

**STUDIES ON UTILIZATION OF BIO-CO<sub>2</sub> IN GRAIN  
STORAGE AS A CONTROLLED ATMOSPHERE (CA) AND  
CROP CULTIVATION IN GREENHOUSE WITH  
ATMOSPHERIC BIO-CO<sub>2</sub> FERTIGATION**

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**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

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by

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Centre for Rural Development and Technology

Submitted

in fulfilment of the requirements of the degree of Doctor of Philosophy

to the



**INDIAN INSTITUTE OF TECHNOLOGY DELHI**

**OCTOBER 2022**

Dedicated to my beloved parents

"Smt. Asharfi Devi

&

Late Maheshwar Maharana"

## CERTIFICATE

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This is to certify that the thesis titled “**Studies on utilization of bio-CO<sub>2</sub> in grain storage as a controlled atmosphere (CA) and crop cultivation in greenhouse with atmospheric bio-CO<sub>2</sub> fertigation**”, being submitted by **Mr. Himanshu Kumar** is report of bonafide research work carried out by him under our guidance and supervision. This thesis has been prepared in conformity with the rules and regulations of Indian Institute of Technology Delhi, New Delhi, India. We further certify that the thesis has attained a standard required for the award of the degree of **Doctorate of Philosophy** in the Institute. The research reported, and results presented in the thesis have not been submitted, in part or full to any other Institute or University for the award of any degree or diploma.

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Place: New Delhi, India

Date: 26.10.2022

**HIMANSHU KUMAR**

## ABSTRACT

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The study evaluated the viability of purified waste gas called bio-CO<sub>2</sub> (CO<sub>2</sub> ≥ 98%, CH<sub>4</sub> ≤ 2.0%, v/v), which is a byproduct of compressed biogas (CBG) plant, as a new controlled atmosphere for wheat grain storage. The findings were compared with the use of pure CO<sub>2</sub> on mortality of *Rhyzopertha dominica* adults, seed germination, and nutritional quality of wheat grain for two- and six-months storage periods. Fifteen tapered plastic bottles of 1 L storage volume were taken for grain storage in the preliminary study at 28±2°C. Insect mortality of 100% was found in 1, 3, and 5 days using bio-CO<sub>2</sub> and 4, 6, and 8 days with pure CO<sub>2</sub> at 80, 60, and 40% concentration. The outcome shows that the use of bio-CO<sub>2</sub> has better pest control efficacy. The seed germination was significantly affected at 80% CO<sub>2</sub> level using both the controlled atmospheres for grain stored for six months. The major nutrient contents were not affected significantly ( $p > 0.05$ ) under bio-CO<sub>2</sub> and pure CO<sub>2</sub> fumigation. Carbohydrate content was significantly reduced ( $p < 0.05$ ), while protein content was increased in control and control-1.

Based on the preliminary study, fifteen grain bins of 10 kg wheat storage capacity were designed and subjected for the field study for two- and six-month storage period. The uniform distribution of the bio-CO<sub>2</sub> in the grain bin remained challenging and was found to be varying by 0.2-0.8 percentage point from top to bottom of the bin. No grain loss was reported in two- and six-months storage under bio-CO<sub>2</sub> fumigation at 80, 60, and 40% CO<sub>2</sub> concentration. However, the mean seed germination was significantly affected at 80% bio-CO<sub>2</sub> level. Results similar to preliminary study concerning major nutritional contents were found for the 10 kg wheat storage study.

The storage of grain under bio-CO<sub>2</sub> fumigation was economical for 5 tonnes grain storage capacity compared to control-1.

The research also investigated cultivation of two leafy vegetables, i.e., spinach (variety-All Green) and fenugreek (variety-PEB) at the elevated condition of bio-CO<sub>2</sub> (atmospheric bio-CO<sub>2</sub> fertigation) at 650±50 ppm in a greenhouse. The parameters, i.e., crop yield, change in micro and macronutrient contents, leaf chlorophyll content, plant nutrient uptake and heavy metal transition from the soil, were measured and compared with the control. The elevated atmospheric bio-CO<sub>2</sub> suppressed the heavy metal (Pb, Cd, Se, Mo, Cu) concentration in the edible portion of both the leafy vegetables. The freshly harvested biomass and dry matter accumulation of both the vegetables were significantly increased under bio-CO<sub>2</sub> fertigation in comparison to control. The total biomass productivity was 54.31 tonnes/ha in spinach and 12.16 tonnes/ha in fenugreek under bio-CO<sub>2</sub> fertigation. The respective total biomass productivity under control was 42.85 tonnes/ha in spinach and 7.36 tonnes/ha in fenugreek. The total biomass productivity was increased by 11.46 tonnes/ha in spinach and 4.8 tonnes/ha in fenugreek under bio-CO<sub>2</sub> fertigation compared to control.

The NPV, BCR, and PP of the greenhouse study in control and bio-CO<sub>2</sub> fertigation were calculated at an average market price of INR 40/ kg of spinach and fenugreek. The production cost of bio-CO<sub>2</sub> incorporated in the economic study was INR 11.1/ m<sup>3</sup>.

Thus, it is evident from the outcomes that instead of releasing the off-stream gas from a CBG plant as waste into the atmosphere, it could be purified and utilized for grain storage as a controlled atmosphere. It could also enhance crop production and thus ensure food security.

## सार

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यह अध्ययन संपीड़ित बायोगैस संयंत्र के अपशिष्ट का शुद्धिकरण कर जैव-कार्बन डाइऑक्साइड (कार्बन डाइऑक्साइड 98%, मीथेन 2.0%, वी/वी) गैस की व्यवहार्यता का मूल्यांकन गेहूं अनाज भंडारण के लिए एक नए नियंत्रित वातावरण के रूप में किया गया, जो कि संपीड़ित बायोगैस संयंत्र का एक उपोत्पाद है। निष्कर्षों की तुलना दो और छह महीने की भंडारण अवधि के लिए *राइजोपार्था डोमिनिका* वयस्कों की मृत्यु दर, बीज अंकुरण और गेहूं के अनाज की पोषण गुणवत्ता पर शुद्ध कार्बन डाइऑक्साइड के उपयोग से की गई थी। प्रारंभिक अध्ययन में  $28 \pm 2$  डिग्री सेल्सियस पर अनाज भंडारण के लिए एक लीटर भंडारण क्षमता की पंद्रह पतला प्लास्टिक की बोतलें ली गईं। शत प्रतिशत कीट मृत्यु दर एक, तीन, और पांच दिनों में जैव-कार्बन डाइऑक्साइड का उपयोग कर और चार, छह, और आठ दिनों में शुद्ध कार्बन डाइऑक्साइड के साथ अस्सी, साठ, और चालीस प्रतिशत सांद्रता में पाई गई। परिणाम से पता चलता है कि जैव-कार्बन डाइऑक्साइड के उपयोग में बेहतर कीट नियंत्रण प्रभावकारिता है। छह महीने के अनाज भंडारण में अस्सी प्रतिशत कार्बन डाइऑक्साइड सांद्रता पर दोनों नियंत्रित वातावरण से बीज अंकुरण प्रभावित हुआ। जैव-कार्बन डाइऑक्साइड और शुद्ध कार्बन डाइऑक्साइड धूमन के तहत प्रमुख पोषक तत्व गैर-महत्वपूर्ण ( $p > 0.05$ ) रहे। नियंत्रित एवं कीट ग्रसित वातावरण में कार्बोहाइड्रेट में कमी और प्रोटीन की मात्रा में वृद्धि पाया गया।

प्रारंभिक अध्ययन के आधार पर, दो और छह महीने की भंडारण अवधि के लिए दस किलो गेहूं भंडारण क्षमता के पंद्रह अनाज के डिब्बे जमीनी स्तर पर अध्ययन के लिए तैयार किए गए। अनाज के डिब्बे में कार्बन डाइऑक्साइड का समान वितरण चुनौतीपूर्ण बना रहा और डिब्बे के ऊपर से नीचे तक 0.2-0.8 प्रतिशतता अंक की भिन्नता पाई गई। बायो-कार्बन डाइऑक्साइड धूमन के

तहत अस्सी, साठ, और चालीस प्रतिशत कार्बन डाइऑक्साइड सांद्रता के तहत दो और छह महीने के भंडारण अवधि में अनाज का कोई नुकसान नहीं हुआ। हालाँकि, अस्सी प्रतिशत जैव-कार्बन डाइऑक्साइड तथा शुद्ध कार्बन डाइऑक्साइड स्तर पर औसत बीज अंकुरण महत्वपूर्ण रूप से प्रभावित हुआ। प्रमुख पोषक तत्व प्रारंभिक अध्ययन के स्वरूप पाए गए।

जैव-कार्बन डाइऑक्साइड धूमन के तहत अनाज का भंडारण पांच टन अनाज भंडारण क्षमता के लिए किफायती पाया गया।

शोध कार्य ग्रीनहाउस में  $650 \pm 50$  पीपीएम जैव-कार्बन डाइऑक्साइड /वायुमंडलीय बायो-कार्बन डाइऑक्साइड फर्टिगेशन के प्रभाव का अध्ययन दो पत्तेदार सब्जियों, पालक (किस्म-आल ग्रीन) और मेथी (किस्म-पीईबी) की खेती में भी की गई। फसल की उपज, सूक्ष्म और मैक्रोन्यूट्रिएंट में परिवर्तन, पत्ती का क्लोरोफिल, पौधों के पोषक तत्व ग्रहण, और मिट्टी से भारी धातु संक्रमण को मापा गया और इसकी तुलना पारंपरिक खेती के साथ की गई। उच्च जैव-कार्बन डाइऑक्साइड ने दोनों पत्तेदार सब्जियों के खाद्य भाग में भारी धातु (सीसा, कैडमियम, सेलेनियम, मोलिब्डेनम, कॉपर) की सांद्रता को कम किया। नियंत्रण की तुलना में बायो-कार्बन डाइऑक्साइड फर्टिगेशन के तहत दोनों सब्जियों के ताजे बायोमास और सूखे पदार्थ के संचय में काफी वृद्धि पाई गई। जैव-कार्बन डाइऑक्साइड फर्टिगेशन के तहत पालक में कुल बायोमास उत्पादकता 11.46 टन / हेक्टेयर और मेथी में 4.8 टन / हेक्टेयर की वृद्धि हुई।

नियंत्रित ग्रीनहाउस अध्ययन और जैव-कार्बन डाइऑक्साइड फर्टिगेशन के शुद्ध वर्तमान मूल्य, लाभ लागत अनुपात, और ऋण वापसी की अवधि की गणना औसतन 40 रुपये प्रति किलो पालक और मेथी के बाजार मूल्य के आधार पर की गई।

परिणामों से यह स्पष्ट है कि संपीड़ित बायोगैस (सीबीजी) संयंत्र से निकलने वाली गैस को कचरे के रूप में वायुमंडल में छोड़ने के बजाय, इसे शुद्ध किया जा सकता है और नियंत्रित वातावरण के

रूप में अनाज भंडारण के लिए उपयोग किया जा सकता है। यह फसल उत्पादन को भी बढ़ा सकता है और इस प्रकार खाद्य सुरक्षा सुनिश्चित कर सकता है।

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## SYMBOLS AND ABBREVIATIONS

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$\rho_b$	=	Bulk density of grain
$\rho_t$	=	True density of grain
$\rho_{wT}$	=	Density of water at temperature T
$\Delta T$	=	Temperature difference
$A^{652}$	=	Absorbances of chlorophyll suspension in methanol at 652 nm
$A^{665.2}$	=	Absorbances of chlorophyll suspension in methanol at 665.2 nm
$A^{750}$	=	Absorbances of chlorophyll suspension in methanol at 750 nm
ANOVA	=	Analysis of Variance
B	=	Boron
Bio-CO <sub>2</sub>	=	Bio-Carbon dioxide
BCR	=	Benefit-cost ratio
$B_t$	=	Gross benefit over time t
$C_t$	=	Total cost incurred in the t <sup>th</sup> year
CA	=	Controlled atmosphere
CBG	=	Compressed biogas
CGA	=	Chlorogenic acid
Chl a	=	Chlorophyll a
Chl b	=	Chlorophyll b
Chl a+b	=	Chlorophyll a+b
$C_c$	=	Concentration of carbon dioxide

Cd	=	Cadmium
CV	=	Calorific value
db	=	Dry basis
ds	=	DeciSiemens
D <sub>1</sub> to D <sub>8</sub>	=	Day first to 8 <sup>th</sup> day
DNA	=	Deoxyribonucleic acid
FFA	=	Free fatty acid
GGCM	=	Global Gridded Crop Models
eCO <sub>2</sub>	=	Elevated carbon dioxide
ET	=	Evapotranspiration
FACE	=	Free-air carbon enriched
GHG	=	Greenhouse gas
ICP-OES	=	Inductively coupled plasma optical emission spectrometry
ICP-MS	=	Inductively coupled plasma mass spectrometry
INR	=	Indian rupee
LAI	=	Leaf area index
Mg	=	Magnesium
Mn	=	Manganese
mbar	=	Millibar
M <sub>p</sub>	=	Mass of dried empty pycnometer
M <sub>ps</sub>	=	Mass of pycnometer and soil
M <sub>pw</sub>	=	Mass of pycnometer and water

Mo	=	Molybdenum
MoPNG	=	Ministry of Petroleum and Natural Gas
n	=	Expected life of the developed system
Nm <sup>3</sup> /h	=	Normal cubic meter per hour
NPV	=	Net Present Value
OTC	=	Open-top chamber
Pg	=	Peta gram
PP	=	Payback period
ppm	=	Parts per million
Ppws	=	Mass of pycnometer, water, and soil
PVC	=	Polyvinyl chloride
P <sub>1</sub>	=	Initial pressure in the bin
P <sub>2</sub>	=	Final pressure in the bin
QCO <sub>2</sub>	=	Volume of carbon dioxide purged
Q	=	Leakage rate
r	=	Discount rate
RH	=	Relative humidity
R1 and R2	=	First and successive season crop
SATAT	=	Sustainable Alternative Towards Affordable Transportation
Se	=	Selenium
SO <sub>2</sub>	=	Sulphur dioxide
t	=	Time
USDA	=	United States Department of Agriculture

- V = Volume of the bin
- v/v = Volume per volume
- V<sub>g</sub> = Volume occupied by grain
- V<sub>s</sub> = Volume of stored commodity
- V<sub>hs</sub> = Volume of head space
- V<sub>pg</sub> = Volume of purge gas added
- wb = Wet basis
- W<sub>od</sub> = Weight of oven dried soil sample
- WUE = Water use efficiency
- W<sub>2</sub> = Weight of oven-dried 10 mL aliquot sample drawn from 10 cm depth of suspension after 7 h and 45 s having less than 2 μm soil particle at 20°C
- W<sub>20</sub> = Weight of oven-dried 10 mL aliquot sample drawn from 10 cm depth of suspension after 4 min and 38 s having less than 20 μm soil particle at 20°C
- W<sub>50</sub> = Weight of oven-dried 10 mL aliquot sample drawn from 10 cm depth of suspension after 45 s having less than 50 μm soil particle at 20°C