOGY, FACULTY OF LIFE SCIENCES IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE (HONOURS) DEGREE (B.Sc) IN PLANT BIOLOGY AND BIOTECHNOLOGY

FEBRUARY, 2025

CERTIFICATION

This is to certify that this work was carried out by Phoebe Udhedheoghene IDEJI of the Department of Plant Biology and Biotechnology, Faculty of Life Sciences, University of Benin, Benin City, Edo State, Nigeria.

PROF. E.D. VWIOKO ___________________

PROJECT SUPERVISOR **Sign and Date**

PROF. E. D.VWIOKO __________________

HEAD OF DEPARTMENT **Sign and Date**

DEDICATION

I humbly dedicate this project to GOD Almighty, whose guidance and wisdom has been my constant source of strength and inspiration. I am grateful for His grace, good health, and for the successful completion of this project.

ACKNOWLEDGEMENT

My utmost gratitude goes to GOD Almighty for guiding me throughout this project, I am grateful for His unending love, grace, wisdom and strength.

I extend my sincere gratitude to my project supervisor and Head of Department, Prof. D.E. Vwioko for his invaluable guidance, unwavering dedication, and continuous support throughout this research project. His expertise, insightful suggestions, and constructive criticisms have greatly enriched the quality of this work.

I am grateful to my project colleagues, Atoe Destiny, Otote Martins and Aigbovoriuwa Blessing, for their assistance and collaboration during the data collection and analysis phase. Their contributions have been instrumental in the successful completion of this research. I would like to acknowledge and appreciate my friends Ehue Osaruese Joy, Onyebuchi Edith Chinyere and Obonumah Ojimaojo Eunice for their friendship, collaboration, and moral support throughout this project. Our discussions and shared experiences have enriched my understanding and perspective.

I want to express my deepest appreciation to my parents Mr and Mrs Ideji Stephen and siblings- Yeltson, Sanctus, Sonia and Osward, for their unwavering support, love, and prayers. Their encouragement and belief in my abilities have been a constant source of motivation.

My deepest gratitude goes to my fiancé for his love, support and care throughout this journey, thank you for being my partner and for always standing by my side.

I also want to take a moment to acknowledge myself for my hard work and perseverance throughout this project. This journey has taught me valuable lessons, and I recognize my growth and commitment towards achieving my goals.

TABLE OF CONTENTS

CHAPTER ONE: INTRODUCTION

CHAPTER TWO: MATERIALS AND METHODS

LIST OF TABLES

LIST OF PLATES

LIST OF FIGURES

ABSTRACT

Heavy metal contamination, particularly lead (Pb) and cadmium (Cd) pollution, poses significant challenges to agricultural productivity and plant health. In this study, *Corchorus olitorius* was grown in soils treated with different concentrations of lead nitrate and cadmium chloride solutions. The heavy metal treatments applied were 50 and 100 ppm Cd; and 100 and 200 ppm Pb. The application of heavy metal solution was carried out eight times and these concentrations were chosen based on literature. The experiment was conducted as a field potted study. Each treatment was replicated four times. Field data were recorded for germination, which includes; plant height, stem girth, and number of leaves produced per plant. Biochemical analyses for chlorophyll, carotenoids and lycopene contents were also done. Spectral indices for stress in plants were carried out spectrophotometrically by scanning leaf extracts using 200 – 900nm wavelengths. Findings from this study shows that cadmium and lead pollution on jute plant induced faster and higher mean germination percentage of 58.75% with moderate concentration of cadmium treatment (50ppm), compared to the control treatments which had a slower and a low mean percentage germination of 26.8%. In terms of mean plant height, plants grown in 200ppm of lead nitrate had the highest plant height which measured 49.00cm compared to control which had plant height of 40.50cm, while 50ppm cadmium had the least mean plant height of 27.75cm, which were observed nine weeks after planting. Spectrophotometric analysis was done, which indicated that the plants had a weak absorption of green wavelengths, but a stronger absorbance range was observed in 200-400 nanometers (nm). Cadmium 50ppm had the highest chlorophyll concentration while the least was observed with 100ppm lead. Findings from the study concluded that heavy metals may enhance the growth of the plant but further research should be carried out to evaluate the prolonged effects of heavy metal stress on the plant.

CHAPTER ONE

INTRODUCTION

1.1 Heavy Metals

Lead and cadmium regarded as environmental contaminants, are toxic heavy metals (Bas *et al.* 2021). Heavy metal pollution is one of the most serious environmental problems and human activities such as industrialization, urbanization, mining, vehicular exhaust, fossil fuel combustion, sewage and waste disposal, use of fertilizers and pesticides, and oil spills, introduce heavy metals into soil and water. Plants are important items of the food chain and can uptake heavy metals from soil and water hence the accumulation of heavy metals is hazardous to plants, animals, and human health (Yu *et al.,* 2018).

There are two types of mechanisms for heavy metal uptake, passive and active uptake. In the case of passive uptake across the root membrane, free metal ions in soil solution are taken up due to transpiration and create a concentration gradient from soil to root. In the case of active uptake, plants excrete organic ligands which bind to heavy metals and create a concentration gradient. The management of cadmium chloride accumulated in plants is complicated due to the fact that most of the key nutrient transporters, such as copper (Cu), manganese (Mn), iron (Fe), and zinc (Zn), also enhance Cadmium (Cd) absorption (Huang, *et al.* 2020).

Cadmium stress impacts plant development, as apparent from a lower dry matter production and leaf area, and stunted growth (Baliardini *et al.,* 2015; Borges *et al.,* 2018). Cadmium influences plant development at both the morphological and physiological level (Shanying *et al.,* 2017). At the total plant level, cadmium toxicity results in; leaf chlorosis, a delay in the growth rate, and suppression of respiration and photosynthesis (Navarro-Leon *et al.,* 2019), increased oxidative damage, and lower nutrient absorption ability (Mohamed, *et al.,* 2012). Cadmium also causes reduction in the seed germination rate of plants (Vijayaragavan *et al.,* 2011). It also affects plant chlorophyll and proline content (Tantrey and Agnihotri, 2010). As yet, it has been demonstrated that cadmium has no biological function in plants (Souguir *et al.,* 2011). According to reports, many cereals, potatoes, legumes, vegetables, and fruits acquire cadmium and people consume at least 70% of the Cd that comes from plant-based food (Wagner, 1993). The harmful effect of another heavy metal, lead on growth and development of rice also been studied (Neha Saini *et al.,* 2017).

Monitoring the growth of plants under environmental perturbations is essential for risk assessment and developing mitigation measures. Spectral remote sensing can measure the spectral reflectance of vegetation in 400 to 2500 nm wavelength range. It provides information on the biochemical, biophysical, and structural properties of plants and thus can be used to monitor the health status of plants. Lab scale spectral imaging systems can measure the spectral reflectance of individual plants, and this can be useful for small plants and seedlings which cannot be observed from a distance (Kong *et al.,* 2016).

1.1.1 Formation and accumulation of Cadmium in Soil and Plant

Generally, cadmium occur naturally in soils, however other anthropogenic activities may influence formation of cadmium in soils (Grant *et al.,* 1997). Large areas of crop land can be regarded to be uncontaminated or just marginally contaminated with Cd from phosphate fertilizer, manure and aerial deposition. Under such conditions, various crops such as durum wheat, flax, sunflowers and potatoes can collect quantities of Cd which exceed current and planned maximum permissible Cd concentrations. Cadmium is easily absorbed by plant roots and its toxicity is 20 times higher than other heavy metals (Dinakar *et al.* 2009).

Cadmium occurs in sedimentary rocks (0.3 mg kg^{-1}), lithosphere (0.2 mg kg^{-1}), and soil (0.53 mg kg^{-1}) (Kabata-Pendias, 2010). Cd enrichment in soil occurs from both anthropogenic and natural sources (Pan *et al.,* 2016). Geological weathering of rocks is the major natural source of Cd contaminants (Khan *et al.,* 2016; Liu *et al.,* 2013), while primary anthropogenic sources of Cd include agrochemicals, manufacturing, vehicular emission, irrigation wastewater, smelting, and mining (Khan *et al.,* 2016). Moreover, improper and uncontrolled waste disposable practices, sea spry, windblown dust, forest fires, and volcanic eruption also increase the Cd level in soils (Khan *et al.,* 2016).

The mechanism of accumulation of heavy metals by plants depends on factors such as cell wall materials of the plants, root exudates and mycorrhiza membrane properties. However, the mechanism by which Cd affects the absorption and utilization of mineral elements is still not totally established. It is hypothesized that Cd may interfere with nutrient absorption by changing the permeability of the plasma membrane and influencing the function of the nutrient transporters (Singh *et al.,* 2015; Qin *et al.,* 2020), resulting to changes in nutrient concentration and composition. For instance, Cd inhibited the absorption of nitrate (NO_3^-) and its transport from roots to shoots, by reducing the nitrate reductase activity in the shoots (Rizzardo *et al.,* 2012). There are large variances in Cd tolerance across species and varieties, but discrepancies occur between the findings of different trials. These discrepancies may be related to the intrinsic differential capability of various species and varieties for Cd accumulation and partitioning in roots and shoots and on the ability to limit Cd in roots (Nazar et al, 2012).

Pirselova and Ondruskova, (2021) examined the variations in the tolerance of fava bean (Vicia faba cv. Aštar) roots to cadmium in nitrate $Cd(NO_3)_2$ and chloride ($CdCl_2$) solutions. The physiological and biochemical markers were examined. The measured dosages of Cd (50, 100, 150 and 300 mg/L) did not affect the germination of seeds. However, substantial growth inhibition and dehydration were found after 96 hours of incubation. The thickness of roots and rupture of cell membranes grew together with the increasing concentration of the metal in the solution. At a Cd dose of 300 mg/L, irrespective of the solution utilized, increased nitrogen concentration and no change in salt content were observed. The content of magnesium rose owing to the dose of 100 mg/L (cadmium nitrate) while the content of calcium increased due to the dose of 300 mg/L (in either nitrate or chloride). The correlation studies revealed to a probable influence of nitrates in the applied solutions on the accumulation of Cd and certain minerals in the roots of the specified type of fava bean. This may be relevant for both research and agricultural practice. The discovery of crops with high tolerance to cadmium, as well as information about the processes of ion interactions at the soil solution–plant level, is significant in terms of such crops' application in the process of the rehabilitation of cadmium-contaminated soils paired with food production.

Recent research has shown that jute mallow can tolerate certain amounts of risk elements in their tissues and can be employed for the phytostabilization or phytoremediation of soils polluted with risk elements. In comparison with other crops (wheat and maize), the Jute mallow may collect and translocate Cd and lead (Pb) in its numerous tissues. Some genotypes have been acceptable for growing in Cd lead-contaminated soil without posing a danger to food safety (Tang *et al.,* 2019).

In the research carried out by Gomes *et al.* (2013), Fe content did not significantly differ between Cd-treated and control plants (except at 25 µmol Cd). Muradoglu *et al.* (2015) found that supplementation of Cd raised K, Mg, Fe, Ca, Cu and Zn concentration in both roots and leaves of strawberry. Several researches have showed that to decrease the concentrations of mineral elements in soil could be achieved by supplementing the soil with cadmium (Hediji *et al.,* 2015; Wang *et al.,* 2016). However, the results may be inconsistent due to changes in the plant species, part and/or test methods used in separate research. During the incubation of germinating seeds in distilled water (without the addition of nutrients), variations in the levels of macro- and micronutrients in roots because of changes in absorption from the environment—were not evaluated. The above-mentioned discrepancies in the concentrations of microelements might also be a result of the fact that the microelements contribute in varied (unequal) shares on the germination capacity of seeds (Li *et al.,* 2012). The reaction of germinating seeds to cadmium ions is a complex, phytohormone-regulated interaction of multiple membrane transporters that is likely to be determined by the genotype as well as by the concentration of the applied metal and its speciation (Martinez *et al.* 2017).

1.1.2 Formation and accumulation of Lead in Soil and Plants

Lead is one of the poisonous and unneeded elements for plants that lowered root length, fresh and dry weight, stem length and height of plant; additionally salicylic acid played a part in minimizing these damages (Mahdavian *et al.* 2016; Ranjbar *et al.* 2011; Padash *et al.* 2016; Fatemi *et al.* 2017). Lead poisoning largely hinders root growth, and the reduction in the development of the root system leads to limiting the growth of the aerial component. The reduction in the growth of the root and aerial portions under lead stress might be due to the buildup of lead in the root and the lignification of the cell walls under heavy metals (Fatemi *et al.* 2017).

Lead nitrate also reduces the antioxidant enzymes activity of plants causing several damages to the plant. One of the critical damages of heavy metals in a plant cell is the increase of reactive oxygen species (ROS). However, plants counterattack with free radicals by using enzymatic and non-enzymatic antioxidant systems (Aghaei *et al.* 2019).

Hassan *et al.* (2022) conducted a study to evaluate and assess the toxic effects of cadmium nitrate and lead nitrate [$Cd(NO_3)2$ and $Pb(NO_3)2$] and their mitigating role on *Capsicum annuum* L. cultivar. The biological effects of Cd and Pb were investigated using stress response indicators such as stomata, gas exchange parameters, proline, and defensive enzyme systems. Fresh seeds were treated with different concentrations (100, 200, 300, 400, and 500 ppm) of both Cd and Pb for 6 h. Cytological effects were observed under a microscope by crushing acetocarmine-stained anthers on glass slides. Stomata size was determined with a scanning electron microscope. Photosynthetic and transpiration rates were measured using an infrared gas analyzer. Chlorophyll and carotenoid pigments were determined analytically with a spectrophotometer. An expected decrease in chlorophyll and carotenoid content was observed with increasing concentrations. Cytotoxic effects of Cd and Pb resulted in various changes in chromosomes including laggard, stickiness, multi-nucleate, and disturbed polarity. The size of stomata decreased at higher concentration and measured to 2.20 and 4.6 µm with low stomata conductance at 500 ppm of Cd and Pb. Photosynthetic and transpiration rates showed a moderate trend with increasing concentrations, where high photosynthetic and transpiration rates were measured to 20.20 and 23.40 m−2 s−1 at 200 ppm concentration. Maximum SOD and CAT activity was 2.82- and 6.34-unit mg−1 at 300 ppm of Cd. These results are valuable for understanding how crop plants respond to heavy metals, especially when using them as inducing agents during sensing experiments.

1.2 Introduction to Jute Mallow

Jute mallow (*Corchorus olitorius* L.) is a fast growing and nutritious leafy vegetable. Due to the rapid growth, jute mallow may be useful for phytoremediation of heavy metal contaminated soil. Jute mallow contributes significantly to food security and nutrition of nations. According to Harborne *et al.* (1999) and Grubben and Denton (2004), the leaves have an average of 15% dry matter, 4.8 g of protein, 259 mg of calcium, 4.5 mg of iron, 4.7 mg of vitamin A, 92 mg of folates, 1.5 mg of nicotinamide, and 105 mg of ascorbic acid per 100 g of leaves.

The plant Jute mallow is referred to as Ewedu, Ooyo, and Eeyo in Yoruba and Ayoyo in Hausa (Musa *et al.,* 2010). It is a significant ethnically valuable vegetable to Western and Northern Nigeria. It is frequently added to other starchy foods like amala, mashed yam, eba, and fufu, as well as consumed as a soup, and because it includes protein, energy-producing minerals (calcium and iron), riboflavin, niacin, thiamin, folate, hormone precursors, and dietary fiber, it is an essential component of the human diet (Antia *et al.,* 2006). Additionally, jute mallow is used for more than simply food, its sturdy and waterproof fibers make it ideal for clothes, furniture, and burlap sacks (Grubben, 1997). This vegetable is classified as a Neglected and Underutilized Species (NUS) in Nigeria due to the lack of scientific study and development despite its nutritional and economic significance.

There are, however, little investigations on the effects of cadmium and lead on the vegetative growth of leafy vegetables (e.g jute mallow) in Nigeria. Thus, this study examines how $CdCl_2$ and $Pb(NO_3)_2$ contamination affects the morphological characteristics of *C. olitorius*.

1.3 Aim

The aim of this study was to investigate the effect of lead and cadmium in soils on the growth of jute mallow.

1.4 Objectives of the study

The specific objectives of the study were to determine;

1. growth of *C. olitorius* in soil polluted with cadmium and lead.
2. chlorophyll , carotenoid and lycopene contents of *C. olitorius* in soil polluted with lead and cadmium.
3. spectral characteristics of leaves extracts of *C. olitorius* in soil polluted with lead and cadmium.
4. the quantification of growth parameters such as plant height, stem girth, number of leaves, of *C. olitorius* plants grown in soil polluted with cadmium and lead.

1.5 Justification of the Study

Growth of jute mallow (*Corchorus olitorius*) contributes to the nation's economic development (Singh *et al.,* 2019). Every year, stress contributes to massive crop losses that endanger the global food supply chain, and early assessment of plant stress might play a significant function in protecting crops and supporting economic growth. Heavy metal contamination, notably from lead (Pb) and cadmium (Cd), poses serious environmental concerns. These hazardous metals regularly pollute agricultural soils owing to industrial operations, mining, inappropriate waste management, and the misuse of fertilizers and pesticides (Zhao *et al.,* 2012). These pollutants are persistent in the environment and can accumulate in soil and water, impacting plant development and production. By evaluating their influence on jute mallow seedlings, this research aids the understanding of the larger consequences of soil pollution for plant health. Lead and cadmium are very poisonous and known to bioaccumulate in food systems, providing major health concerns to people and animals. Chronic exposure to these metals can result in neurological, renal, and cardiovascular damage (Tchounwou *et al.,* 2012).

Understanding the extent to which heavy metals influence crop development and potentially infiltrate the human diet is crucial for designing methods to decrease their impact on public health. While extensive research exists on heavy metal toxicity in plants, fewer studies focus explicitly on jute mallow. Additionally, the application of spectral characteristics for assessing plant responses to these contaminants remains underexplored. By merging these two components, this study aims to merge the major gap in environmental and crop production research, enhancing understanding on how individual crops respond to harmful environmental circumstances.

Recently, spectral imaging methods have emerged as useful instruments for early identification of plant stress.

This study is justified on numerous levels: it tackles the immediate issue of heavy metal contamination, helps efforts to assure food security, uses modern spectral imaging technology, and contributes to the larger scientific knowledge of plant responses to environmental stress. Moreover, the research coincides with worldwide initiatives to promote sustainable agriculture, safeguard public health, and create effective solutions for managing environmental toxins.

1.6 Literature Review

1.6.1 Botany of Jute Mallow (*Corchorus olitorius*)

The genus *Corchorus* contains about 40-100 species of flowering plants from the Malvaceae family, the genus is native to tropical and subtropical regions throughout the world (Stewart, 2011).

Generally, plants in genus *Corchorus* are annual herbs, with an average height of 2-4metres, usually unbranched or characterized with few adventitious branches. The simple, lanceolate, alternating leaves are 5 to 15 cm long, with a coarsely serrated or lobed border and an acuminate apex. The fruit is a capsule with numerous seeds, and the blooms are tiny (2–3 cm in diameter), yellow, and have five petals.

C. olitorius grows as an erect woody plant, 0.5 to 1.2 m (to 2.5 m under intense cultivation) with leaves up to 15 cm long (UN-EUE, 2001). Leaves are oval to elliptic, with serrated margins, yellow flowers with short, five-part seed capsules holding angular seeds.

1.6.2 Taxonomy of Corchorus olitorius (Jute Mallow)

Kingdom: Plantae
Clade: Tracheophytes
Clade: Angiosperms
Order: Malvales
Family: Malvaceae
Genus: *Corchorus*
Specie: *olitorius*

Source: Whitlock and Alverson, (2003)

1.6.3 Planting Temperature

Cultivation of Jute mallow requires warm and humid environment ranging between 16°C-40°C, however the optimal temperature for cultivation of jute mallow is (24°C- 37°C), most commercial farmers cultivate Jute mallow plants throughout rainy season with at least 500 mm of rainfall (NFSM, 2017). To guarantee effective development, farmers should till the soil carefully, maintain a pH of 5 to 8 (with 6.0 to 7.6 being best), and make sure it is well-aerated, not heavy textured or waterlogged (Pallvi, 2017).

Then for equal distribution, mix seeds for broadcast with loose dry sand or a comparable sized material, or plant them at a depth of 3-5 cm with 20 cm between rows and 10 cm between plants, with a seeding rate of 8 kg per ha for commercial output (Pallvi, 2017). Jute mallow is not demanding, responding to compost or low-levels of fertilizer. Commercial rates are 30-60 kg nitrogen ha-1 and 20-40 kg ha-1 for both phosphorus and potassium (Pallvi, 2017). Growing young plants in containers or spreading them wider in the field (opposed to fiber production) generates more palatable leaves for harvesting in as little as 30 days.

1.6.4 Pests

Worldwide, insect and pests are the main reason for crop production losses, and controlling pests is essential to ensuring food security and generating revenue for farmers (Zhang *et al.,* 2018). According to Nigel (1980), insect pests account for 8.7% of the 27.7% global losses in vegetable output, which might result in further losses if left unchecked. According to the Food and Agriculture Organization (FAO, 1997), insects alone are responsible for an estimated 15% to 20% of vegetable losses worldwide each year during field production and 18–20% during storage. In Nigerian farming systems, damage from insect pests is undoubtedly one of the greatest obstacles to increasing vegetable production and is the main reason for low-quality and low yields (Aderolu *et al.,* 2013).

Economically significant pests of jute mallow include; the hairy jute caterpillar (*Spilosoma obliqua*), jute semi-looper (*Anomis sabulifera*) and stem rot (*Macrophomina phaseolina*) Maity *et al.* (2012); Li *et al.,* (2022). Aside from these pests, jute mallow is largely disease-free, however it shares some minor pests with cotton, a near cousin. These include African grasshoppers (*Zonocerus* sp.), cotton leaf rollers (*Sylepta* sp.), flea beetles (*Podagrica* sp.), and cotton stainers (*Dsysdercus* sp.).

Study carried out by Danjuma *et al.* (2022) on the evaluation of plant materials for the control of leafworm (*Acraea tersicore* L.) on Jute mallow. The research was conducted in Lapai, Niger State, Nigeria. The study sought to determine how well three plant materials black pepper (Piper nigrum L.), neem seed (*Azadirachta indica* A. Juss.), and alligator pepper (*Aframomum melegueta* K. Schum) could suppress the leaf worm *Acraea terpsicore* (L.) on jute marshmallow. Separately, the plant components were powdered and weighed at 100g per liter of water. Before being sprayed, the materials were individually soaked in water for a whole day. To get rid of any tiny particles, they were then sieved using muslin cloth and filtered again using Whatman filter paper. After that, the extracts were put into the sprayer so the plant could be sprayed. The number of leafworms was recorded prior to spraying and again one day following the spraying. The spraying was carried out every three days, at four, six, and eight-weeks following planting (WAP), the quantity of damaged leaves was also tallied. Neem seed extract resulted in the lowest number of damaged leaves at 4, 6, and 8 WAP and the considerably higher mortality after each spray at the conclusion of the study, followed by black pepper. On the other hand, alligator pepper had no discernible impact on the leaf worm. At 4, 6, and 8 WAP, the control exhibits the greatest amount of leaf worms and damaged leaves. In conclusion, the leaf worm *Acraea terpsicore* without control generally affects the growth of jute mallow.

Gbedolo *et al.,* (2018) in their study carried out in Southern Benin, in their study, between 10-100 percent of farmers in the research area reported that the seven most prevalent potential pest includes; *Acrea* sp., *Aulacophora africana*, *Helicoverpa armigera*, *Spodoptera litoralis*, *Zonocerus variegatus*, *Podagrica* spp., and *Acrea acerata*. Infestations by these pests vary by location rather than being associated with certain *C. olitorius* morphotypes. Farming techniques (number of harvests, seedling after planting, intercropping, and dormancy cutting) employed by the farmer might influence the kind of *C. olitorius* pests found in that location.

1.7 Benefits of Jute Mallow (Corchorus olitorius)

1.7.1 Food and nutrition

The 'Thai' variety produces more tender leaves and stems than more fibrous forms of jute mallow (*C. capsularis*). People cook and serve tender leaves and stems, like its relative okra for which jute mallow can serve as a replacement in recipes. Jute mallow has high levels of Beta-carotene, ascorbic acid, and calcium, and is a good source of folic acid, iron, and protein (AVRDC, 2009).

Corchorus leaves are utilized in the culinary practices of several nations. *Corchorus olitorius* is mostly utilized in the culinary practices of southern Asia, the Middle East, North Africa, and West Africa, whereas *Corchorus capsularis* is prevalent in Japan and China. It has a mucilaginous (slightly "slimy") texture, comparable to okra, when cooked. The seeds serve as a flavoring, and a herbal tea is prepared from the desiccated leaves. The foliage of Corchorus is abundant in beta-carotene, iron, calcium, and vitamin C. The plant has antioxidant activity comparable to a substantial amount of α-tocopherol, a form of vitamin E. In North Africa and the Middle East, the young leaves of Corchorus species are referred to in Arabic as malukhiyah and utilized as green leafy vegetables. Malukhiyah is eaten regularly in Egypt and some consider it the Egyptian national dish. It is included in cuisines from Lebanon, Palestine, Syria, Jordan and Tunisia. In Turkey and Cyprus, the plant is known as molohiya or molocha and is commonly prepared into a form of chicken stew (Anonymous, 2011). The leaves of Corchorus have been a staple Egyptian cuisine since the time of the Pharaohs and it is from there that it receives its notoriety and appeal. Varieties of jute mallow leaves are eaten with rice, a widely known Middle Eastern food.

In Nigerian cuisine, it is used in a stew known as ewedu, a seasoning to other starch-based meals, such as amala or mixed with gbegiri a traditional Nigerian soup. In Northern Nigeria it is known as Ayoyo. They use it to prepare a sauce called (Miyan Ayoyo) which is often eaten with Tuwon Masara or Tuwon Allebo.

In Ghana, it is predominantly consumed by the people in the North and it is called ayoyo. It is typically eaten with Tuo Zaafi (food cooked with cornflour) (Mustapha, 2024)
In Sierra Leone it is called as krain krain (or crain crain) and is eaten as stew. The stew is frequently served with rice or foofoo (a traditional meal prepared from cassava)(Tenove, 2011). Jute leaves are also consumed among the Luhya people of Western Kenya, where it is widely known as mrenda or murere. It is eaten with starchy meals like ugali, a staple for most people in Kenya. In Northern Sudan it is called khudra, meaning "green" in Sudanese Arabic. The Songhai people of Mali name it fakohoy. In India, it is locally called as nalta sag. It is a beloved cuisine

during the summer months, especially in Sambalpur and the western region of Odisha. Usually it is briefly sautéed and served together with rice or rice gruel.

In the Philippines, *C. olitorius* is known as saluyot. It is typically served as a green vegetable paired with bamboo shoots (Danny, 2010)

1.7.2 Medicinal

The antioxidant chemicals (e.g. ascorbic acid, thiols, and polyphenols) found in *C. olitorius* contribute to the treatment of a wide list of maladies that practitioners of natural medicine promote jute mallow for treating (Islam, 2013). There are more of these antioxidant chemicals present in the leaves, young stems, and mature roots during the flowering of jute mallow and these are greater in *C. olitorius* than in *C. capsularis* (Abdel-Razek *et al.,* 2022). Medicinal uses cited in the literature are wide ranging (Islam, 2013; Abdel-Razak *et al.,* 2022; Biswas *et al.,* 2023).

1.8 Spectral Imaging (SI)

The use of spectral imaging for sensing originated from imaging spectrometry (Liu *et al.,* 2015). In the mid-1980s imaging spectrometry, a novel Earth remote sensing technology, was developed at the Jet Propulsion Laboratory (JPL) of the California Institute of Technology in Pasadena, connected with the National Aeronautics and Space Administration (NASA). Airborne and spaceborne sensors permitted the identification of surface materials immediately and remotely; pictures of the seen surface were produced, concurrently with reflectance values originating from up to 200 contiguous spectral bands in the reflectance spectrum (Goetz *et al.,* 1985).

During the last several decades, various imaging and spectroscopic approaches have been developed and utilized by the agricultural and food sectors for the assessment and categorization of goods based on their inherent traits and attributes (ElMasry and Sun, 2010). In recent years, the combination of imaging and spectroscopy through the development of SI technology has made it feasible to combine their benefits, reaching outcomes that are impossible to attain with standard imaging and spectroscopic technologies (Lu and Park, 2015).

Compared to non-imaging spectral technology, spectral imaging data can provide more information, such as shape, gradient, color, etc. The resolution of image data of spectral imaging technique is great with a wavelength variation of 10−2λ (Xing *et al.,* 2017). In the visible to shortwave infrared region, the spectrum has a resolution level of a nanometer. There might be dozens or even hundreds of spectral bands. The spectral bands are continuous, and a complete spectral resolution spectral curve may be derived at each pixel position of the picture data. Therefore, the spectral data frame is produced as a three-dimensional picture cube. The X-Y dimension expresses the spatial location information of the picture. The third dimension (λ) is the spectral/wavelength dimension, which is formed of multiple bands in the spectral space. By making a multidimensional section of the spectral image cube, different types of spectral features can be obtained, such as the spectral characteristics at any point pixel, the spectral change of a spectral interval on an arbitrary spatial profile, or the spatial image of any band in the spectral dimension, etc. With the aforesaid information, we can not only identify the object according to the picture feature in the spatial portion but also analyze the spectrum feature in the spectral dimension. As a consequence, it will improve the recognition of the kinds, components, and contents of the substances.

Spectral imaging play critical role in the agricultural sector especially in terms of monitoring the level of heavy metal present in the plant without destroying the plants. Yi *et al.* (2023) investigated the potential for spectral prediction of cadmium concentration in the leaves of pepper and eggplant, resulting in the establishment of a spectral prediction model for cadmium content in these leaves. The preliminary of the study identified the sensitive wavebands for predicting cadmium concentration in leaves by correlation analysis based on the indoor spectrum. Partial least squares regression (PLSR) and support vector machine regression (SVMR) were employed to develop spectral prediction models, with the final sensitive wavebands identified based on the magnitude of the model index. The results indicate that the SVMR model had superior predictive accuracy compared to the PLSR model. The RPDp (relative percent difference of prediction set) values for the optimal SVMR prediction models for pepper leaves and eggplant leaves were 1.82 and 1.49, respectively. The Rp2 values (coefficient of determination for the prediction set), which quantitatively estimate the Cd concentration in leaves, were 0.897 ($p < 0.01$) and 0.726 ($p < 0.01$), respectively. This study established that the leaf spectra of pepper and eggplant in the field may predict the Cd content in leaves, serving as a reference for future monitoring of Cd levels in the fruits of these plants.

The benefits of spectral mapping unity, which can accurately track crop development and illnesses, are fully used in the application of spectral imaging technology in agriculture (Wang *et al.* 2020). However, thus far, spectral cameras are still pricey, making them difficult to be extensively employed in agriculture. The process of spectral collection is easily affected by external conditions. It also takes a long time to gather, analyze, and process the spectral image data, which restricts the employment of spectral imaging systems in agricultural real-time monitoring and online detection. When the pre-established model is applied to another index system, data analysis and model transformation are necessary (Wang *et al.* 2020).

The features of the sample may impact its categorization findings and prediction accuracy. In addition, spectral imaging methods provide significant redundancy in picture processing. To decrease the time consumption of gathering and processing spectral data, it is often necessary to isolate featured wavelengths for specialized applications in various crops, which enables the numerous spectral imaging of the individual stressors or illnesses and reduces the cost (Wang *et al.* 2020).

Other than viruses, spectral image information may also reveal stresses induced by abiotic environmental elements, crop growth process, and biological harm. With the merging of the newest machine learning models and spectral data processing tools for plant disease diagnosis, new methods should be presented to cope with complex natural situations. Thus, additional biotic or abiotic stress impacts on plant spectrum features might be excluded from plant disease diagnosis models. As a consequence, this technology could be more beneficial for field practice. Meanwhile, plant disease detection models should effectively contribute to the decision support system to carry out real-time control strategies.

According to Daud *et al.,* (2016**),** the indoor leaf spectrum with higher reflectivity should be chosen for further examination in order to improve the modeling impact. Overall, Cd stress had no discernible effect on the pepper and eggplant leaf spectra in the sample plot, and the leaf spectra were in line with the typical spectral properties of plant leaves. The visible spectrum is dominated by chlorophyll, the near-infrared spectrum is primarily impacted by leaf cell structure, and the far-infrared spectrum is heavily impacted by water content. The spectral noise at these wavebands was comparatively high since the outside spectrum lies at 350–400 nm and 2400–2500 nm at both ends of the test range, while the strong absorption band of water dominates at 1400 nm and 1900 nm.

Souza *et al.,* (2022) classified cadmium contaminated leafy vegetables using spectral imaging and machine learning. The primary goal of this study was to determine whether SI can be used as a non-destructive method to classify plants according to the Cd concentration in two distinct types of leafy greens crops: kale and basil. Secondly, different machine learning algorithms were compared with the aim of identifying an optimal classification model for detecting kale and basil plants with Cd concentrations higher than the FAO safety threshold value of 0.2 mg kg $^{-1}$ of fresh plant weight (FAO and WHO, 2015). The experiment was conducted using pots without drainage holes to prevent contamination and related hazards. For irrigation, each pot received a certain amount of fertigation solution to maintain the target weight of 5 kg and keep the pots near field capacity. As the plants grew over time, the target weight was slightly increased to compensate for the increase in plant biomass.

Cadmium was applied superficially on the growing plants without directly contaminating the soil, to achieve total soil Cd concentrations of 0, 5, 10, and 15 mg kg1, respectively, and pots were adjusted with an aqueous solution of $CdCl_2$ (99.995% purity, Sigma Aldrich). These rates were chosen because they accurately reflect the amounts of Cd prevalent in agricultural soils that are low to moderately polluted. In order to allow Cd to adsorb onto soil particles, all of the pots were then watered with 1200 cc of water and left to equilibrate for two weeks. Following the incubation period, 32 pots were filled with kale (cv. Lacinato kale) that had been sowed in potting soil (Berger, Ca) four weeks prior, and the remaining half were filled with basil (cv. Genovese basil). Eight duplicates were made for kale and basil, respectively, for every Cd concentration level. Plants were classified based on their Cd concentrations (greater or lower than the 0.2 mg kg^{1}) Cd safety criterion. The greatest rankings of wavelengths for Cd detection were between 519 and 574 and 692 and 732 nm, suggesting that the presence of Cd changed the internal structure of the leaves and probably the amount of chlorophyll in the plants. The plants could be grouped by all models, but the ANN for the validation subset, which used reflectance from all wavelengths, had the highest F1 score. Although more research is required to modify this strategy for more complicated field settings, our work shows that SI and ML are viable technologies for the quick and accurate identification of Cd in leafy green plants.

Currently, the most common strategy to detect Cd in plant tissues is using destructive, post-harvest wet chemical procedures that rely on analytical equipment such as inductively coupled plasma mass spectrometry (ICP-MS). While extremely successful, these technologies are time consuming and expensive, and they also create a lot of hazardous waste as plant tissues must be digested in concentrated acid prior to detection of Cd using ICP-MS. This is particularly troublesome when trying to screen thousands of plants in a breeding program to promote those with minimal heavy metal uptake. Alternatively, new technologies such as spectral imaging (SI) might be developed to evaluate Cd-induced stress reactions and predict uptake. For example, we previously established that it is possible to measure Cd-induced stress responses in basil and kale using SI that were hard to detect with the human eye (Zea *et al.,* 2022). SI blends digital imaging methods with spectroscopic analysis algorithms that enable for quicker and more accurate non-destructive plant physiological process assessments. This approach evaluates a broad spectrum of light instead than only assigning main colors (red, green, blue) to each pixel. It works in the visible (VIS) and Near Infrared (NIR) bands, which encompass 400 nm–1400 nm. Changes in reflectance in these wavelengths have been examined to capture changes in leaf pigmentation

(400–700 nm) and mesophyll cell structure (700–1300 nm) in plants (Knipling, 1970), which can be changed by toxic heavy metals like Cd (He *et al.,* 2015; Ruffing *et al.,* 2021).

The effect of cadmium chloride, lead nitrate, silver nitrate, methyl jasmonate, and salicylic acid was examined by Abdollahi *et al.,* (2023) using many morphometric and biochemical properties of *Hypericum perforatum* L. commonly known as St. John's wort plant, using the Taguchi statistical approach. The results indicated cadmium chloride and lead nitrate impaired the morphometric and biochemical characteristics of St. John's wort whereas salicylic acid compensated for the unfavorable effects of heavy metals. Simultaneously, usage of salicylic acid and silver nitrate with cadmium chloride and lead nitrate minimized the harmful effects of these metals on morphometric properties. Methyl jasmonate boosted growth characteristics at low levels and inhibited at greater ones. Also, according to the data, salicylic acid might lessen the effects of heavy metals on the biochemical characteristics, whereas silver nitrate functions like heavy metals, especially at greater doses. Salicylic acid decreased the detrimental effects of these heavy metals and at all levels was able to provide a superior induction effect on St. John's wort. These elicitors largely affected the harmful effects of heavy metals by enhancing the pathways of the antioxidant system in St. John's wort. The study assumptions were proven, which shows that the Taguchi technique might be regarded in an optimal cultivation of medicinal plants under different treatments such as heavy metals and elicitors.

Furthermore Martyna *et al.* (2019) accessed the strength and weakness associated with the usage of spectral imaging in the assessment of plants' conditions. In light of the advantages of spectral imaging, ecologists now assess plant health by measuring photosynthetic efficiency. Photosynthetic efficiency is often measured by the rate of CO_2 absorption and the amount of chlorophyll fluorescence (Sarijeva *et al.* 2007). Depending on the method used to measure chlorophyll fluorescence, different fluorimeters can be distinguished (such as advanced laser fluorimeters (ALF), fast repetition rate (FRR) fluorimeters, and pulse amplitude modulation (PAM) fluorimeters), but the phenomenon under study is always the same (Sarijeva 2007). Following adaption in the dark, chorophyll a fluorescence kinetic induction is measured in the presence of light (Kautsky effect). The red band (~690 nm) and the far-red band (735-740 nm) exhibit the highest emission of fluorescence of chlorophyll in vivo (Govindjee 1995; Sarijeva *et al.* 2007).

Martyna *et al.* (2019) pointed out that the results acquired by testing hundreds or even thousands of people may sometimes be unreliable. It takes a lot of time and is often not feasible to do simultaneously. Using a single fluorimeter, the measurement of chlorophyll fluorescence for 50 individuals of our research object*, Hieracium pilosella* L., would take 91 hours and 40 minutes, assuming that each individual produced 10 daughter ramets, that we randomly selected 5 leaves from each mother and daughter ramet for the measurement, and that the measurement of one leaf takes two minutes. Additional time for shading the plants and attaching and removing the equipment is not included into this conclusion. It is well acknowledged that the pace of growth is closely correlated with the intensity of photosynthesis which is the key strategy in the evaluation of plant life strategies' key component (Wuyts *et al.* 2015). Each species grows at a different pace.
However, there may also be intra-specific differences, such as how plastic plants react to outside influences like competition, light intensity, and nutrition availability. Since the pace of growth is a life history feature (Sensu Stearns 1992), a negative link with other life history qualities may be anticipated based on the resource allocation principle. Therefore, by demonstrating the significance of photosynthesis and positioning it on the trade-off continuum with other features,

chlorophyll indices may further define plant strategy in addition to reflecting plant condition. If this is the case, different people may have different index values—not necessarily because they are in better health, but rather because they are at various periods of life that call for different resource allocations.

1.9 Spectral Response Curves in Detecting Plant Stress

Detailed knowledge of the spectral properties of plants is essential in order to correctly interpret remote sensing imagery. Every entity on land selectively reflects electromagnetic radiation. The term "spectral characteristic" refers to the strength of this variation across various spectrum bands. Emissionsivity, absorption, transmission, and reflection are among the optical characteristics of plants that are typical for each wavelength. The leaf surface, the stage of plant growth, the relative area covered by vegetation, the location, the water content, and the geometry of the sun-object-detector arrangement all affect these characteristics (Jensen 2007). Studies of vegetation are often carried out in the visible and near-infrared (350–2500 nm) portions of the electromagnetic spectrum. The structure of the leaf and the quantity of pigment, nutrients, and water inside the leaf has the most effects on the amount of energy reflected from the plant within this range.

There is a discernible drop in the quantity of reflected radiation in the red and blue areas when examining the spectral characteristics of a healthy plant. These are areas where chlorophyll is absorbed. The two pigment types found in plant chlorophyll are; chlorophyll a, which is green-blue, and chlorophyll b, which is green-yellow, which combines to provide the appearance of green. The wavelengths of 430 and 660 nm absorb chlorophyll a, whereas the 450 and 650 nm areas absorb chlorophyll b. Plant structures include many minor pigments, including phycocyanin, phycoerythrin, and carotenoids. Stressful conditions (such as low water or sunshine levels or high temperatures) cause the plant's chlorophyll content to drop, which reduces the quantity of energy absorbed in the 430 and 660 nm bands and increases reflectance.

Soil and water salinity is the most limiting factor for plant growth and productivity. Due to a high rate of evaporation, agricultural lands become saline in arid regions after a while. This leads to a decline in plant production. Mokhtari *et al.* (2014) investigated the capability of visible and near infrared (VNIR) spectrophotometry as a non-destructive method in detecting salinity effect on wheat leaves. A completely randomized design was worked out with four salinity levels and three replicates. Wheat seeds were planted in plastic pots and irrigated with four levels of saline water [0 (control), 4, 8 and 12 dS/m] Leaf spectrophotometry at VNIR (190-1100 nm) wavelength was performed on wheat leaves at the nodule-formation growth stage. The results indicated that treatments are discriminated mostly by reflectance and absorption spectra of 530-660 nm although a difference existed between the control treatment and the other treatments at 700-1100 nm. The difference between the treatments of T0, T4 and T12 was found to be significant ($P<0.01$) in the reflectance with an absorption value of 530-660 nm. Although all the treatments were discriminated at 700-1100nm visually, the difference between them was statistically insignificant at this wave range.

Plate 1.1: Jute Mallow (*Corchorus olitorius)*

CHAPTER TWO

MATERIALS AND METHOD

2.1 Study Area

The study was conducted in an open space beside the African Centre for Mushroom Research and Technology and Innovation (ACMRTI), University of Benin, Benin City, Edo State, Nigeria, with coordinate latitude 6.40288°N and longitude 5.60919°E.

2.2 Materials

The plant used for this study was Jute Mallow (*Corchorus olitorius* L.) seeds obtained from National Horticultural Research Institute (NIHORT). The chemical used were; lead nitrate $Pb(NO_3)_2$ and cadmium chloride $CdCl_2$, which were were obtained from a chemical vendor, University of Benin, Benin City.

2.3 Collection and Preparation of Soil

The composite soil was gotten from a fallow ground within the University of Benin, Benin City. The humus was gotten from the Botanical Garden, University of Benin while the sandy soil was gotten from a building site in the Faculty of Life Sciences, University of Benin.

The soil sampled were weighed (4kg) and then distributed into each of the twenty four (24) planting bowls which were previously perforated for aeration. Then, 10g of NPK fertilizers were weighed and added to each planting bowl, thoroughly mixed with soil and left to stand for seven (7) days prior to seed planting

2.4 Preparation and Application of Salts to the Soil Samples

Two salts treatment were used for this experiment, lead nitrate and cadmium chloride, with each of the treatments having a designated control treatment. The respective concentrations for the lead nitrate were 0ppm, 100ppm and 200ppm, while the concentrations for cadmium chloride were, 0ppm, 50ppm and 100ppm. Each of the respective weighed salt treatment were dissolved to 1 litre of deionized water; for 100 ppm of lead nitrate, 0.1g was dissolved in 1 litre, for 200ppm of lead nitrate ($Pb(NO_3)_2$), 0.2g was dissolved in 1 litre of deionized water, 50ppm ($CdCl_2$) 0.05g was dissolved to 1 deionized litre, 100ppm 0.1g ($CdCl_2$) was dissolved to 1 litre of deionized water.

250ml of the salt concentrates were measured and added to all the bowls with treatment tags for two days consecutively.

2.5 Planting of seeds

Forty seeds were planted per bowls, each bowl had 10 drills and each drill had four seeds and the planting depth was less than 1 centimetre. The bowls were watered daily.

2.6 Application of Heavy Metals Solutions

After planting, 250ml of the heavy metal treatments were added to bowls two times consecutively before planting. After planting, 250ml of the respective treatments were added every four days, this was done six times.

2.7 Measurements of the Physiological Characteristics of the Plant

Data collected for the study were

2.7.1 Germination

This was done by counting the newly sprouted plants daily to get the total number of germinated plants.

2.7.2 Number of leaves

This was done by counting the number of leaves per plant every two weeks.

2.7.3 Plant height

A measuring rule was used to measure the height of the plant

2.7.4 Stem girth

The girth was estimated by means of a thread and a measuring rule. The thread was used to wrap the stem and the thread was straightened and measured against a measuring rule

2.8 Preparation of Samples for Biochemical Analysis and Scanning for Spectral Indices

Leaves were plucked and labelled appropriately from the plants growing in each of the treatments. The leaves samples were cleaned and 80% acetone was used for the extraction of chlorophyll, while for the extraction of carotenoid, petroleum ether and sodium hydroxide were used.

2.8.1 Total Chlorophyll

The total chlorophyll content of leaves was estimated according to the method of Arnon (1949). One gram of leaf tissues were cut into pieces and macerated with 80% (V/V) acetone, with a pinch of calcium carbonate. The homogenate was centrifuged at 3000g for 10mins and supernatant was made up to a known volume with 80% acetone. The optical density of green supernatant was determined at 645 and 663nm in a spectrophotometer (model- systronics, Spectrophotometer 119 USA), against 80% acetone as blank. All the procedures were carried out in dim light.

The total chlorophyll content was calculated using the following formula:

$$Total\ chlorophyll = \frac{(20.2\times A_{645})-(8.02\times A_{663})}{1000\times w\times a}\times \mathrm{V(mg/g\ FW)}$$

Where;

A – Absorbance at specific wavelength (nm)

w – Fresh weight of the sample (g)

V – Volume of sample (mL)

a – Length of the light path in the cell (cm)

Chlorophyll a and b were estimated using the values for absorbance obtained using the formula;

$$Chlorophyll - a = \frac{(12.7\times A_{663})-(2.69\times A_{645})}{1000\times w\times a}\times \mathrm{V(mg/g\ Fw)}$$

$$Chlorophyll - b = \frac{(22.9\times A_{645})-(24.88\times A_{663})}{1000\times w\times a}\times \mathrm{V(mg/g\ Fw)}$$

2.8.2 Estimation of Carotenoids and Lycopene

Total carotenoids and lycopene were estimated by the method described by Zakaria *et al.* (1979).

Principle

Total carotenoids and lycopene can be extracted in the sample using petroleum ether and absorbance read at 450nm and 503nm respectively.

Reagents

1. Petroleum ether (40C – 60C)
2. Anhydrous sodium sulphate
3. Calcium carbonate
4. Alcoholic potassium hydroxide (12%) (ethanol and KOH)

Procedure

The experiment was carried out in the dark to avoid photolysis of carotenoids once the saponification was complete. The sample (0.5g) was homogenized and saponified with 2.5ml of 12% alcoholic potassium hydroxide in a water bath at 60^0C for 30 minutes. The saponified extract was transferred to a separating funnel containing 10-15ml of petroleum ether and mixed well. The lower aqueous layer was then transferred to another separating funnel and the upper petroleum ether layer containing the carotenoids was collected. The extraction was repeated until the aqueous layer became colourless. A small amount of anhydrous sodium sulphate was added to the petroleum ether extract to remove excess moisture. The final volume of the petroleum ether extract was noted. The absorbance of the yellow colour was read in a spectrophotometer

(Genesys 10-S, USA) at 450nm and 503nm using petroleum ether as blank. The amount of total carotenoids and lycophene was calculated using the formulae,

$$Amount\ of\ total\ carotenoids = \frac{A_{450}\ X\ Volume\ of\ the\ sample\ X\ 100\ X\ 4}{Weight\ of\ the\ sample}$$

$$Amount\ of\ total\ carotenoids = \frac{3.12\ X\ A_{503}\ X\ Volume\ of\ the\ sample\ X\ 100}{Weight\ of\ the\ sample}$$

The total carotenoids and lycopene were expressed as mg/g of the sample.

2.8.3 Spectrophotometric Analysis

The UV/VIS Spectrophotometer was powered and allowed to initialize. Spectrum work space was selected and the wavelength range of 200-900nm was entered. The solvent was used for the baseline correction before the spectrum of the sample volume was read using the curvette, inserting it on the light path of the UV light. The spectrum was then printed to check the peak at which the absorbance occurred maximally.

2.9 Statistical Analysis

The means and the standard errors of the replicates were calculated from the data obtained.

CHAPTER THREE

RESULTS

The results obtained in this study are shown in Tables 3.1-3.4, and Figures 3.1- 3.3, Plates 3.1 to 3.11

Table 3.1 shows the percentage germination of *Corchorus olitorius* plants sown in Pb and Cd treated soils. Data shows that on the fourth day after planting (day 4), seeds sown in cadmium 50ppm exhibited the highest percent germination (38.13%), followed by 200ppm Pb which had a percent germination of 30%, while the lowest percent germination were observed in the 100ppm Pb which was 18.75%. Eleven days after planting, significant percent germination was observed with 50ppm Cd treatment which had the highest percent germination of 58.87% while the least percentage germination was observed in 100ppm Pb with 37.50%.

Table 3.1: Percent germination (%) of *Corchorus olitorius* seeds grown in Pb and Cd Treated Soils

Soil Treatments	**Days after Planting (DAP)**		
	4 DAP	**8 DAP**	**11 DAP**
0ppm Cd (Control)	21.88±2.77	34.38±3.13	37.63±2.23
50ppm Cd	38.13±3.13	56.88±6.57	58.75±6.25
100ppm Cd	23.75±3.75	45.63±3.59	46.25±3.31
100ppm Pb	18.75±2.60	34.38±5.63	37.50±7.22
200ppm Pb	30.00±5.20	51.25±7.74	53.75±6.33

Values are Mean ± Standard error of four replicates of each treatment

The plant height (cm) of *Corchorus olitorius* plant grown in Pb and Cd treated Soil is presented in Table 3.2. The results presented shows that at 5 weeks after planting (5 WAP), plants grown in 200ppm Pb exhibited the highest stem length (24.25cm), followed by plants grown in 0ppm Cd which exhibited a plant height measurement of (9.75cm), 0ppm Pb exhibited the lowest stem height (4.13cm). At week 9, plant heights of 34.50cm and 37.75cm were observed for 0ppm and 100ppm Pb respectively. The highest plant height was observed by plants grown in 200ppm Pb.

Table 3.2: Plant Height (cm) of *Corchorus olitorius* Grown in Pb and Cd Treated Soil

Soil Treatments	**Weeks After Planting**		
	5 WAP	**7 WAP**	**9 WAP**
0ppm Cd (Control)	9.75±1.75	29.50±4.13	40.50±3.12
50ppm Cd	7.00±0.74	13.13±1.27	27.75±4.70
100ppm Cd	4.44±0.57	9.88±0.77	33.00±7.87
100ppm Pb	8.88±1.39	26.75±3.09	37.75±2.63
200ppm Pb	24.25±5.48	36.25±8.61	49.00±5.87

Values are Mean ± Standard error of four replicates of each treatment

Table 3.3 shows the stem girth (cm) of *Corchorus olitorius* plant grown in Pb and Cd treated soil. The experiment shows that plants that were exposed to 200ppm Pb at Week 5 of the experiment measured a mean stem girth of 1.63cm which was the highest while the lowest mean stem girth was 0.70cm which was observed by grown in 100ppm cadmium. All other treatments showed significant stem girth on week 9 after planting (9 WAP), 200ppm measured a mean stem girth of 2.03cm followed by 0ppm Cd (control) that exhibited a mean stem girth of 2.03cm.

Table 3.3: Stem girth (cm) of *Corchorus olitorius* plant grown in Pb and Cd Treated Soil

Soil Treatments	**Weeks After Planting**		
	5 WAP	**7 WAP**	**9 WAP**
0ppm Cd	1.33±0.21	1.80±0.25	2.03±0.23
50ppm Cd	0.93±0.05	1.15±0.07	1.33±0.20
100ppm Cd	0.70±0.00	0.85±0.07	1.58±0.05
100ppm Pb	1.25±0.21	1.88±0.19	1.95±0.26
200ppm Pb	1.63±0.32	2.08±0.31	2.05±0.10

Values are Mean ± Standard error of four replicates of each treatment

Table 3.4 shows the number of leaves of *Corchorus olitorius* plant grown in Pb and Cd treated soil. The experiment shows that at week 5 of the experiment, the highest mean leaf number were shown by 200ppm Pb plants, 0ppm Pb plants had 8.75 mean leaves, 100ppm Cd had 6.75 mean leaves. At week 9, plants that were exposed to 200ppm Cd had 102.25 mean leaves, while 100ppm Pb and 0ppm Cd had 80.00 mean leaves respectively, the lowest leaf number was observed in 50ppm Cd which had a mean leaf of 24.

Table 3.4: Number of Leaves of *Corchorus olitorius* plant grown in Pb and Cd Treated Soil

Soil Treatments	**Weeks After Planting**		
	5 WAP	**7 WAP**	**9 WAP**
0ppm Cd (Control)	23.50±6.02	55.25±18.31	80.75±27.52
50ppm Cd	7.75±0.25	15.50±1.56	24.00±7.45
100ppm Cd	6.75±0.25	15.00±3.32	43.50±8.09
100ppm Pb	22.75±6.54	43.50±9.74	80.00±21.12
200ppm Pb	32.50±15.05	70.25±19.26	102.25±28.52

Values are Mean ± Standard error of four replicates of each treatment

Figure 3.1 shows the total chlorophyll content of *Corchorus olitorius* plants grown in Pb and Cd treated soils. The experiment shows that plants that were exposed to no heavy metal treatment had a mean chlorophyll concentration of 2.815(mg/kg FW), 50ppm Cd had chlorophyll concentration of 2.825(mg/kg FW), 100ppm Cd had chlorophyll concentration of 2.725(mg/kg FW), 100ppm Pb had chlorophyll concentration of 2.875(mg/kg FW), while 200ppm Pb, had similar chlorophyll concentration in leaves with 50 ppm Cd, which shows that plants grown in lead 100ppm concentration absorbed the most chlorophyll with 100 ppm Cd having the least chlorophyll absorbance.

Lycopene content of *Corchorus olitorius* plants, grown in Pb and Cd treated soils are presented in Figure 3.2. Leaves exposed to different concentration of Pb and Cd had varying lycopene content, the highest was observed in plants grown in 0ppm which had 1971 (mg/kg FW), the lowest lycopene concentration were observed in the leaves of plants grown in 50ppm which was 1413(mg/g FW).

Figure 3.3 shows the carotenoid content of *Corchorus olitorius* plants grown in Pb and Cd treated soils. The experiment shows that plants that were exposed to 100ppm Pb had the highest carotenoid absorbance with a mean of 8041(mg/g FW) while the least carotenoid absorbance was shown in plants with no heavy metal exposure with a mean of 7501(mg/g FW).

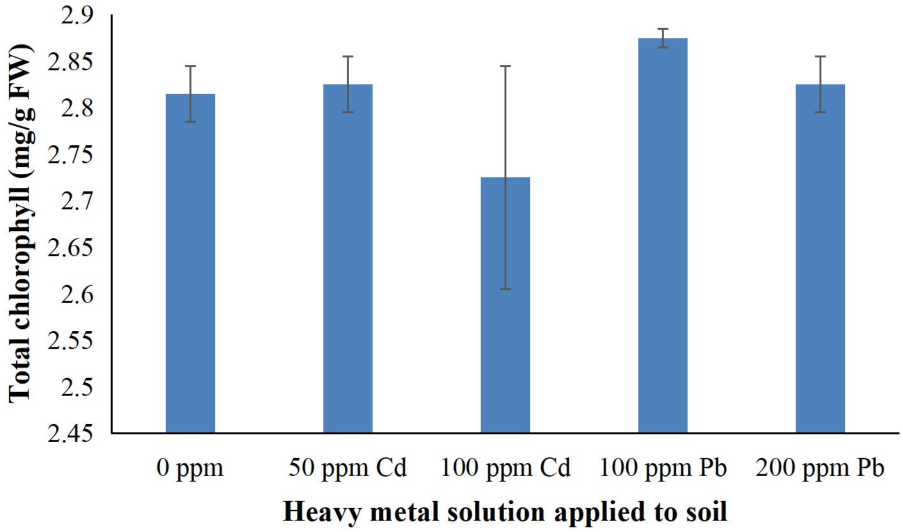


Figure 3.1: Total chlorophyll content of *Corchorus olitorius* plants, grown in Pb and Cd treated soils (error bars represent standard error of mean)

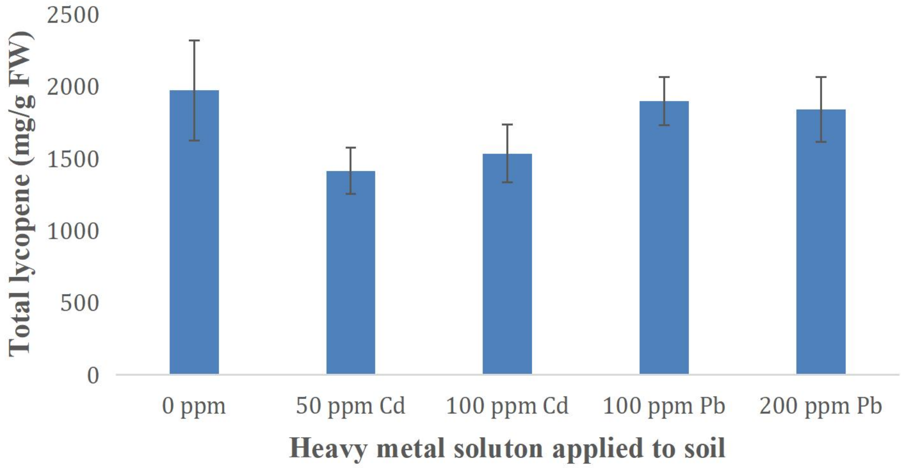


Figure 3.2: Lycopene content of *Corchorus olitorius* plants grown in Pb and Cd treated soils (error bars represent standard error of mean)

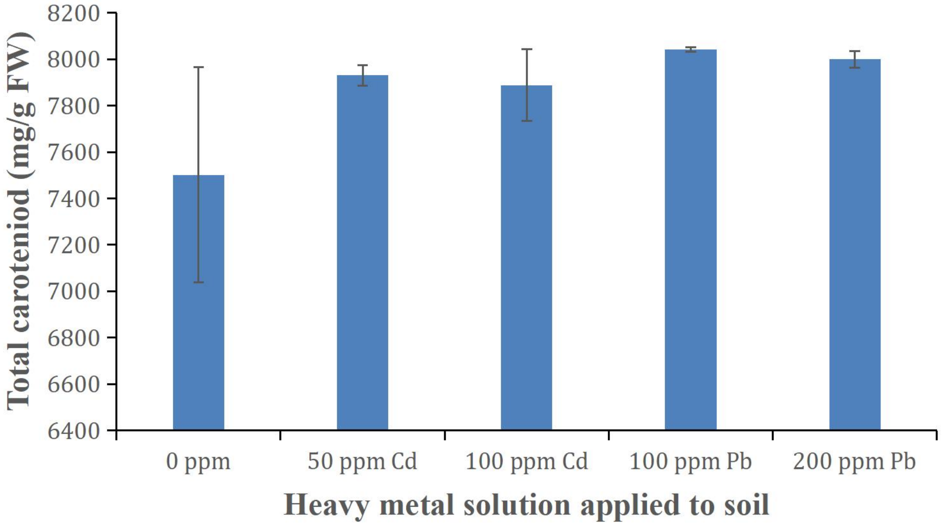


Figure 3.3: Carotenoid content of *Corchorus olitorius* plants grown in Pb and Cd treated soils (error bars represent standard error of mean values)

Plate 3.1 shows the spectral analysis of chlorophyll content in jute (*Corchorus olitorius*) plant cultivated in 0ppm cadmium (cd). The experiment shows that the spectral reflectance and absorbance measurement for plant grown in 0ppm cadmium values at a wavelength ranged from 200-400 and 640nm.

The spectral analysis of chlorophyll content in jute (*Corchorus olitorius*) plant cultivated in 50ppm cadmium (cd) is presented in Plate 3.2 The strongest absorption occurs in the 400–500nm range, which indicating a blue absorption (chlorophyll **a and b)** in the blue region. Weak absorption is noted around 600–700nm.

Plate 3.3 shows the spectral analysis of chlorophyll content in jute (*Corchorus olitorius*) plant cultivated in 100ppm cadmium (cd). The experiment shows that the spectral reflectance and absorbance measurement for plant grown in 100ppm cadmium had a strong absorption at wavelength ranged from 200-400 and weaker absorption at 640nm.

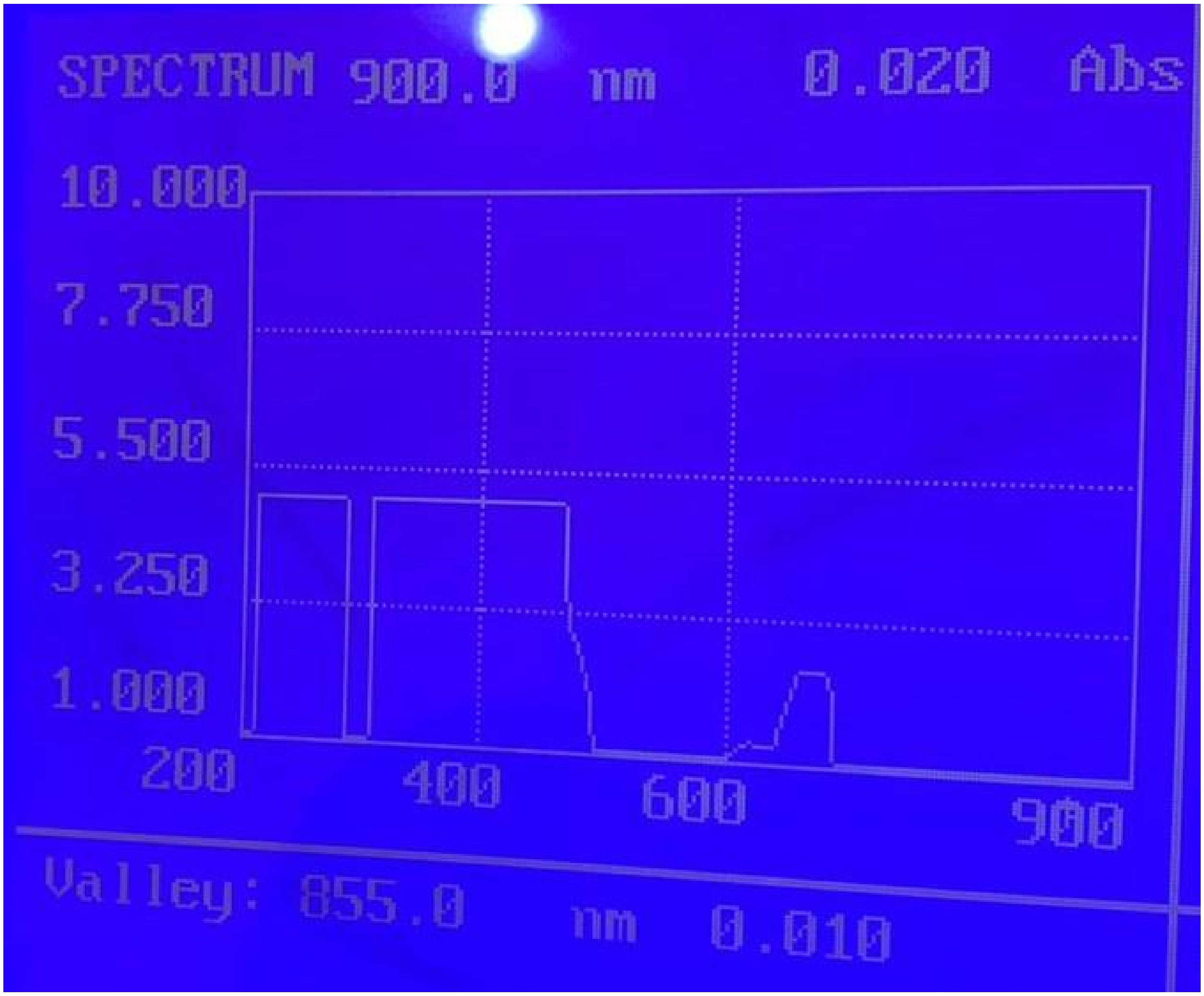


Plate 3.1: Spectral Analysis of Chlorophyll Content in Jute (*Corchorus olitorius*) Leaves Cultivated in 0ppm Cadmium (Cd)

Plate 3.2: Spectral Analysis of Chlorophyll Content in Jute (*Corchorus olitorius*) Leaves Cultivated in 50ppm Cadmium (Cd)

Plate 3.3: Spectral Analysis of Chlorophyll Content in Jute (*Corchorus olitorius*) Leaves Cultivated in 100ppm Cadmium (Cd)

The spectral analysis of chlorophyll content in jute (*Corchorus olitorius*) plant cultivated in 100ppm lead (Pb) is presented in Plate 3.4. The strongest absorption occurs in the 400–500nm range, which indicating a blue absorption (chlorophyll **a and b)** in the blue region. Weak absorption is noted around 600–680nm.

Plate 3.5 shows the spectral analysis of chlorophyll content in jute (*Corchorus olitorius*) plants cultivated in 200ppm lead (Pb). The experiment shows that the spectral reflectance and absorbance measurement for plant grown in 200ppm cadmium had a strong absorption at wavelength which ranged from 200-580nm.

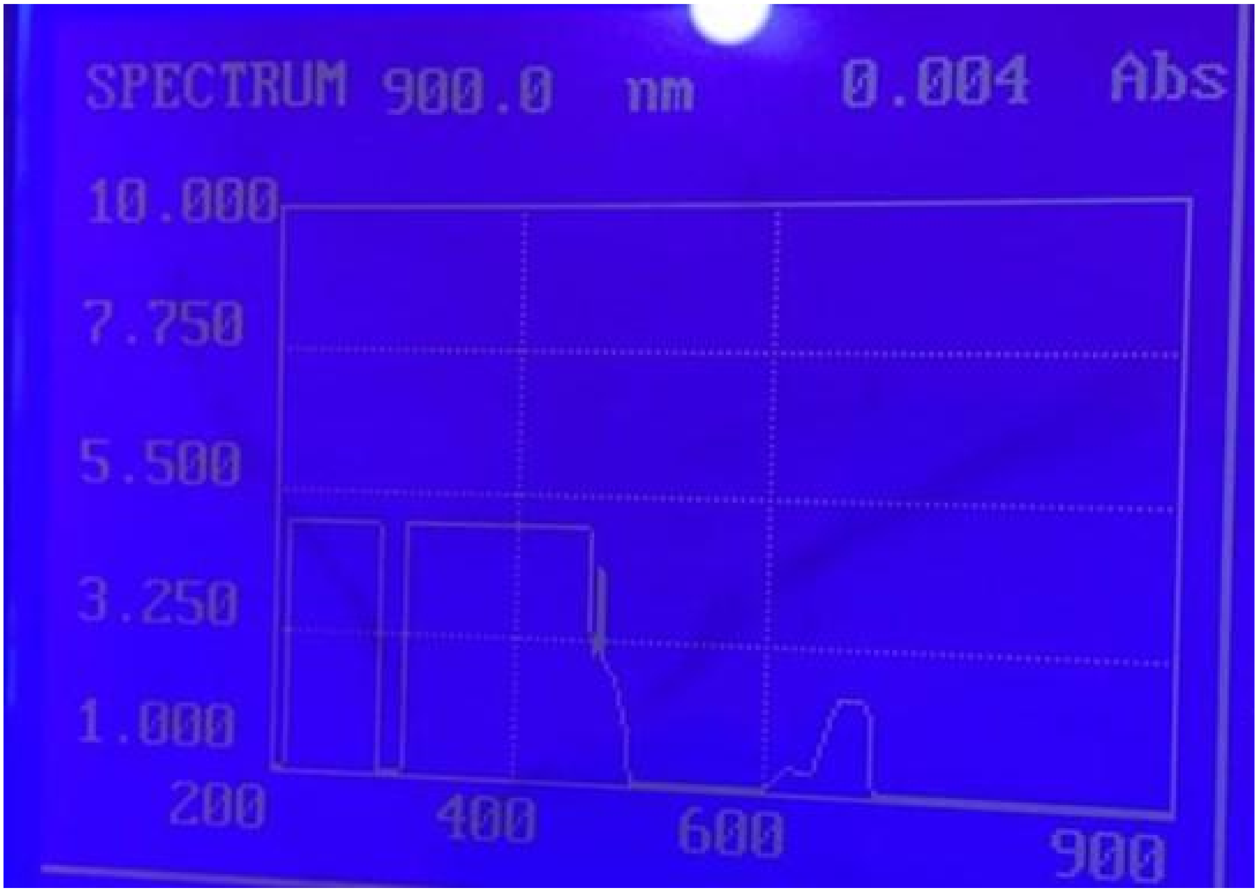


Plate 3.4: Spectral Analysis of Chlorophyll Content in Jute (*Corchorus olitorius*) Leaves Cultivated in 100ppm Lead (Pb)

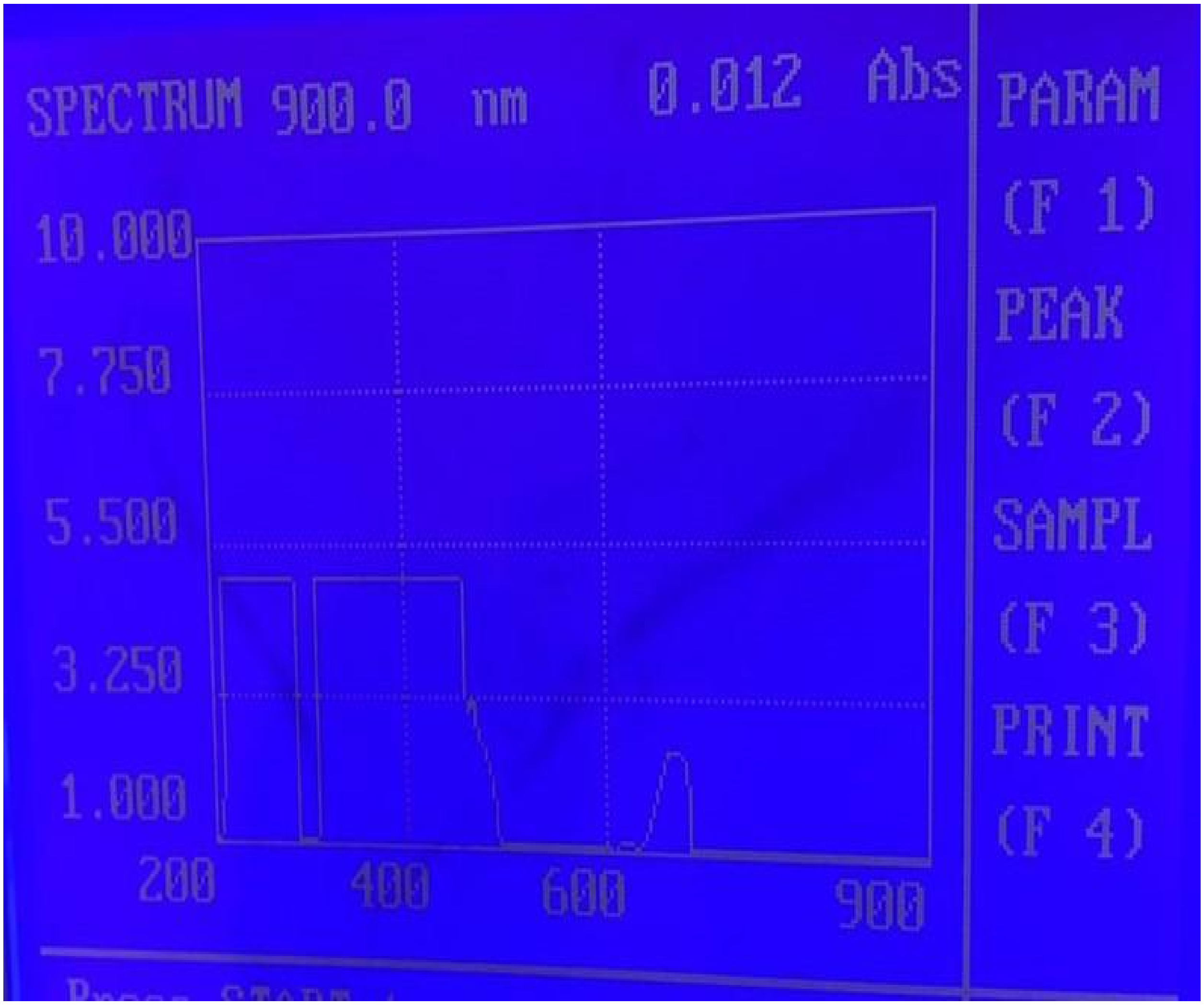


Plate 3.5: Spectral Analysis of Chlorophyll Content in Jute (*Corchorus olitorius*) Leaves Cultivated in 200ppm Lead (Pb)

Plate 3.6 shows the spectral analysis of carotene content in jute (*Corchorus olitorius*) plant cultivated in 0ppm Cadmium (Cd). The experiment shows that the spectral reflectance and absorbance measurement for plant grown in 0ppm lead (Pb) values at a wavelength ranged from 200-400nm.

The spectral analysis of carotene content in jute (*Corchorus olitorius*) plant cultivated in 50ppm Cadmium (Cd) is presented in Plate 3.7. The strongest absorption occurs in the 400–500nm range, which indicating a blue absorption in the blue region.

Plate 3.8 shows the spectral analysis of carotene content in jute (*Corchorus olitorius*) plant cultivated in 100ppm cadmium (cd). The experiment shows that the spectral reflectance and absorbance measurement for plant grown in 100ppm cadmium had a strong absorption at wavelength ranged from 320-580nm.

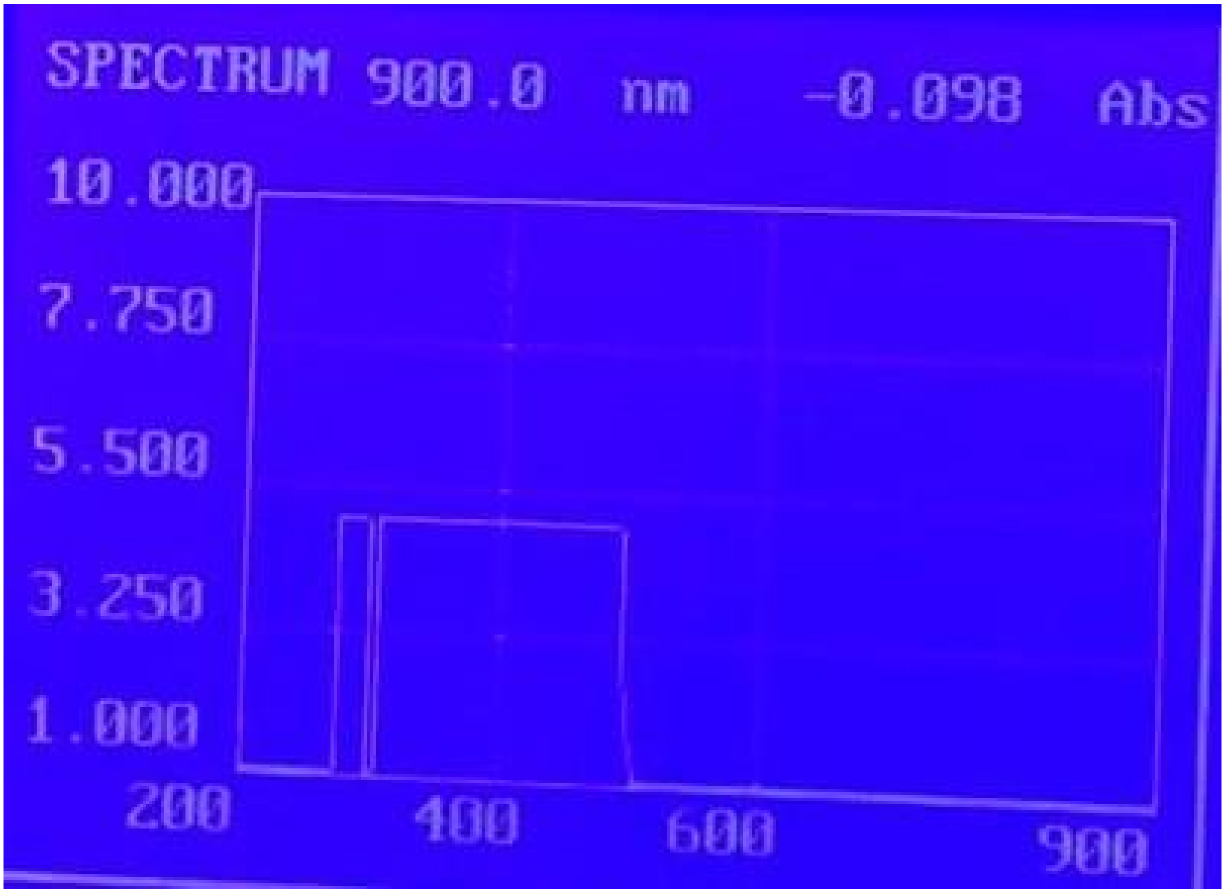


Plate 3.6: Spectral Analysis of Carotene Content in Jute (*Corchorus olitorius*) Leaves Cultivated in 0ppm Cadmium (Cd)

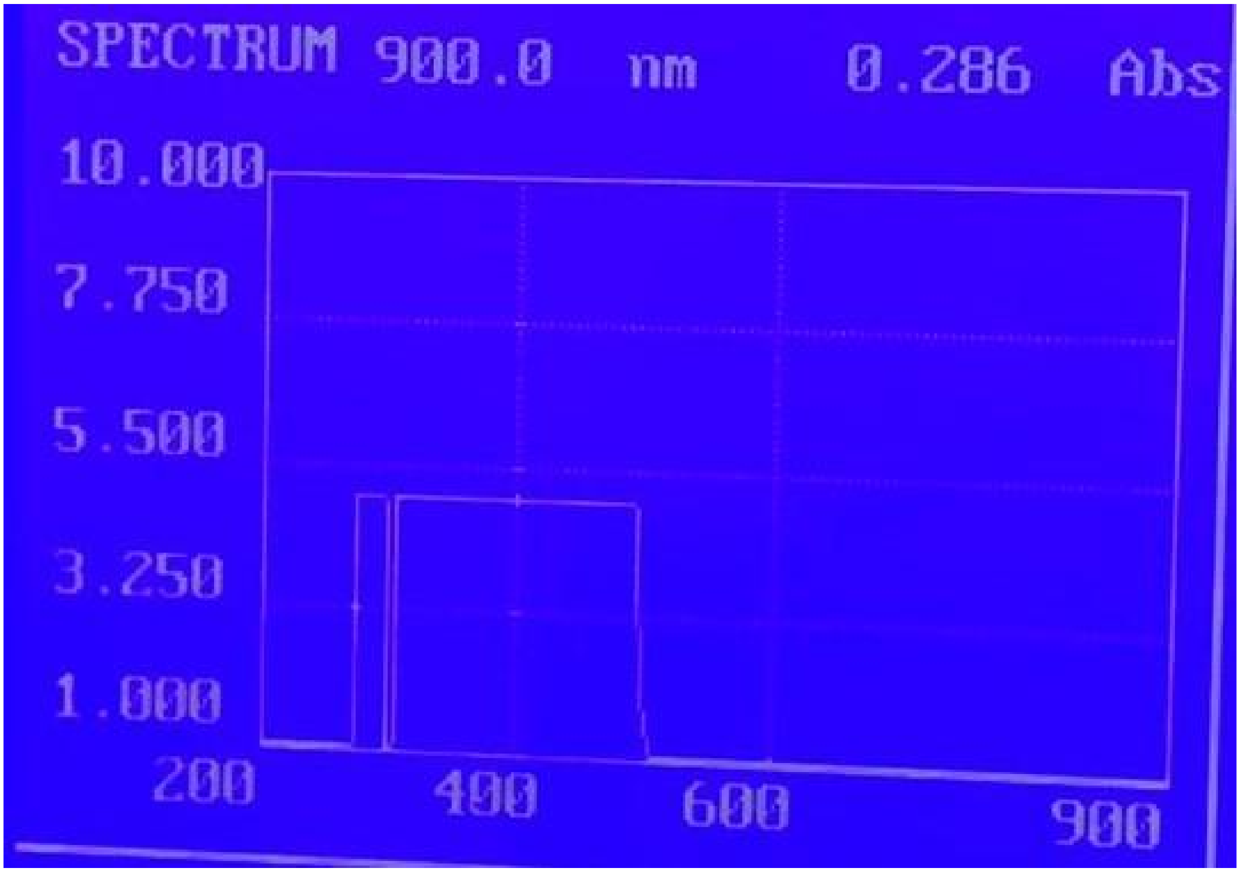


Plate 3.7: Spectral Analysis of Carotene Content in Jute (*Corchorus olitorius*) Leaves Cultivated in 50ppm Cadmium (Cd)

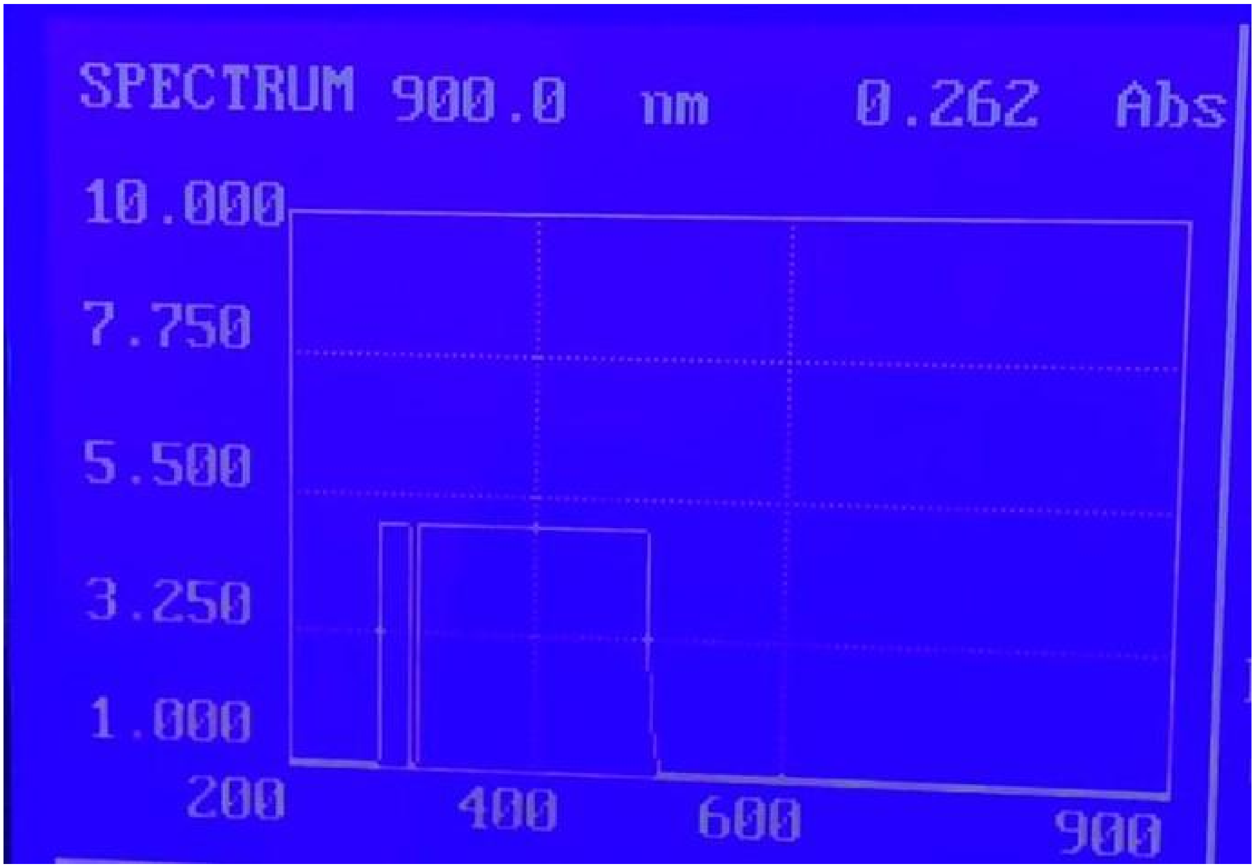


Plate 3.8: Spectral Analysis of Carotene Content in Jute (*Corchorus olitorius*) Leaves Cultivated in 100ppm Cadmium (Cd)

The spectral analysis of carotene content in jute (*Corchorus olitorius*) plant cultivated in 100ppm Lead (Pb) is presented in Plate 3.9. The strongest absorption occurs in the 400–500nm range, which indicating a blue absorption in the blue region.

Plate 3.10 shows the spectral analysis of carotene content in jute (*Corchorus olitorius*) plant cultivated in 200ppm lead (Pb). The experiment shows that the spectral reflectance and absorbance measurement for plant grown in 200ppm lead had a strong absorption at wavelength ranged from 200-580nm.

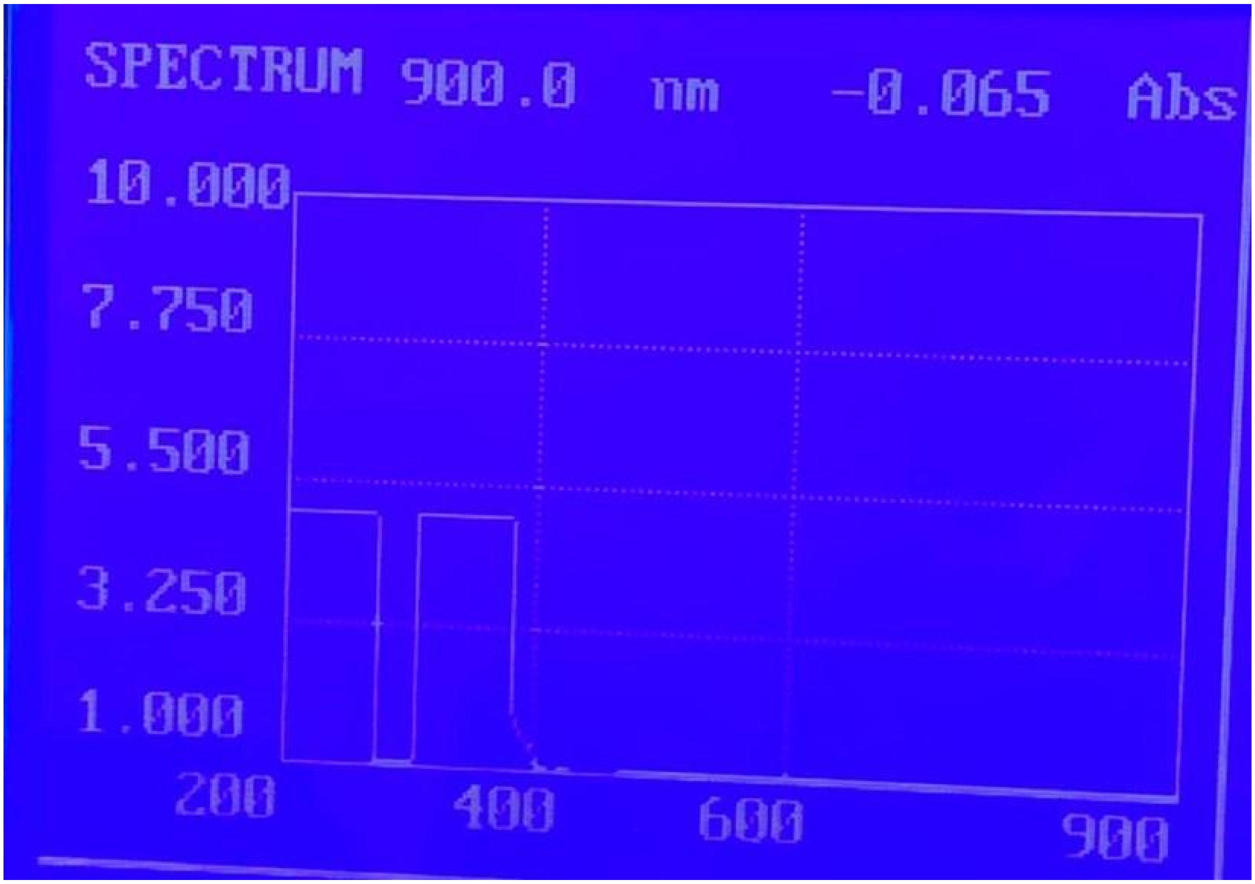


Plate 3.9: Spectral Analysis of Carotene Content in Jute (*Corchorus olitorius*) Leaves Cultivated in 100ppm Lead (Pb)

Plate 3.10: Spectral Analysis of Carotene Content in Jute (*Corchorus olitorius*) Leaves Cultivated in 200ppm Lead (Pb)

Plate 3.11: Root of *Corchorus olitorius* plants grown in cadmium polluted soil showing white patches

CHAPTER FOUR

DISCUSSIONS

This study evaluated the effects of lead nitrate and cadmium chloride on the growth of jute mallow plant (*Corchorus olitorius*). The effects of cadmium and lead on the germination of jute plant showed that moderate concentration of cadmium (50ppm) induced faster germination and higher germination percentage, compared to the control treatments which had a slower germination rate and a low germination percentage of 26.8%. Although, the percentage germination was high with cadmium treated plants, high mortality, yellowing of leaves and stunted growth was observed at the time the treatments were applied to the soil, but these effects reduced after the application of heavy metals stopped. Generally, from this study it was seen that the seedlings sown in heavy metal exposed soil had a higher percentage germination. The findings of this study align with the results of Baryla *et al.* (2022) who reported that lower cadmium concentration enhanced seed germination but as the concentration increases, the observed germination percentage reduces across the treatments. Wahid *et al.* (2007) ascribe this impact to be due to cadmium having an impact on the nutritional content of different plant portions, thus, the percentages of germination that were hindered by low levels of cadmium showed that these levels were well within the range that *Corchorus olitorius* seedlings could tolerate. However, germination percentages in high-level treatments were negatively impacted, indicating that a higher cadmium and lead concentration was not beneficial for seed germination (Mondal *et al.,* 2013). In contrast to the findings of Hosseini *et al.* (2012) who asserted that heavy metals (Pb and Cd) affect the plants resulting to varying percentages of germination and poor seedling growth with low concentration of heavy metals, it has been found in other studies that the effect of toxicity of heavy metals may affect the physiological parameter of plants after surviving through the germination (Mondal *et. al.,* 2013).

Physiological parameters of plant such as stem length, number of leaves and size of stem girth indicates the health status of the plant, indicating if the plant is undergoing stress or not. Findings from this study on the effects of Cd and Pb on the stem height (cm) showed that 200ppm lead significantly enhanced the stem height of the plant followed by the control treatment. The findings of this study is not in tandem with the report of Li *et al.* (2018) who reported that treatment of lead (Pb) on plant inhibits the growth of the plant, reason being that both lead and cadmium have significant negative effects on mitosis, primarily causing a reduction in the mitotic index (rate of cell division) and inducing abnormal cell division with various chromosomal abnormalities like chromosome stickiness, bridges, and micronuclei, essentially disrupting the normal process of cell division by interfering with the spindle apparatus and DNA replication mechanisms; with lead generally exhibiting a more pronounced inhibitory effect compared to cadmium (Liu *et al.* 2014).

Heavy metal in soil has been reported to significantly impact morphological traits such as stem girth. However, findings from the assessment of stem girth in *Corchorus olitorius* (jute mallow) under varying concentrations of lead (Pb) and cadmium (Cd) showed that the heavy metals had varying effects on stem girth, with Pb exhibiting a stimulatory effect at moderate concentrations, while Cd caused a significant reduction in growth. The control group (0 ppm Pb) displayed a gradual increase in stem girth, progressing from 0.78 cm at 5 weeks after planting (WAP) to 1.58 cm at 9 WAP. In contrast, Pb-treated plants exhibited increased stem girth with higher Pb concentrations. Notably, at 200 ppm Pb, the stem girth was significantly larger, measuring 1.63 cm at 5 WAP, 2.08 cm at 7 WAP, and 2.05 cm at 9 WAP, indicating that lead enhances stem girth. The findings of this study align with previous research investigating heavy metal stress in plants. Adebayo *et al.* (2020) observed that lead exposure at moderate levels (50-200 ppm) in *Amaranthus hybridus* initially increased stem girth, likely due to stress adaptation mechanisms such as enhanced lignification. However, prolonged exposure ultimately reduced growth at higher concentrations. Similarly, Singh et al. (2018) reported that cadmium exposure led to a significant decline in the stem girth of *Vigna radiata*, which is consistent with the observed growth suppression in *C. olitorius* under Cd stress. In contrast to the findings of this study Zhang *et al.* (2019) found that Pb exposure in *Brassica napus* resulted to reduced stem girth beyond 100 ppm, contradicting the current study, where Pb promoted stem girth at 200 ppm. However, the tolerance range of species from similar genus differs (Kumar *et al.,* 2021) which may affect how the plant responds to metal toxicity.

Heavy metal contamination, particularly lead (Pb) pollution, poses significant challenges to agricultural productivity and plant health. Lead stress affects physiological and biochemical processes in plants, primarily by interfering with chlorophyll synthesis, disrupting cellular integrity, and reducing photosynthetic efficiency. Spectral imaging is a powerful tool for detecting stress-induced changes in plants by analyzing spectral reflectance and absorbance characteristics across different wavelengths. Chlorophyll content is a crucial indicator of plant health, photosynthetic efficiency, and stress response. Spectral analysis is a non-destructive technique used to assess chlorophyll levels in plants by measuring absorbance at various wavelengths. Findings from this study indicated that the absorbance ranges of plant grown in 0, 50 and 100 ppm Cadmium (Cd) showed a strong absorbance range at 380-550 nm indicating a weak absorption of green light, which is the essential pigmentation for activating light reaction stage of photosynthesis, this may have accounted to the reduced growth observed in the morphological parameters of plant exposed to cadmium. The findings of this study align with the research of Sharma and Dubey, (2005); Gupta *et al.* (2022) who demonstrated that heavy metals, including lead and cadmium, interfere with chlorophyll biosynthesis, leading to reduced absorption in the red and blue spectral regions. A comparative study on *Zea mays* under lead stress showed similar spectral shifts, particularly in the 600–700 nm range, due to decreased chlorophyll content and disrupted electron transport in photosynthesis. Another research by Xie *et al.* (2021) found that lead exposure affects leaf water content and cellular structure, reducing NIR reflectance beyond 800 nm. The spectral valley observed at 855 nm in *Corchorus olitorius* suggests that similar physiological disruptions occurred in the present study. Zeng et al. (2019) reported that cadmium-induced oxidative stress in *Brassica juncea* led to lower NIR reflectance, mirroring the results seen in *Corchorus olitorius*. The spectral imaging results indicate that lead contamination significantly alters the spectral properties of *Corchorus olitorius*. The reduced absorbance in chlorophyll-associated regions (400–700 nm) and the spectral valley at 855 nm suggest that lead stress compromises pigment synthesis and cellular structure.

Lycopene and carotenoid content in *Corchorus olitorius* plants grown in lead (Pb) and cadmium (Cd) treated soils exhibited significant variations depending on the metal concentration. Lycopene content was highest in plants grown in control conditions (0 ppm heavy metals), with a concentration of 1971 mg/kg FW, indicating optimal physiological conditions for pigment synthesis. Pb-treated plants showed a gradual decline in lycopene content with increasing Pb concentrations, with 100 ppm Pb at 1898.915 mg/kg FW and 200 ppm Pb at 1840.415 mg/kg FW. The lowest lycopene concentration was observed in plants grown in 100 ppm Cd, suggesting that Cd had a stronger inhibitory effect on lycopene biosynthesis than Pb. Lycopene is a crucial antioxidant pigment, and its reduction under heavy metal stress suggests potential oxidative stress or interference with the metabolic pathways responsible for carotenoid synthesis. These findings align with previous studies on heavy metal effects on plant pigments. Jahan *et al.* (2019) reported that heavy metal exposure in *Brassica juncea* resulted in a decrease in lycopene content, with Cd having a more pronounced inhibitory effect than Pb, which is consistent with the current study. The reduction in lycopene levels under heavy metal stress could be due to metal interference in enzymatic pathways related to carotenoid biosynthesis, particularly affecting phytoene synthase activity, a key enzyme in lycopene production. Contrary to the decline in lycopene, the increase in carotenoid content aligns with findings from Kumar et al. (2020), who observed that *Solanum lycopersicum* exposed to Pb and Cd exhibited increased carotenoid levels. The study suggested that the accumulation of carotenoids under metal stress serves as a protective mechanism against oxidative stress. Similarly, Singh et al. (2021) found that *Spinacia oleracea* grown in metal-contaminated soil exhibited enhanced carotenoid levels, particularly under Pb stress, supporting the hypothesis that Pb-induced oxidative stress triggers an upregulation of carotenoid synthesis as a defense mechanism.

Carotenoid content in *C. olitorius* followed a different trend. Plants exposed to 0 ppm Cd had a mean carotenoid concentration of 7501.505 mg/kg FW, while those grown in 50 ppm Cd had an increased carotenoid content of 7930 mg/kg FW. This trend continued at 100 ppm Cd, which had 7888.505 mg/kg FW, indicating a possible stress-induced accumulation of carotenoids in response to Cd exposure. Similarly, plants grown in Pb-treated soils exhibited increased carotenoid content, with 100 ppm Pb showing the highest carotenoid concentration at 8041.51 mg/kg FW and 200 ppm Pb slightly lower at 7999.505 mg/kg FW. The elevated carotenoid levels under Pb and Cd stress suggest an adaptive response, as carotenoids play a crucial role in mitigating oxidative damage by scavenging reactive oxygen species (ROS) generated due to heavy metal stress. However, contradictory findings have been reported by Zhao et al. (2018), who found that in *Zea mays*, both Pb and Cd exposure led to a significant reduction in carotenoid levels, suggesting that species-specific responses to heavy metal stress play a role in pigment metabolism. The decrease in carotenoid content in maize under heavy metal stress was attributed to metal-induced damage to plastids, where carotenoids are synthesized. This contradiction highlights the complexity of plant responses to heavy metal exposure, which may depend on species, growth conditions, and the specific detoxification mechanisms employed by different plants.

Conclusion

From the findings of the study the objectives of this research were met in evaluating the effects of cadmium and lead on the growth of Jute (*Corchorus olitorius*) indicating that cadmium enhances the germination rate of jute plant, but didn't have significant impact in promoting stem height, girth and leaves number, but led to stunted growth and yellowed leaves, compared to lead which had impact on the morphological parameter but had slower germination rate compared to the plants grown in cadmium polluted soil. The spectral analysis of jute plants grown in heavy metal-contaminated soil reveals lower chlorophyll absorption, particularly in the red and NIR regions, indicating stress-induced pigment loss. Future studies should incorporate biochemical assays to correlate spectral data with chlorophyll degradation pathways, enhancing the accuracy of pollution stress monitoring in plants.

REFERENCES

Abdel-Razek, M. A., Abdelwahab, M. F., Abdelmohsen, U. R. and Hamed. A. N. (2022). Pharmacological and phytochemical biodiversity of *Corchorus olitorius*. *Research Advances,* **12**(54): 35103–35114.

Abdollahi, A. Farsad-Akhtar, N., Kazemi, E. M. and Kolahi, M. (2023). Investigation of the combined effects of cadmium chloride, silver nitrate, lead nitrate, methyl jasmonate, and salicylic acid on morphometric and biochemical characteristics of St. John's wort. *Physiology and Molecular Biology of Plants*, **29**(2):173–184. https://doi.org/10.1007/s12298-023-01281-0

Adebayo, S. A. (2020). Heavy Metal Stress and Growth Responses in *Amaranthus hybridus*: Implications for Phytoremediation." *Environmental Toxicology and Chemistry*, 39(2): 178-190.

Aderolu, I. A., Omoloye, A. A. and Okelana, F. A. (2013).Occurrence, abundance and control of the major insect pests associated with Amaranths in Ibadan, Nigeria. *Entomology Ornithology and Herpetology,* **2:** 123-137.

Aghaei, K., Rahkhosravani, B., Moghanlu, L. and Ghotbi, R. A. (2019) Study of the effect of cadmium accumulation on some physiological and biochemical characteristics of basil plants (*Ocimum basilicum* L.). *Journal of Plant Process Function,* **8**(33):107–122

Anonymous (2011). Turkish-Cypriot Cuisine. [Available: Online] http://www.cypnet.co.uk/ncyprus/culture/cuisine/veg/molohiya.html [Accessed: 10 January, 2025].

AVRDC. (2009). Jute mallow. Discovering Indigenous Treasures: Promising Indigenous Vegetables from Around the World. World Vegetable Center. Taiwan. [Available online at: https://avrdc.org/jute-mallow-corchorus-olitorius] [Accessed 12 January 2025].

Baliardini, C., Meyer, C. L., Salis, P., Saumitou-Laprade, P. and Verbruggen, N. (2015). Cation EXCHANGER1 cosegregates with cadmium tolerance in the metal hyperaccumulator Arabidopsis halleri and plays a role in limiting oxidative stress in *Arabidopsis* spp. *Plant Physiology*, 169: 549–559.

Baryla, A., Carrier, P., Franck, F., Coulomb, C., Sahut, C. and Havaux, M. (2001). Leaf chlorosis in oilseed rape plants (*Brassica napus*) grown on cadmium- polluted soil: causes and consequences for photosynthesis and growth, *Planta,* 212: 696–709.

Bas, H., Apaydin, F.G., Kalender, S. and Kalender, Y. (2021). Lead nitrate and cadmium chloride induced hepatotoxicity and nephrotoxicity: Protective effects of sesamol on biochemical indices and pathological changes. *Journal of Food Chemistry*, 4**:** 1-13.

Bautista, O. V. Fischer, G. and Cárdenas, J. F. (2013). Cadmium and chromium effects on seed germination and root elongation in lettuce. Spinach and Swiss chard. *Agronomía Colombiana*, **31**(1): 48-57.

Baweja, P., Kumar, D., Maheshwari,V., Singla, M., Parul, R., Jariyal, N. and Akshita. (2020). Effect of Cadmium stress on Growth and Development of *Cicer arietinum* (Fabaceae). *Environmental international Journal of Science and Technology*, 15: 49-59.

Benelli, A., Cevoli, C. and Fabbri, A. (2020). In-field hyperspectral imaging: An overview on the ground-based applications in agriculture, *Journal of Agricultural Engineering,* 1-13.

Biswas, A., Dey, S., Xiao, A., Huang, S., Birhanie, Z. M., Deng, Y., Liu, L. and Li. D. (2023). Phytochemical content and antioxidant activity of different anatomical parts of *Corchorus olitorius* and *C. capsularis* during different phenological stages. *Heliyon*, **9**(6): 1-13. https://doaj.org/article/1dfdfb60c76642239d23e747235774b5

Borges, K. L. R., Salvato, F., Alcântara, B. K., Nalin, R. S., Piotto, F. Â. And Azevedo, R.A. Temporal dynamic responses of roots in contrasting tomato genotypes to cadmium tolerance. *Ecotoxicology,* 27: 245–258.

Chris, T. (2011). Cultivating research in a war-ravaged city. *International Development Research Centre,* **12:** 23-43.

Danjuma, S., Yusuf, S. and Musa, M. M. (2022). Evaluation of plant materials for the control of leafworm (*Acraea terpsicore* l.) on jute mallow (*Corchorus olitorius* l.) in lapai southern guinea savannah of Nigeria

Daud, M. K., Mei, L., Azizullah, A., Dawood, M. Ali, I., Mahmood, Q., *et al.* (2016). Leaf-Based Physiological, Metabolic, and Ultrastructural Changes in Cultivated Cotton Cultivars under Cadmium Stress Mediated by Glutathione. *Environmental Science Pollution Research,* 23: 15551–15564

Daud, M., Ali, S., Variath, M. and Zhu, S. (2013). Differential physiological, ultramorphological and metabolic responses of cotton cultivars under cadmium stress. *Chemosphere*, **93**: 2593–2602.

Dinakar, N., Nagajyothi, P. C., Suresh, S., Damodharam, T. and Suresh, C. (2009). Cadmium induced changes on proline, antioxidant enzymes, nitrate and nitrite reductases in *Arachis hypogaea* L. *Journal of Environmental Biology,* **30**(2):289–294

Fatemi, H., Esmaielpour, B., Soltani-Toolarood, A. and Nematolah, Zadeh. A. (2017) Effects of silicon nano-particle nutrition on growth and physiological characteristics of *Coriandrum sativum* L. under lead stress. *Iranian Journal of Medicinal Aromatic Plants Research,* **33**(5):853–870

Food and Agriculture Organization (FAO) (1997). *Quarterly Bulletin of Statistics*; Food and Agriculture of United Nations: Rome, Italy, 65p.

Food and Agriculture Organization of the United Nations, (FAO). (2024). Future Fibers. [Available Online at: https://www.fao.org/economic/futurefibres/fibres/jute/en/] [Accessed 13 January 2025]

Gomes, M., Marques, T. and Soares, A. (2013). Cadmium effects on mineral nutrition of the Cd hyperaccumulator Pfaffia glomerata. *Biologia*, 68: 223–230.

Gupta, D. K. (2022). Spectral Analysis of *Zea mays* Under Lead Exposure."*Plant Physiology and Biochemistry*, **172**: 25-34.

He, S., He, Z., Yang, X., Stoffella, P. J. and Baligar, V. C. (2015). Soil biogeochemistry, plant physiology, and phytoremediation of cadmium-contaminated soils. In: *Advances in Agronomy*, 135–225.

Hédiji, H., Djebali, W., Belkadhi, A., Cabasson, C., Moing, A., Rolin, D., Brouquisse, R., Gallusci, P. and Chaïbi, W. (2015). Impact of long-term cadmium exposure on mineral content of *Solanum lycopersicum* plants: Consequences on fruit production. *South African Journal of Botany,* **97**: 176–181.

Hosseini, Z. Nadian, H. and Heidari, M. (2012) Effect of cadmium levels on seed germination and seedling growth of Spinach (Spinaciaoleracea) under salinity stress. *World Applied Sciences Journal,* **18**(3): 332-335.

Huang, R., Dong, M., Mao, P., Zhuang, P., Paz-Ferreiro, J. and Hu, X. (2020). Evaluation of phytoremediation potential of five Cd (hyper) accumulators in two Cd contaminated soils. *Science Total Environment,* **721**: 137-148.

Islam, M. 2013. Biochemistry, medicinal and food values of Jute (*Corchorus capsularis* L. and *C. olitorius* L.) leaf: a review. *International Journal of Enhanced Research in Science Technology and Engineering*, **2**(11): 35-44.

Kabata-Pendias, A. (2010). *Trace Elements in Soils and Plants;* CRC Press: Boca Raton, FL, USA, Pp. 123-125.

Khan, S., Munir, S., Sajjad, M. and Li, G. (2016). Urban park soil contamination by potentially harmful elements and human health risk in Peshawar City, Khyber Pakhtunkhwa. *Pakistan Journal of Geochemical Exploration*, 165: 102–110.

Knipling, E. B. (1970). Physical and physiological basis for the reflectance of visible and near-infrared radiation from vegetation. *Remote Sensing of Environment*, **1**: 155–159.

Kong, W., Liu, F., Zhang, C., Zhang, J. and Feng, H. (2016). Non-destructive determination of Malondialdehyde (MDA) distribution in oilseed rape leaves by laboratory scale NIR hyperspectral imaging. *PubMed Central*, **2**: 1-24.

Kumar, P. (2020). Adaptive Responses of Jute Plants to Heavy Metal Stress: Chlorophyll Retention and Spectral Characteristics. *Plant Physiology Reports*, **35**(1): 110-125.

Kumar, P. (2021). Comparative Study of Lead and Cadmium Stress in Oryza sativa: Morphological and Biochemical Impacts. *Plant Physiology Reports*, **36**(1): 99-115.

Li D., F. Ahmed, N. Wu, and A.I. Sethi. 2022. YOLO-JD: A Deep Learning Network for Jute Diseases and Pests Detection from Images. *Plants* 11(7): 937.

Li, L., Chen, J., He, Q., Khan, M. D. and Zhu, S. (2012). Characterization of physiological traits, yield and fiber quality in three upland cotton cultivars grown under cadmium stress. *Australian International Journal of Crop Science,* **6:** 1527–1533.

Liu, D., Jiang, W., Wang, W., Zhao, F. and Lu, C. (2014). Effects of lead on root growth, cell division, and nucleolus of *Allium cepa, Environmental Pollution,* **86**(1): 1-4.

Liu, W. (2020). Effects of Heavy Metal Stress on Chlorophyll Content and Spectral Response in Plants. *Environmental Science and Pollution Research*, **27**(5): 5123-5135.

Liu, Y.; Xiao, T.; Ning, Z.; Li, H.; Tang, J.; Zhou, G. High cadmium concentration in soil in the Three Gorges region: Geogenic source and potential bioavailability. Appl. Geochem. 2013, 37, 149–156.

Mahdavian, K., Ghaderian, M. and Tourk, Z. M. (2016) The effect of different concentrations of lead on some physiological parameters in two populations of *Harmal Peganum* harmala. *Journal of Cell Tissue,* **4**(6):543–555

Mahlein, A. K. (2016). Plant disease detection by imaging sensors – Parallels and specific demands for precision agriculture and plant phenotyping. *Plant Disease*, 100(2): 241–251.

Maity, S., Chowdhury, S. and Animesh, D. (2012). Jute Biology, Diversity, Cultivation, Pest Control, Fiber Production and Genetics. In: *Organic Fertilisation, Soil Quality and Human Health*. 10.1007/978-94-007-4113-3_9.

Martínez-Ballesta, M. C., Egea-Gilabert, C., Conesa, E., Ochoa, J., Vicente, M. J. *et al*. (2020). The importance of ion homeostasis and nutrient status in seed development and germination. *Agronomy,* **10**: 504.

Martyna, D., Paweł, O., Macie,j N. and Marlena, L. (2019). Hyperspectral imaging in assessing the condition of plants: strengths and weaknesses. *Biodiversity Reserves and Conservation,* 55: 25-30.

Mohamed, A. A., Castagna, A., Ranieri, A. and di Toppi, L. S. (2012). Cadmium tolerance in *Brassica juncea* roots and shoots is affected by antioxidant status and phytochelatin biosynthesis. *Plant Physiology Biochemistry*, 57:15–22.

Mokhtari, M. H., Sodaeezadeh, H. R., Hakimzadeh, M. A. and Tarighat. F. (2014). Application of visible and near-infrared spectrophotometry for detecting salinity effects on wheat leaves (*Triticum asativum* L.). *Agric Eng Int: CIGR Journal*, **16**(4): 35-42.

Mondal N. K. (2013). Effect of varying cadmium stress on chickpea (*Cicer arietinum* l) seedlings: an ultra-structural study, *Annals of Environmental Science*, **7**: 59-70.

Muradoglu, F., Gundogdu, M., Ercisli, S., Encu, T., Balta, F., Jaafar, H.Z.E. and Zia-Ul-Haq, M. (2015). Cadmium toxicity affects chlorophyll a and b content, antioxidant enzyme activities and mineral nutrient accumulation in strawberry. *Biological Research,* 48: 11.

Mustapha, A. H. (2024). Health benefits of Ayoyo. [Available online] [Accessed from https://web.archive.org/web/20211022222148/http://miczd.gov.gh/news/99] [Accessed: 10 January 2025]

National Food Security Mission (NFSM) (2017). Jute: Brief note. National Food Security Mission. [Available Online at: https://nfsm.gov.in/BriefNote/BN_Jute.pdf] [Accessed 11 January 2025]

Navarro-León, E., Oviedo-Silva, J., Ruiz, J. M. and Blasco, B. (2019). Possible role of HMA4a TILLING mutants of *Brassica rapa* in cadmium phytoremediation programs. *Ecotoxicology and Environmental Safe*, 180: 88–94.

Nazar, R., Iqbal, N., Mashood, A., Khan, M.I.R. Syeed, S. and Khan, N. A. (2012). Cadmium toxicity in plants and role of mineral nutrients in its alleviation. *American Journal of Plant Science*, **3**: 1476–1489.

Nigel, S. (1980). *Pest and Disease Control Handbook*; Lovenham-Press Limited: Lavenhannem, UK, 1980; pp. 163–172.

Oyedele, D. J., Aina, P. O. and Osonubi, O. (2006). Effect of lead contamination on growth and nutrient uptake of *jute mallow* (*Corchorus olitorius*). *Science of the Total Environment*, **367**(2–3):100–107.

Padash, A., Ghanbari, A. and Asgharipour, M. (2016) Efect of salicylic acid on concentration of nutrients, protein and antioxidant enzymes of basil under lead stress. *Iranian Journal of Plant Biology,* **8**(27):17–32

Pallvi, G. (2017). Jute: Origin, Distribution and Production. Agriculture in India. [Available Online at: https://www.agricultureinindia.net/agronomy/jute/jute-origin-distribution-and-production-essayagronomy/12517]

Pan, L. B., Ma, J. Wang, X. L. and Hou, H. (2016). Heavy metals in soils from a typical county in Shanxi Province, China: Levels, sources and spatial distribution. *Chemosphere*, **148**: 248–254.

Piršelová, B. and Ondrušková, E. (2021). Effect of Cadmium Chloride and Cadmium Nitrate on Growth and Mineral Nutrient Content in the Root of Fava Bean (*Vicia faba* L.). Plants [Available Online at: https://doi.org/ 10.3390/plants10051007] [Accessed February 2025]

Qin, S., Liu, H., Nie, Z., Rengel, Z., Gao, W., Li, C.H. and Zhao, P. (2020). Toxicity of cadmium and its competition with mineral nutrients for uptake by plants: A review. *Pedosphere* **30**: 168–180.

Ranjbar, M., Yazdi, L. and Boroumandi, H. S. (2011) The effect of salicylic acid on photosynthetic pigments, contents of sugar and antioxidant enzymes under lead stress in *Brassica napus* L. *Iran J Plant Biol,* **3**(9):39–52

Rayhana, R. Zhenyu, M., Liu, Z., Xiao, G., Ruan, Y. and Sangha, J. (2023). A Review on Plant Disease Detection Using Hyperspectral Imaging. *IEEE Transactions on AgriFood Electronics*. 10.1109/TAFE.2023.3329849.

Rizzardo, C., Tomasi, N., Monte, R., Varanini, Z., Nocito, F. F., Cesco, S. and Pinton, R. (2012). Cadmium inhibits the induction of high-affinity nitrate uptake in maize (*Zea mays* L.) roots. *Planta,* **236**: 1701–1712.

Ruffing, A. M., Anthony, S. M., Strickland, L. M., Lubkin, I. and Dietz, C. R. (2021). Identification of metal stresses in *Arabidopsis thaliana* using hyperspectral reflectance imaging. *Front. Plant Science,* **12:** 1-12.

Sarijeva G., Knapp M. and Lichtenthaler H. K. (2007). Differences in photosynthetic activity, chl carotenoid levels, and in chlorophyll fluorescence parameters in green sun and shade leaves of Ginkgo and Fagus. *J. Plant Physiol*. **164** (7): 950-955.

Shanying, H., Xiaoe, Y., Zhenli, H. and Baligar, V. C. (2017). Morphological and physiological responses of plants to cadmium toxicity: A review. *Pedosphere*, 27: 421–438.

Sharma, P. and Dubey, R. S. (2005). Lead Toxicity in Plants: Biochemical and Molecular Aspects. *Brazilian Journal of Plant Physiology*, **17**(1): 35-52.

Singh, R. (2018). "Cadmium-Induced Growth Reduction in Vigna radiata: Physiological and Biochemical Mechanisms. *Journal of Plant Physiology*, **224:** 80-90.

Singh, R. (2019). Impact of Heavy Metal Contamination on Chlorophyll Content in Jute Plants: A Spectroscopic Analysis. *Environmental Pollution Research*, **45**(3): 233-245.

Singh, S., Parihar, P., Singh, R., Singh, V. P. and Prasad, S. M. (2015). Heavy metal tolerance in plants: Role of transcriptomics, proteomics, metabolomics, and ionomics. *Front. Plant Sci.* **6:** 1143.

Souza, A. Rojas, M. Z., Yang, Y., Lee, L. and Hoagland, L. (2022). Classifying cadmium contaminated leafy vegetables using hyperspectral imaging and machine learning, *Heliyon,* **8**: 1-9.

Tang, L., Hamid, Y., Zehrab, A., Sahito, Z. A., He, Z., Hussaina, B., Gurajala, H. K. and Yang, X. (2019). Characterization of fava bean (*Vicia faba* L.) genotypes for phytoremediation of cadmium and lead co-contaminated soils coupled with agro-production. *Exotoxicology Environment Saf*, **171**: 190–198.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K. and Sutton, D. J. (2012). Heavy metal toxicity and the environment. *Molecular, Clinical and Environmental Toxicology*, 133, 133–164.

UN-EUE (United Nations-Emergency Unit for Ethiopia). 2001. Famine Food Field Guide. Addis Ababa, Ethiopia. [Available Online at: https://www.africa.upenn.edu/faminefood/category1/cat1_Oloqiloqota_ok.html] [Accessed January 2025]

Vijayaragavan, M., Prabhakar, C., Suresh, K. J., Natarajan, A. Vijayarengan, P. and Sharavanan S. (2011). Toxic effect of cadmium on seed germination growth and biochemical content of cowpea (*Vignaunguiculata* L.). Plants. *International Multidisciplinary Research Journal*, **1**(5): 1-6.

Wagner, G. J. (1993). Accumulation of cadmium in crop plants and its consequences to human health. *Advances in Agronomy*, **51**: 173-212.

Wahid, A., Ghani, A., Ali, I. and Ashraf, M.Y. (2007). Effects of cadmium on carbon and nitrogen assimilation in shoots of mungbean [*Vignaradiata* (L.) Wilczek] seedlings, *Journal of Agronomy and Crop Science*, 193:357–365.

Wan, L., Li, H., Li, C., Wang, A., Yang, Y. and Wang, P (2020). Hyperspectral Sensing of Plant Diseases: Principle and Methods. *Agronomy,* **12** (1451): 1-19.

Wang, W. W., Bai, X.Y., Dong, Y. J., Chen, W. F., Song, Y. L. and Tian, X.Y. (2016). Effects of application of exogenous NO on the physiological characteristics of perennial ryegrass grown in Cd-contaminated soil. *Journal of Plant Science and Nyutrients*,**16**: 731.

Whitlock, B. A. Karol, K. G. and W. S. Alverson. 2003. Chloroplast DNA Sequences Confirm the Placement of the Enigmatic *Oceanopapaver* within *Corchorus* (Grewioideae: Malvaceae s.l., Formerly Tiliaceae). *International Journal of Plant Sciences,* **164**: 35–41

Xie, T. (2021). Hyperspectral Imaging for Monitoring Heavy Metal Stress in Plants. *Remote Sensing of Environment*, **259**: 112-123.

Xing, H., Feng, H., Fu, J., Xu, X. and Yang, G. (2017). Development and Application of Hyperspectral Remote Sensing; Springer: Berlin, Germany, **546**: 271–282.

Yi, X., Wen, X., Lan, A., Dai, Q.,Yan, Y., Zhang, Y. and Yao, Y. (2023). Monitoring Cadmium Content in the Leaves of Field Pepper and Eggplant in a Karst Area Using Hyperspectral Remote Sensing Data. *Sustainability*, **15**: 3508.

Yu, K., Van Geel, M., Ceulemans, T., Geerts, W., Marcos Ramos, M., Sousa, N., M. L. Castro, P., and Somers, B. (2018). Vegetation reflectance spectroscopy for biomonitoring of heavy metal pollution in urban soils.

Zea, M., Souza, A., Yang, Y., Lee, L., Nemali, K. and Hoagland, L. (2022). Leveraging highthroughput hyperspectral imaging technology to detect cadmium stress in two leafy green crops and accelerate soil remediation efforts. *Environmental Pollution,* **292**: 13-26.

Zeng, F. (2019). Cadmium-Induced Spectral Changes in *Brassica juncea*: A Hyperspectral Analysis Approach. *Ecotoxicology and Environmental Safety*, **174**: 40-48.

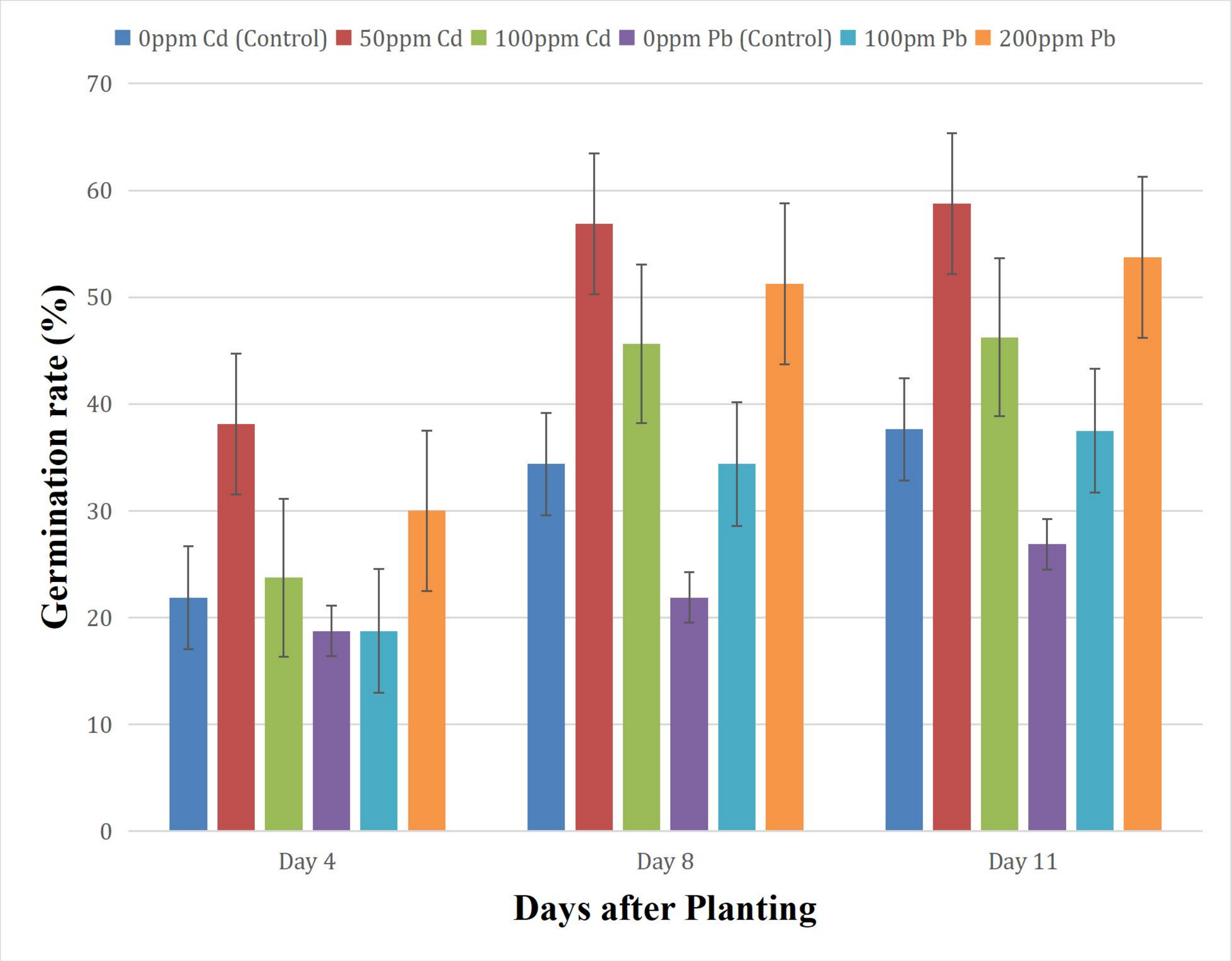
Zhang, W., Kato, E., Bianchi, F., Bhandary, P., Gort, G. and van der Werf, W. (2018). Farmers' perceptions of crop pest severity in Nigeria are associated with landscape, agronomic and socio-economic factors. *Agricultural and Ecosystem Environment*, **259**: 159–167.

Zhang, Y. (2019). Lead Toxicity and Growth Responses in Brassica napus: An Anatomical and Physiological Analysis. *Environmental Science and Pollution Research*, **26**(5): 4123-4132.

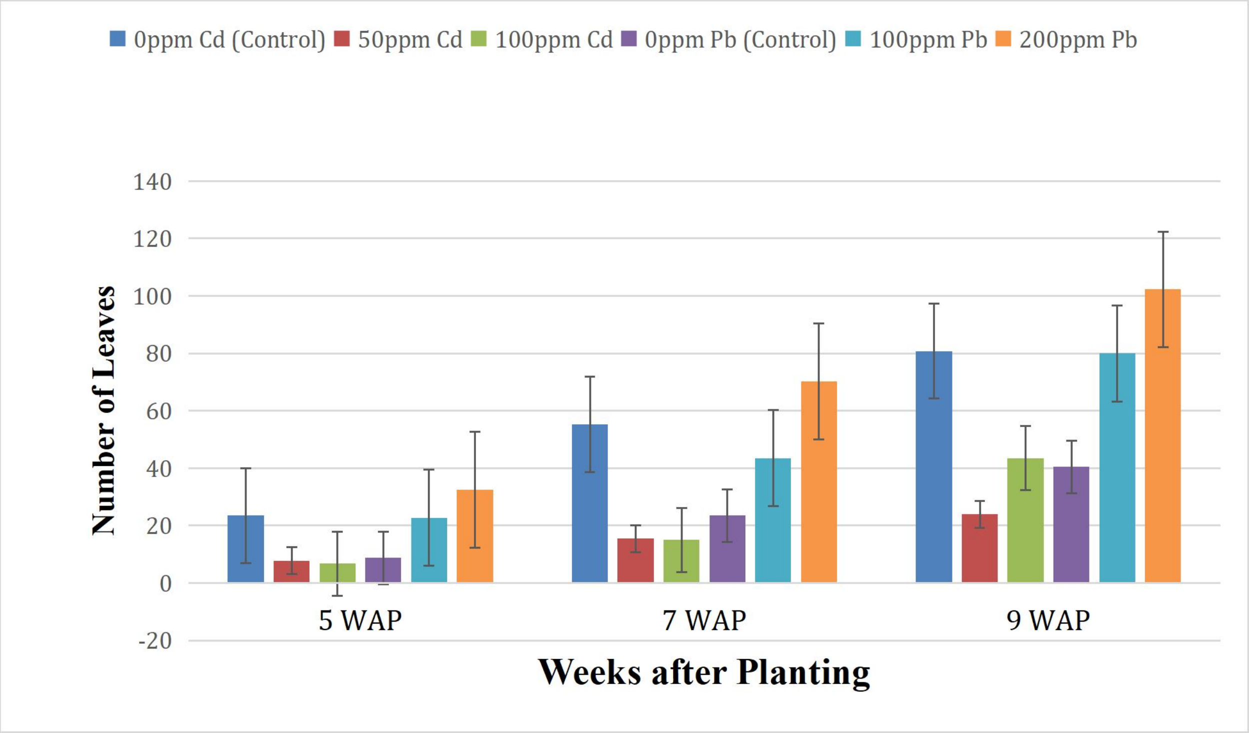
Zhang, Y. (2021). Lead and Arsenic Toxicity in Crops: Effects on Photosynthesis and Spectral Absorption. *Journal of Agricultural Science*, **78**(2): 190-204.

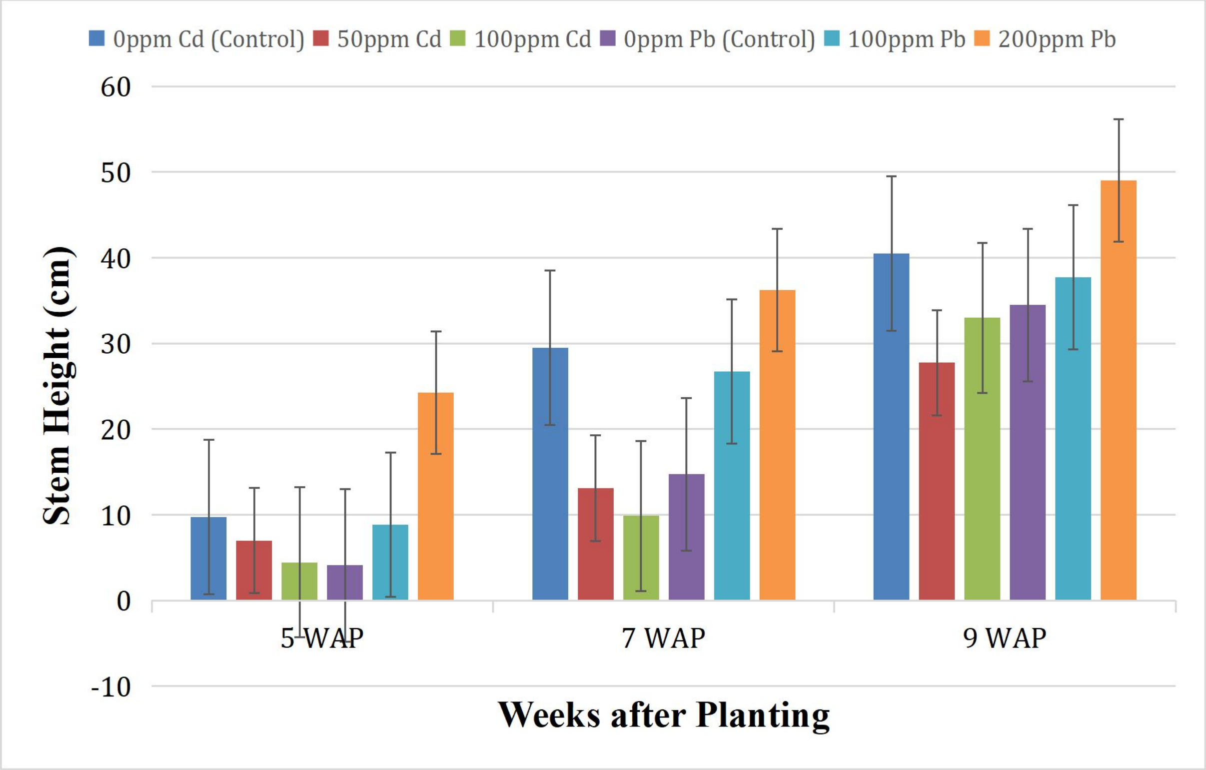
Zhao, F. J., Ma, Y., Zhu, Y. G., Tang, Z. and McGrath, S. P. (2012). Soil contamination in China: Current status and mitigation strategies. *Environmental Science and Technology*, **46**(4): 120–135.

Appendices



0ppm Cd (Control)
50ppm Cd
100ppm Cd
0ppm Pb (Control)
100pm Pb
200ppm Pb
70
60
50
40
30
20
10
0
Germination rate (%)
Day 4
Day 8
Day 11
Days after Planting


0ppm Cd (Control)
50ppm Cd
100ppm Cd
0ppm Pb (Control)
100ppm Pb
200ppm Pb
Number of Leaves
140
120
100
80
60
40
20
0
-20
5 WAP
7 WAP
9 WAP
Weeks after Planting


0ppm Cd (Control)
50ppm Cd
100ppm Cd
0ppm Pb (Control)
100ppm Pb
200ppm Pb
Stem Height (cm)
60
50
40
30
20
10
0
-10
5 WAP
7 WAP
9 WAP
Weeks after Planting

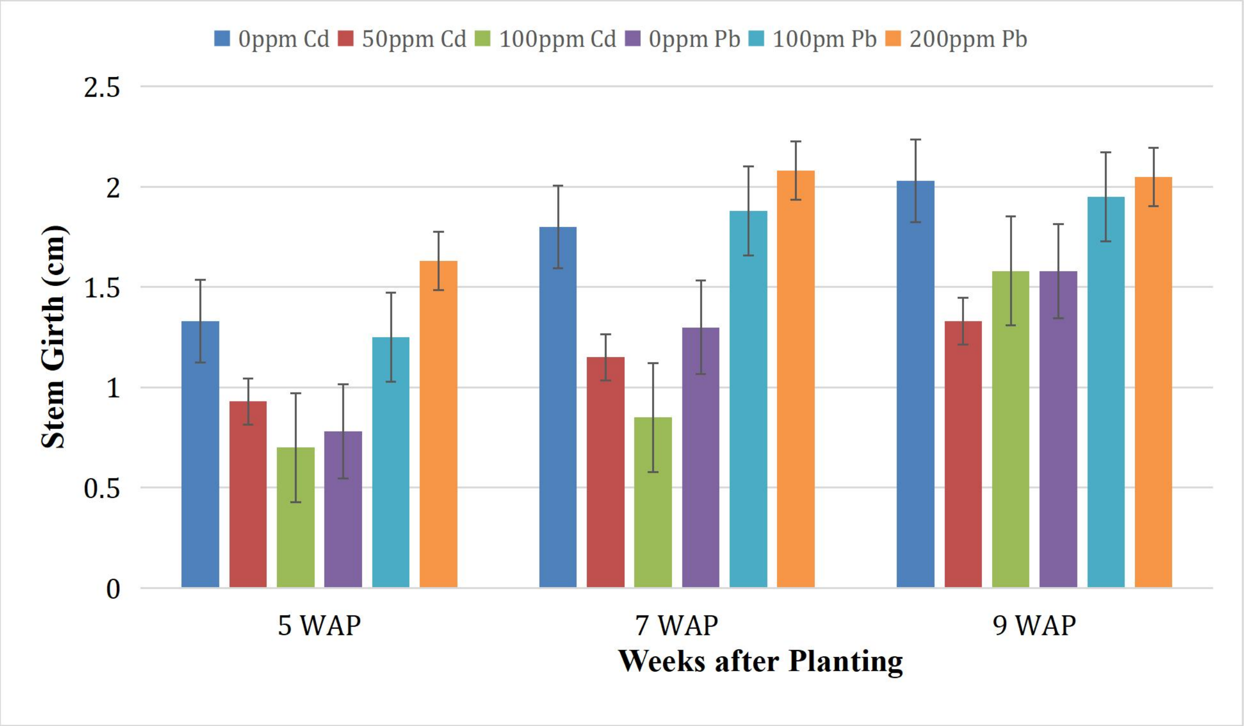

0ppm Cd
50ppm Cd
100ppm Cd
0ppm Pb
100pm Pb
200ppm Pb
2.5
2
1.5
1
0.5
0
Stem Girth (cm)
5 WAP
7 WAP
9 WAP
Weeks after Planting

Table 5: Total chlorophyll content of *Corchorus olitorius* plants, grown in Pb and Cd treated soils

Soil Treatments	**Chlorophyll Concentration**
0ppm Cd (Control)	2.815±0.03
50ppm Cd	2.825±0.03
100ppm Cd	2.725±0.12
100ppm Pb	2.875±0.01
200ppm Pb	2.825±0.03

Values are Mean ± Standard error of four replicates of each treatment

Table 6: Lycopene content of *Corchorus olitorius* plants, grown in Pb and Cd treated soils

Soil Treatments	**Lycopene Concentration**
0ppm Cd (Control)	1971.455±346.15
50ppm Cd	1413.365±160.13
100ppm Cd	1535.045±201.66
100ppm Pb	1898.915±165.96
200ppm Pb	1840.415±224.60

Values are Mean ± Standard error of four replicates of each treatment

Table : Carotenoid content of *Corchorus olitorius* plants, grown in Pb and Cd treated soils

Soil Treatments	**Carotenoid Concentration**
0ppm Cd (Control)	7501.505±464.15
50ppm Cd	7930.505±45.39
100ppm Cd	7888.505±154.09
100ppm Pb	8041.505±9.91
200ppm Pb	7999.505±36.28

Values are Mean ± Standard error of four replicates of each treatment

;.