ONE-POT HYDROTHERMAL FABRICATION OF CARBON NANODOTS FROM NATURAL PRODUCTS FOR MULTIFACETED APPLICATIONS

Thesis submitted in partial fulfilment for the Award of Degree

Doctor of Philosophy

By

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It is certified that the work contained in the thesis titled ***"One-pot Hydrothermal Fabrication of Carbon Nanodots from Natural Products for Multifaceted Applications"*** by ***Mr. Gaurav Gopal Naik*** has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive, Candidacy and SOTA for the award of Ph.D. degree.

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DECLARATION BY THE CANDIDATE

I, ***"Gaurav Gopal Naik"***, certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of ***"Dr. Alakh N. Sahu"*** from ***"January 2019" to "July 2022"***, at the **"Department of Pharmaceutical Engineering & Technology"**, Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, *etc*., or available at websites and have not included them in this thesis and have not cited as my own work.

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It is certified that the above statement made by the student is correct to the best of my knowledge.

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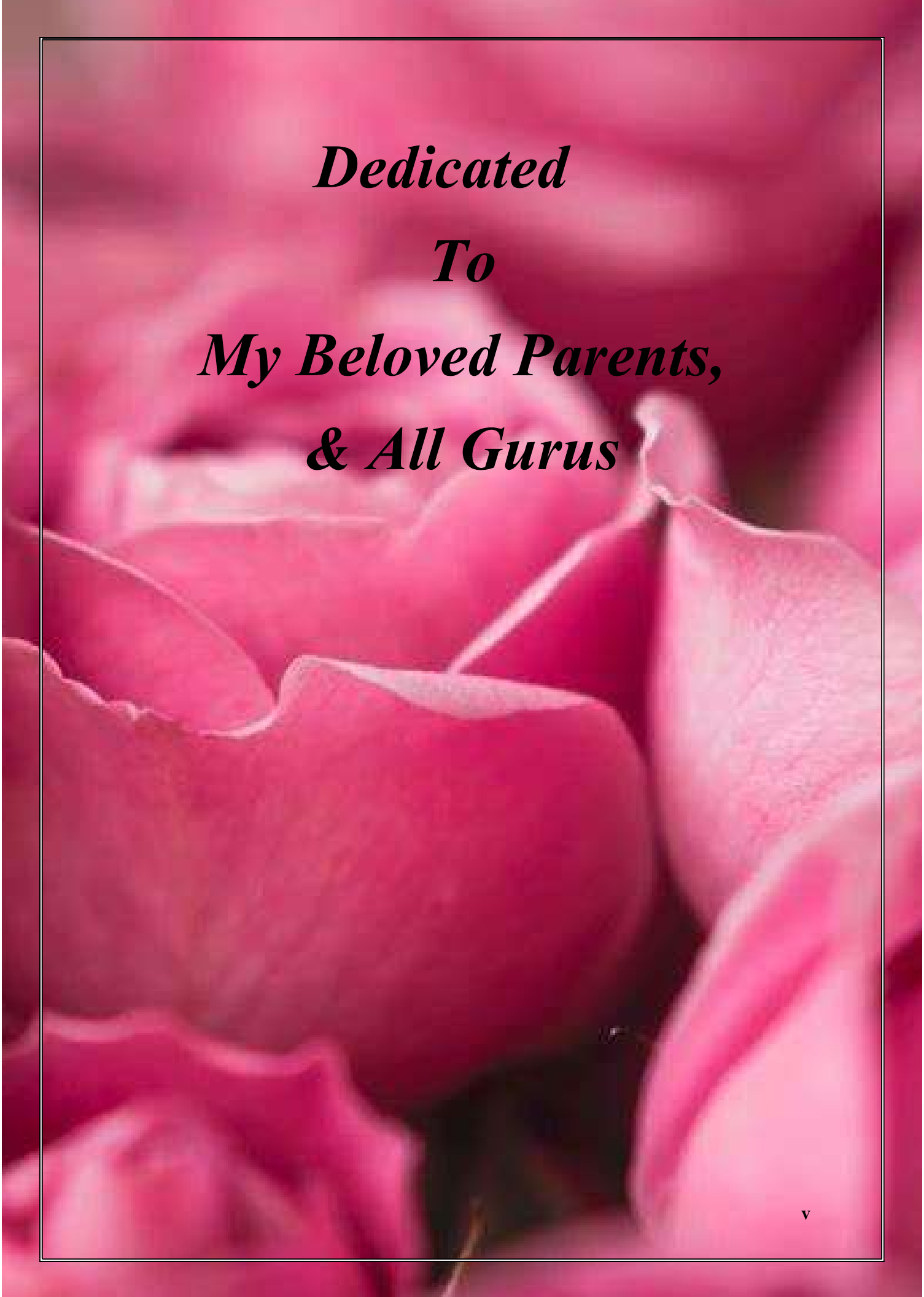

Dedicated

To

My Beloved Parents,

& All Gurus

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"The education which does not help the common mass of people to equip themselves for the struggle for life, which does not bring out strength of character, a spirit of philanthropy, and the courage of a lion— is it worth of the name? Real education is that which enables one to stand on one's own legs."

Swami Vivekanand

"Educationists should build the capacities of the spirit of inquiry, creativity, entrepreneurial and moral leadership among students and become their role model."

A.P.J. Abdul Kalam

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"Education is the most powerful weapon you can use to change the world."

B.B. King

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"Being a family means you are a part of something very wonderful. It means you will love and be loved for the rest of your life."

Lisa Weed

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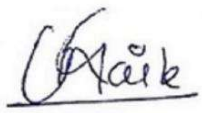

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Celsius	C
Centimeter	cm
Decilitre	dL
Degree	^{0}
Gram	g
Hour	h
Intraperitoneal	i.p.
Microgram	µg
Microliter	µL
Micrometer	µm
Milli molar	mM
Milliampere	mA
Milliliter	mL
Millimeter	mm
Minutes	min
Molar	M
Nanometer	nm
Percentage	%
Plus minus	±
Potential of hydrogen	pH
Revolutions per minute	rpm
Seconds	sec
Unit	U
Versus	vs
Volume per volume	v/v
2,2-diphenyl-1-picrylhydrazyl	DPPH
3-[4,5-dimethylthiazol-2-yl]-2,5 diphenyl tetrazolium bromide	MTT
Andrographis paniculata	AP
Andrographolide	Ad
Aqueous extract of *Andrographis paniculata*-derived carbon nanodots	AAPCDs
Asparagus racemosus	AR

Asparagus racemosus-derived carbon nanodots	ARCDs
Bovine serum albumin	BSA
Carbon Nanodots	CNDs
Carrageenan	CAR
Concentration	conc.
Distill water	DW
Energy Dispersive X-ray Spectroscopy	EDAX
Ethanolic extract of *Andrographis paniculata*-derived carbon nanodots	EAPCDs
Ethylenediaminetetraacetic acid	EDTA
Fourier transform infrared spectroscopy	FT-IR
Limit of Detection	LOD
Mueller-Hinton agar	MHA
Multidrug-resistant	MDR
Natural products	NP
One-way Analysis of variance	ANOVA
Phosphate-Buffered Saline	PBS
Photoluminescence	PL
Polyethylene glycol	Pg
Polyethylenimine	PEI
Potassium Chloride	KCl
Potassium dihydrogen phosphate	KH_2PO_4
Quantum Yield	QY
Quercetin-derived carbon nanodots	qCD
Reverse-transcriptase Polymerase chain reaction	RT-PCR
Revolutions per minute	rpm
Room temperature	RT
Selected area diffraction	SAED
Sisco-Research Laboratories	SRL
Sodium Chloride	NaCl
Sodium dodecyl sulphate	SDS
Standard error of Mean	SEM
Thermogravimetric analysis	TGA
Transmission Electron Microscopy	TEM
World Health Organization	WHO
X-Ray Diffraction	XRD

PREFACE

The interdisciplinary amalgamation of Nanomaterial technology and Natural products may lead to development of eco-friendly nano-probes for tackling modern challenges. Carbon nanodots (CNDs) are fluorescent zero-dimensional carbon nanomaterials with a size under 10 nm. Their outstanding features, including as tunable fluorescence, high photostability, good biocompatibility, and physico-chemical properties, have attracted a lot of attention from the scientific community. All of these characteristics led to their diverse applications in various domains such as optoelectronic devices, solar cells, batteries, catalysis etc. The current thesis aims to fabricate CNDs from natural products using one-pot hydrothermal method with the goal of altering their sensing properties by surface functionalization and doping. The structure, size, surface nature, photoluminescence properties, sensing abilities are characterized by different techniques. These nanodots were also evaluated for thermal stability, colloidal dispersion stability, and photostability. The plants have been authenticated by certified taxonomist and via DNA fingerprinting technique. The fabrication methods, structure, properties and potential applications of these CNDs have been summarized in different chapters.

The entire thesis is divided into eight chapters. **Chapter 1** deals with introduction of different CNDs with different synthetic routes and their applications. We have also discussed the literature review on natural products-derived CNDs and their significance. In this chapter, we have underlined our motivation to undertake this work. **Chapter 2** deals with the rationale and the proposed objectives of research work. **Chapter 3** deals with materials and methods used in various studies. **Chapter 4** illustrates a simple and green synthetic approach to fabricate blue fluorescent CNDs from aqueous extract of *Andrographis paniculata* leaves and their various healthcare applications. **Chapter 5**

deals with a simple and green synthetic approach to fabricate pink fluorescent CNDs from ethanolic extract of *Andrographis paniculata* leaves and their various healthcare applications. **Chapter 6** illustrates fabrication of fluorescent bluish-green CNDs using *Asparagus racemosus* via facile one-step hydrothermal carbonization approach and their various healthcare applications. **Chapter 7** illustrates quercetin-derived CNDs and their application in sensing metal ions, drug delivery, cytotoxicity, antibacterial against MDR strains, free radical sensing-scavenging activity. **Chapter 8** deals with summary and conclusions of this work.

Thus, our findings suggest the potential of natural products-derived carbon nanodots for wide healthcare applications.