This small piece of work is dedicated to the beloved memory of
my former supervisor

Late Dr. Palash Mandal

and
my father

Late Taurit Husain

Sir you were more than a mentor to me – you were a guiding light, a source of inspiration, and a true friend, philosopher and guide. Your sudden departure left a void that words can hardly express. I am reminded of the countless hours we spent discussing ideas, overcoming challenges, and celebrating small victories. You possessed a rare combination of wisdom, kindness, and unwavering support. You taught me to experiment with courage, analyze challenges with resilience, and draw conclusions with wisdom. Though you may not be physically present, your spirit resonates in the corridors of academia, reminding me to strive for excellence. Sir you will always be remembered not only for your scholarly achievements but for the indelible mark you left on the hearts and minds of those fortunate enough to know you. Your legacy lives on in the pages of my thesis, and I am forever grateful for the privilege of having had you as my mentor, my guide, and my friend.

……Solmon (*the pronunciation you used to call me****)***

Abba, you were always there for me, no matter what bad choices I might have made. You lovingly repaired my broken spirit, helped me find a new horizon, and set me free to fly on my own once again. Although you are not present with me physically, I still feel your impact in every moment because it is not the flesh or the blood but the heart that makes us father and son. I know your guiding hand on my shoulder will remain with me forever. You are the person who inspired me, but you will not read this, and as you look down from heaven, I hope you're proud of your boy. I miss you, Abba…

.....Your Son

DECLARATION

I, ***Mr. Md Salman Haydar****, hereby declare that the research work presented in my thesis, entitled* **"APPLICATION OF ESSENTIAL CATIONIC MICRONUTRIENTS AS NANO-FERTILIZER ON VEGETATIVE PROPAGATION AND GROWTH OF MULBERRY,"** *has been carried out by me under the supervision of* ***Dr. Swarnendu Roy****, Assistant Professor, Department of Botany, University of North Bengal, for the award of the* ***Doctor of Philosophy (Ph.D.) in Science (Botany)****. I also declare that this thesis or any part of this thesis has not been submitted for any other degree/diploma either to this or other Universities.*

Md Salman Haydar

Date: 03/04/2024 **[Md Salman Haydar]**

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समानो मन्त्रः समितिः समानी

CERTIFICATE OF SUPERVISOR

TO WHOM IT MAY CONCERN

It is certified that the work presented in the thesis entitled, **"APPLICATION OF ESSENTIAL CATIONIC MICRONUTRIENTS AS NANO-FERTILIZER ON VEGETATIVE PROPAGATION AND GROWTH OF MULBERRY,"** *submitted by* ***Mr. Md Salman Haydar,*** *has been carried out under my supervision. I am forwarding his thesis for the* ***Ph.D. Degree in Science (Botany)*** *at the University of North Bengal. He has fulfilled all the requirements according to the rules of the University of North Bengal regarding the works existing in his thesis. This thesis or any part of this has not been submitted for any degree or diploma either to this or other Universities.*

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It is certified that the work contained in the thesis titled **"APPLICATION OF ESSENTIAL CATIONIC MICRONUTRIENTS AS NANO-FERTILIZER ON VEGETATIVE PROPAGATION AND GROWTH OF MULBERRY"** by **"Md Salman Haydar"** has been carried out following University guideline and it has been approved by the members present in the meeting of the Departmental Research Committee in Botany for processing by the Board of Research Studies.

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Acknowledgement

Little achievements often require long, tortuous effort and bitter experiences including some sacrifices. Such endeavors find fruition when the benevolent hand of the Almighty bestows a handful of blessings upon an individual. In humble acknowledgment, I submit everything beneath the divine feet of God.

I extend my heartfelt gratitude to the numerous individuals who have played pivotal roles in shaping this thesis. Foremost among them is my supervisor, ***Dr. Swarnendu Roy****, Assistant Professor, Department of Botany, University of North Bengal. I am profoundly grateful for his wholehearted acceptance into his laboratory and unwavering guidance, particularly during the challenging period following the sudden demise of my former supervisor. Dr. Roy not only directed my research efforts but also assumed the responsibility of mentoring me with compassion and dedication. Beyond the realm of academia, I have gleaned invaluable lessons in morality and personal growth under his guidance, contributing significantly to my overall development. His constant inspiration, keen observations, and constructive feedback have been instrumental in defining the final shape of my thesis. I am profoundly appreciative of the opportunity to work alongside a talented team of researchers under his leadership. It was indeed a rewarding experience.*

In the tapestry of my Ph.D. journey, there exists an indelible thread woven with the profound guidance and unwavering support of my esteemed former supervisor, the late ***Dr. Palash Mandal****. His sudden departure during the course of my doctoral pursuit left an indescribable void, casting a shadow over the academic landscape that he so brilliantly illuminated. Dr. Mandal was not merely a mentor; he embodied the quintessence of a father figure, a friend, a philosopher, and an irreplaceable guide. His influence transcended the boundaries of academia, reaching into the very core of my being, providing solace and strength during moments of personal tribulation. It was his compassionate and motivating presence that became my anchor when I grappled with the profound loss of my father, offering not only intellectual guidance but also a comforting paternal presence that transcended the boundaries of our academic relationship. His memory is a beacon that continues to guide me, and I am profoundly grateful for the privilege of having shared a portion of my academic journey with a mentor whose influence extends far beyond the boundaries of conventional academic relationships. Sir you will be forever remain a cherished mentor, a guiding light, and a source of strength etched in the pages of my Ph.D. narrative.*

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In the aftermath of the profound loss of my former supervisor, Dr. Palash Mandal, a guiding light emerged in the form of ***Dr. Chandrani Choudhuri*** *(Assistant Professor, North Bengal St. Xavier's College), whom I affectionately address as Chandrani Di. She extended unwavering support and motivation during the most challenging chapter of my academic journey. Chandrani Di became not only a mentor but a pillar of strength, consistently uplifting my spirits with her words of encouragement. Her resolute belief in my capabilities echoed through every "you can do it" and "you have to do it," serving as a constant reminder of the tenacity required to navigate the challenges in my career. Chandrani Di's profound impact transcended the professional realm, touching the depths of my soul and reaffirming the resilience of the human spirit in the face of adversity.*

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Ph.D. itself is a prolonged and stressful journey, where friends act as antioxidants, alleviating the challenges with their words and smiles. At the outset, I would like to express my gratitude to my friends, friendly seniors, and juniors, including ***Mr. Sandipan Ghosh, Mr. Sahadeb Sarkar, Mr. Praveen Mandal, Miss. Suyojna Tamang, Miss. Ankita Roy, Miss. Jayeeta Sarkar, Miss. Keya Modak, Mr. Biswajit Paul, Mr. Satyajit Sarkar, Miss. Tanushree Sarkar, Mr. Subhrajyoti Saha, Mr. Kalyan Roy, and Mr. Gourav Kumar Barman****. Their roles as stress busters have been invaluable, providing much-needed support and companionship throughout this challenging journey.*

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being my junior, has proven to be greater than me in taking liability and responsibility. Serving as a steadfast guardian, he stood by my side, offering motivational, financial, and multifaceted support, especially after the sudden demise of our father. Their collective presence has been a constant source of support, strength, and inspiration, not only during my Ph.D. but throughout my entire academic journey. The sacrifices they've made are immense, beyond what mere words can enumerate. Special acknowledgment is extended to Mrs. Amina Bibi, my aunt, who served as my first teacher, introducing me to the alphabets, words, and the world. Furthermore, I extend my sincere thanks to Mr. SK Golam Murtaza, my elder cousin brother, Mrs. Ayesha Bibi, my aunt, SK Abbasuddin (mama), and Mrs. Afsana Parvin (mami) for their unwavering support during challenging times. Their consistent presence has been a source of comfort and strength. This acknowledgment would be incomplete without paying tribute to my grandfather, ***Late Abdul Baki****—a personal storyteller and guiding force in my life. Wherever he is, I believe he would take pride in the person I have become.*

Md Salman Haydar

Place: University of North Bengal **[Md Salman Haydar]**

Date: 03/04/2024

PREFACE

In the pursuit of sustainable agriculture and enhanced crop productivity, the realm of nanotechnology has emerged as a promising frontier, offering innovative solutions to address the challenges faced by the global agricultural community. This doctoral thesis represents a dedicated exploration into the application of micronutrient nano-fertilizers and their impact on the vegetative propagation and growth of mulberry plants.

Mulberry, an important plant in sericulture, serves as the lifeblood of the silk industry, supporting a substantial portion of global silk production. In the context of India, the second-largest silk producer globally, the economic significance of mulberry cultivation is undeniable, contributing significantly to the nation's GDP, exports, and employment. However, the cultivation of this vital plant faces challenges, including limited cultivable land, water scarcity, and inefficient nutrient management. The conventional methods of nutrient management have proven to be insufficient and environmentally detrimental.

In response, this research delves into the innovative realm of nanotechnology, specifically focusing on the green synthesis of iron, zinc, manganese, and copper nanoparticles using the pruning litter from tea plants, a by-product abundantly available in North East and South Eastern India. The precised synthesis process, coupled with the utilization of waste materials, exemplifies the commitment to sustainability inherent in this research.

Through meticulous experimentation and systematic analysis, this study explores the efficacy of micronutrient nano-fertilizers in enhancing the vegetative propagation process of mulberry plants. Furthermore, the study examines the phytotoxicity of nanoparticle treatments, ensuring the safety of both plants and the environment. Beyond vegetative propagation, this thesis investigates the impact of micronutrient nano-fertilizers on mulberry growth under drought conditions and their subsequent effects on silkworm rearing. The findings highlight the potential of nanotechnology to mitigate the adverse effects of drought stress and enhance the nutritional quality of mulberry leaves.

The exploration doesn't stop here. The thesis delves into the realm of slow release nano-fertilizers (SRNFs), offering a solution to nutrient leaching issues associated with traditional fertilizers. This innovative approach significantly contributes to improving mulberry growth, propagation, and internal health, as evidenced by morpho-biochemical analyses.

As the findings unravel, the thesis emphasizes the importance of precision in micronutrient management for mulberry, acknowledging the role of nanotechnology in shaping the future of sustainable agriculture. However, it also calls attention to the need for a comprehensive understanding of the long-term effects of nano-based fertilizers on soil microbiome, human health, and the ecosystem.

As we embark on this academic journey, it is imperative to acknowledge the collaborative efforts and invaluable support of mentors, colleagues, and research collaborators who have contributed to the completion of this thesis. In essence, this thesis represents a journey of scientific rigor, environmental management, and a commitment to advancing agricultural practices for a sustainable and resilient future. May the insights gleaned from these pages serve as a catalyst for continued exploration and innovation in the empire of nanotechnology for agriculture.

LIST OF FIGURES

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