Growth dynamics and physiological response of selected forestry species to CO_2 enriched atmosphere

By

ANUSHA R M

2014-20-127

THESIS

Submitted in partial fulfilment of the

Requirement for the degree of

B.Sc-M.Sc (Integrated) CLIMATE CHANGE ADAPTATION

Kerala Agricultural University

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR - 680 656

KERALA, INDIA

2019

DECLARATION

This is to certify that the M.Sc. Thesis entitled, **"Growth dynamics and physiological response of selected forestry species to CO_2 enriched atmosphere"** under the guidance of Dr. Nameer P.O, Special officer, Academy of Climate Change Education and Research and the co-guidance of Dr. Hukum Singh Scientist-B, Forest ecology, Forest influence and Climate Change Division, Forest Research Institute Dehradun submitted to Forest Research Institute (Deemed to be) University, and Kerala Agricultural University for the partial fulfilment of award of the degree of integrated (BSc-MSc). Climate Change Adaptation is a record of my original piece of work carried out at Forest Protection Division, Forest Research Institute, Dehradun. No part of this work has been submitted for the award of any degree or equivalent.

Date: 11 July,2019

Place: Vellanikara

Anusha R M

CERTIFICATE

Certified that the thesis entitled **"Growth dynamics and physiological response of selected forestry species to CO_2 enriched atmosphere"** is a record of research work done independently by **ANUSHA R M (2014-20-127)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Date:

Place: Vellanikkara

Dr. Nameer P.O
Chairman, Advisory Committee
Special Officer
Academy of Climate Change Education and Research

CERTIFICATE

We, the undersigned members of the advisory committee of **Miss. Anusha R M (2014-20-127)** a candidate for the degree of BSc- MSc (Integrated) Climate Change Adaptation agree that the thesis entitled **"Growth dynamics and physiological response of selected forestry species to CO_2 enriched atmosphere."** may be submitted by**Miss. Anusha R M**, in partial fulfillment of the requirement for the degree.

Dr. P. O. Nameer
Special officer and head
Academy of Climate Change Education and Research,
Kerala Agricultural University.

Dr. Hukum Singh
Scientist
Forest Ecology and Climate Change Division,
Forest Research Institute, Dehradun.

Dr. Manoj Kumar
Scientist & In-charge GIS Center, Forest Research Institute, Dehradun.

Dr. Anitha S
Professor (Agronomy)
College of Horticulture
KAU, Vellanikkara.

EXTERNAL EXAMINER

AKNOWLEDGMENTS

First of all I would like to thank God Jesus, who along with me the working period and for his precious presence with me.

I would like to acknowledge with profound gratitude my indebtedness to my supervisor Dr. Nameer P. O, Special Officer, Academy of Climate Change Education and Research, for his guidance and valuable suggestion for this thesis work.

I would like to acknowledge with profound gratitude my indebtedness to my co-supervisor Dr. Hukum Singh, Scientist-B, Forest Ecology and Climate Change Division, Forest Research Institute, Dehradun for his implacable guidance and valuable suggestion for successful completion of this thesis.

I would like to acknowledge with profound gratitude my indebtedness to my advisor Dr. Anita S, Professor (Agronomy), College of Horticulture, Kerala Agricultural University, Vellanikkara, for her implacable guidance and valuable suggestion for successful completion of this thesis.

I would like to acknowledge with profound gratitude my indebtedness to my advisor Dr. Manoj Kumar, Scientist & in-charge GIS centre, Forest Research Institute, Dehradun for his implacable guidance and valuable suggestion for successful completion of this thesis.

I am also thankful to Ms. Saloni Singh, Mr. Amith Kumar, Mr. Nirmal and Mr. Sanjo Jose for their valuable suggestion and help to complete the thesis.

I would like to extend my gratitude to Mr. Arun K Kandwal for his immense help during Lab works.

I would like to extend my gratitude to Mr. Vishnu, College of Forestry for his immense help during statistical analysis.

I would like to thank to my friends specially Ms. Anakha Mohan, Ms. Arya, Ms. Dharani, Ms Mahima, and Ms. Mithinam for their help, support and inspiration to complete my work.

I would like to thank to my friends, seniors and juniors in my college for support and inspiration to complete my work.

Finally, I express my grateful acknowledgment to my parents, grandparents, my sister and brother for their guidance, support and care.

Date: 11 July 2019

Place: Vellanikara

Anusha R M

7

ABBREVATIONS

- Absolute Growth Rate (AGR)
- CAM (Crassulacean Acid Metabolic Pathways)
- Carbon dioxide (CO_2)
- Carboxylation Efficiency (Pn/ci)
- Dry Weight (DW)
- Fresh Weight (FW)
- Global Climate Models (GCM)
- Instantaneous Water Use Efficiency (Pn/E)
- Intercellular CO_2 Concentration (Ci)
- Inter-Governmental panel on Climate Change (IPCC)
- Intrinsic Water Use Efficiency (Pn/gs)
- Leaf Area Index (LAI)
- Leaf Area Ratio (LAR)
- Leaf Weight Ratio (LWR)
- Mesophyll Efficiency (Ci/gs)
- ml (milli liter)
- mm (milli meter)
- Moisture Content (MC)
- Net Assimilation Rate (NAR)
- Night Leaf Respiration (NLR)
- Open Top Chambers (OTC).
- PAL (Phenylammine Ammonia Lyse)
- Photosynthetic Rate (Pn)
- Relative Growth Rate (RGR)
- Shoot Root Ratio (SRR)
- Special Report on Emission Scenario (SRES)
- Specific Leaf Area (SLA)
- Specific Leaf Weight (SLW)
- Stomatal Conductance (gs)
- Transpiration Rate (E)
- United Nations Frame work on Climate Change (UNFCC)
- Organic carbon (OC)

8

TABLE OF CONTENTS

LIST OF TABLES

11

LIST OF FIGURES

15

LIST OF PLATES

18

INTRODUCTION

CHAPTER 1

INTRODUCTION

Climate change is a burning issue faced world-wide. "Climate change" means the change of climate attributed directly or indirectly to human activity which alters the composition of the global atmosphere is in addition to natural climate variability observed over comparable periods (UNFCC, 1992). As defined by IPCC(2011) "Climate change refers to a change in the state of the climate that was identified by changes in the average and the variability of its properties, and that persists for a longer period, typically a few decades or more. It refers to any changes in climate over time, weather due to natural variability or as a result of human activity".

The atmospheric CO_2 has changed from its preindustrial (more than 40%) concentration of 280 ppm CO_2 to the current level of approximately 411 ppm, largely due to anthropogenic activities (IPCC, 2014). If atmospheric CO_2 levels continue to increase at the current level (2.11 ppm), it is projected to reach 720-1000 ppm causing increased air temperature (2.6–5.4 °C) before the end of this century (IPCC, 2007 & 2013; Dlugokencky and Tans, 2017). Increase in greenhouse gas has a scientific and political issue in global warming from past decades. Greenhouse gases and particles trap the infrared rays and fossil fuel combustion, deforestation, etc., are reasons to increase the concentration of atmospheric CO_2 (Scheneider, 1989).

Terrestrial vegetation plays a critical role on earth's carbon cycle, however very little is known about the changing response of plants to anthropogenicaly induced CO_2 enriched atmosphere (Bazzaz, 1995 and Amthor, 1995). Plants were grown under elevated CO_2 show an increase in soil microorganism, organic matter, and nitrogen availability. The rate of photosynthesis, water use efficiency, etc. are also higher in plants grown under elevated CO_2 than ambient. Morphological readings of plants (including the number of leaves, number branches, collar diameter, shoot length, leaf area, number of roots, etc.) are high in elevated condition. The increased root system helps to absorb more water nutrients and minerals from the soil. Therefore, nutrient availability is high in plants grown under high CO_2. CO_2 induces the quantity of microbial biomass and the availability of nitrogen (N) and carbon (C), for both the rhizosphere and soil (Zak, 1993). The atmospheric CO_2 concentration has positive feedback on the N availability for soil carbon and nitrogen dynamics. Also, CO_2 has a good influence on below-ground production and allocation.

Atmospheric CO_2 affects plant functioning directly through impacts on physiology, resulting in changes in growth and ultimately, productivity. The growth dynamics and physiological response of forestry species in future predicted conditions, especially rising atmospheric CO_2 is not clear and requires strong understanding for selection of forestry species having higher adaptation and mitigation efficiency to climate change. However, there is a shortage of information regarding the adaptation and mitigation response of tree species to increasing CO_2 concentrations. This information is urgently required for understanding the adaptation and mitigation behaviour, biomass, and yield in future conditions (Sharma *et al.*, 2018).

Due to climate change, some non-native species migrate to nearby suitable areas, and they suppress the native species when they (non-native) get good conditions to establish than their native region (Walter, 2002). Some species are completely extinct due to climate change and interactions disrupted by some species (Parmesan, 2006). Climate change was favourable for weed species, and they cause dangerous ecological consequences for species interactions and ecosystem structure and functioning (Weitere *et al.*, 2009).

Ancient humans considered medicinal plants as a natural cure for a wide range of diseases (Ghulam, 2017). Therapeutic agents and chemical compounds are present in medicinal plants responsible for curing diseases. In 2020, the world population may reach 7.5 billion, but still, 80% of people accept traditional medicine based on medicinal plants (Ramawat, 2008). For the present study, different species of Terminalia were selected based on certain considerations.

Family: Combretaceae

Terminalia arjuna is an evergreen, deciduous tree commonly seen in mixed dry deciduous tropical forest and native to India. Arjuna has a reputed position in Ayurvedic and Yunani medicine. It is buttressed, and branches are drooping. It may grow up to 18 to 25m. This tree has multipurpose uses. Its wood portion is mainly used in constructions, agricultural implements, mine props, carts, boats, and many others. Seed are edible. *Terminalia arjuna* is used for balancing three "humour" in Ayurveda (Kapha, pitta, and vata) and also used for asthma, bile duct disorders, scorpion stings and poisonings. *Terminalia arjuna* was traditionally used for heart diseases, and therefore it also called "Guardian of the heart."

Terminalia bellirica is a large, fast-growing deciduous tree seen throughout the tropics. It is indigenous to India. It is buttressed, and the globose crown reaches up to 50m. It is a multipurpose tree, mainly used for medicine, fodder, fuel, cosmetics, timber, etc. The tree is used as ornamental and intercropping along with crops. *Terminalia bellirica* is used for high cholesterol and digestive disorders and also HIV infection. Besides, it is also used to protect the liver and treat respiratory conditions and lotion for sore eyes. It is traditionally used in Ayurveda, Siddha and Unani (Deb et al. 2016). In traditional Ayurvedic *Terminalia bellirica* used as "health harmonizer" in combined with *Terminalia chebula* and *Emblica officinalis*. This helps to lower cholesterol and to prevent the death of heart tissues. Its fruit is the main commercially important part.

Terminalia chebula is a medium to the large deciduous tree. It is known as the miraculous herb due to its healing power. It is mainly found in mixed dry deciduous forest and tropical and subtropical zones, especially hilly tracks. *Terminalia chebula* used for dysentery, sore throat, eye diseases, cholesterol and digestive disorders and increases longevity and a good tonic for the liver. It was an important ingredient in *Triphala*. It is seen scattered in Teak forest. It grew up to 30m and found throughout South East Asia including India, Sri-Lanka, Bhutan and Nepal.

The three agroforestry species are beneficial for the production of medicinal, fodder, timber, and tannin. Production of these trees helps farmers to improve their economy. It is also reported to have medicinal properties which may cure many harmful diseases like HIV, cardiac disorders, urinary infections etc. In the project, it was proposed to study the growth dynamics and physiological response of there species (*Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula*) subjected to CO2 enriched atmosphere using open-top chambers (OTC).

The present study was organized with the following objectives.

1. To study the adaptive behaviour of selected trees exposed to elevated CO_2 concentration.

2. To estimate mitigation efficiency of selected trees exposed to elevated CO_2 concentration.

3. To study the biochemical response of selected trees grown under elevated CO_2 concentration

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

A literature review is the most crucial part of a research study, and it gives an independent review of the already existed research studies on the on-going subject. Due to climate change trees may respond differently to the environmental factors such as temperature, pressure, humidity, nutrients and CO_2.

2.1 Response of plants under elevated CO_2

According to Wong (1979), under elevated CO_2 cotton seedlings showed good leaf area and dry weight than ambient, but maize seedlings show very short improvement in leaf area and dry weight than ambient condition, and they decreased with the decrease of nitrogen nutrient. The plants are grown under elevated CO_2, and high nitrogen showed high assimilation rate. Both cotton and maize grown in high CO_2 showed less assimilation rate in ambient CO_2 compared to ambient air. Water use efficiency doubled in high CO_2 at all nutrient treatment in both the cotton and wheat.

In the short term, exposure of CO_2 increases the photosynthesis, but in the long term, it may decrease photosynthesis rate and plant growth, and this phenomenon is called photosynthetic accumulation or down-regulation. The responses are managed in root volume according to pot size, i.e. when the size of the pot is less, and then the amount of root is reduced (Arp 1991, Thomas and strain, 1991). Impact of rising CO_2 in PCO (Photosynthetic Carbon Oxide) and PCR (Photosynthetic Carbon Reduction) cycles are acted good predictive indicators of photosynthetic response of single leaf to elevated CO_2 for a short term (Acock and Allen, 1985). In long term responses to CO_2, it will be moderated by some abiotic factors such as N availability (Weerakoon *et al.*, 1999) or alteration in PAR (Photosynthetically Active Radiation) (Sims *et al.*, 1999). Night respiration of plants is slower in light than darkness at photosynthetic tissue (Pinelli and Loreto, 2003). At high concentration of CO_2 (i.e. thousands of ppm) dark respiration will reduce dramatically (Palta and Nobel, 1989). Stomatal conductance is decreased with an increase in CO_2. CO_2 level influences stomatal closing and opening (Assman 1999). Increasing CO_2 enhances the WUE (Water Use Efficiency) of leaves (Jones, 1998).

2.2 Responses of medicinal plants under elevated CO_2

Various studies worldwide show that plants grown under elevated CO_2 have a good impact on growth dynamics, physiological response, and biochemical process. Different species of plants show varying responses because of higher CO_2 (Bazzaz *et al.*, 1995). The effect of medicinal plants phenolic and chemical compounds in a CO_2 enriched atmosphere was also studied by many scientists. Medicinal plants grown under CO_2 have enhanced biomass and medicinal contents (Zobeyad, 2004). In alpine ranges, the temperature and precipitation enhance the biodiversity of lower elevation plants (Salick, 2014). CO_2 enrichment can improve plant biomass, primary and secondary metabolites synthesis and antioxidant activities (Ghasemzadeh, 2011). The flavonoid concentrations, total non-structural carbohydrates (TNC) and nitrogen are increased under CO_2 enrichment but dependent on growth stages (Esterate, 1999). The concentration of total soluble phenolics, catechin concentration, proanthocyanidins (PA), lignin and nitrogen are increased in elevated CO_2 condition. The chemical composition was affected by elevated CO_2 and low nitrogen availability and the metabolic allocation, plant-pathogen interactions, decomposition rate and mineral nutrient cycling of the plant (Booker and Mayer, 2001).

Jaafar *et al.* (2012) indicated that the commonly present phenolic and flavonoids compounds gallic acid increase tremendously in alata, pumila and quercetin increase in lanceolate at CO_2 1200ppm. Kaempferol, is present in ambient condition but after CO_2 enrichment it was undetected, but caffeic acid increases rapidly in alata and pumila. But pyrogallol and rutin were only seen in alata and pumila under ambient, but in CO_2 enriched condition it was undetected because under high CO_2 rutin will decrease. Another one is naringenin, which also presents in ambient condition but after CO_2 enrichment it not be detected in all varieties except pumila. The PAL (phenylalanine ammonia-lyase) activity, DPPH and FRAP increase with increased CO_2 and also improve health-promoting qualities of Labisia pumila Benth. (var. alata, pumila and lanceolate).

Ibrahim et al. (2014) stated that the production of plant secondary metabolites, sugar, chlorophyll content, antioxidant activity, and malondialdehyde contents have effects on CO_2 and light intensity. The highest accumulation was of 1200 µmol/mol (CO_2) and 225 µmol/m/s (light intensity). The production of chlorophyll and malondialdehyde are the highest at 400 µmol/mol CO_2 and 900 µmol/m /s light intensity. Under high CO_2 photosynthesis, stomatal conductance, fv /fm (maximum efficiency of photosystem II), and PAL activity increased tremendously. Under high CO_2 secondary metabolites shows a negative relationship with malondialdehyde.

Ghasemzadeh *et al.* (2010) observed that both varieties of Malaysian young ginger (Halia Bentong and Halia Bara) showed an increased effect in flavonoids and phenolic in response to CO_2 enrichment from 400 to 800 µmol mol-1 CO2. Rhizomes show greater response than leaves. Under elevated CO_2 kaempferol and fisetin (flavonoid compounds) and gallic acid and vanillic acid (phenolic compounds) in both varieties show good response. When the CO_2 level increased from 400 to 800 µmol mol-1, free radical scavenging power (DPPH) enhanced about 30% and 21.4% (Halia Bentong and Halia Bara respectively). But the rhizomes showed enhanced effect on free radical scavenging power by 44.9% and 46.2% (Halia Bentong and Halia Bara respectively). Under the controlled environment, production and CO_2 enrichment have enhanced the pharmaceutical quality of Malaysian young ginger varieties.

Ibrahim et al. (2011), observed that secondary metabolites, glutathione, oxidized glutathione and their antioxidant activities increased in descending order of 1200ppm>800ppm>400ppm (from all leaves, stem, and root). They also noticed a positive effect on antioxidant activities with total phenolics, flavonoids, GSH, GSHH exhibiting an increase in anti-oxidative activity in Labisia pumila. Under elevated CO_2 Labisia pumila's medicinal potential and anti-oxidative activity are increased tremendously.

2.3 Physiological response of plants to CO_2 enriched atmosphere

Idso (1988), reported that the plants grown under well-watered optimum growth rate phase with CO_2 concentration 640ppm showed increased productivity. However, plants grown under nonlethal water-stressed phase with CO_2 concentration 640ppm shows more than and effective productivity.

Increasing CO_2 stimulates plant growth relative to current CO_2 concentration (Kimball, 1993; Ghannoum *et al.*, 2000). Doubling of CO_2 could enhance seed germination (Esashi *et al.*, 1989; Ziska and Bunce, 1993) because CO_2 increase the production of ethylene, a plant growth regulator which enhance seed germination (Esashi, 1989). Also, CO_2 enhances root growth as an increase in root length, root diameter and root cortex width (Rogers *et al.*, 1992; Ziska *et al.*, 1996). The floral number and pollen production are increased with increase in CO_2 (Reekie *et al.*, 1997; Zisk and Caulfield, 2000) besides increase in seed and fruit size, number and quality (Garbutt and Bazzaz, 1984; Curtis *et al.*, 1994; Ward and Strain, 1997). Elevated CO_2 can alter the plant growth as slower (carter and Peterson, 1983) faster (St. omer and Horvath, 1983) or same (both faster and slower) (Garbutt and Bazzaz, 1984). Increase in CO_2 alters plant senescence, in some case, it will increase (St. Omer and Horvath, 1983; Sicher 1998; Jach and Ceulemans, 1999) and in some other cases, it delay (Hardy and Haveka, 1975). Increase in CO_2enhances plant size and initiates the reproduction (Reekie and Bazzaz, 1991).

Curtis and Wang (1998) reported that the total biomass and CO_2 assimilation increase concurrently in elevated condition than ambient. Low soil nutrient storage will reduce CO_2 stimulation by half under an optimal condition, but low light increases the response. Under high CO_2, no significant allocation for biomass. The plants grown under growth chamber had low response than plants grown under open-top chamber or greenhouses. No consistent evidence for photosynthetic assimilation to CO_2 enrichment except plants grown in pots and no stomatal conductance on CO_2 enrichment. Under elevated CO_2, both the night leaf respiration and leaf nitrogen reduced. In low nutrient gymnosperms, leaf starch content increased.

According to Sage *et al.* (1989), long term CO_2 exposure will affect the photosynthesis in different ways mainly, an initial response not affected and the photosynthetic rate increased, initial CO_2 response decreased but photosynthesis rate little affected, and both conditions decreased. The study was done on five C_3 species (Chenopodium album, Phaseolus vulgaris, Solanum tuberosum, Solanum melongena, and Brassica oleracea). They exhibited an increase in photosynthesis at high CO_2 and is simulated by a decrease of the partial pressure of O_2 or high concentration of CO_2. In elevated CO_2 there is a change or increase occur in leaf N per area. Rubisco content was small in two of the five, and long term exposure shows a decrease in all species. The leaf rubisco content remained excess during growth in elevated CO_2 that support enhances the photosynthetic rate.

Poorter (1993) pointed out that C_3 plants show more CO_2 stimulation than C_4 plants, but CAM plants show less growth than C_4 plants (C_3>C_4>CAM). Within the C_3 plants, herbaceous crop plants show more growth responses than herbaceous wild species and fast-growing species shows the increase in weight than slow-growing species. More over N_2 fixing C_3 plants show more growth than other C_3 plants. According to him, within the group of C_3 species, there are differences in growth under elevated CO_2.

Rozema (1993) observed that at elevated CO_2 plant growth, net assimilation rate (NAR), and photosynthesis increased, but photorespiration decreased. The plants grown under high salinity showed a reduction in transpiration and stomatal conductivity with elevated CO_2, and there was an increase in water use efficiency and shoot water potential. In early stages of elevated CO_2 leaf area per plant and leaf area per leaf will increase but later leaf area ratio (LAR) and specific leaf area (SLA) will decrease. The plants grown under salt stress show an increase in dark respiration as a sink for photosynthesis, and it will not show such assimilation under elevated CO_2. Plant growth will be stimulated at elevated CO_2 and decreased with ultraviolet B (UV-B), and there is a shortage in data with the combined effect of both elevated and UV-B. Plant responses to elevated CO_2, salinity and UV-B are species-specific because plant species sensitivity differs to salinity and UV-B as well other environmental factors such as drought and nutrients. Therefore, the combined effect of elevated CO_2 and UV-B are physiologically complex to plants.

According to Sharma *et al.* (2018), elevated CO_2 increases the photosynthetic rate, stomatal conductivity, transpiration rate, water use efficiency, soil respiration, net primary productivity, and carbon content of plant tissues such as leaf, stem and root and soil carbon and biomass production (stem and root) decline in night leaf respiration of *Withania somnifera*. Increased primary productivity will improve the mitigation of plants by sequestering elevated CO_2 levels.

Estiarte *et al.* (1999) noted that the wheat grown under elevated CO_2 showed higher flavonoid concentration than ambient and higher total non-structured carbohydrate (TNC) and lower N concentration in the upper canopy throughout the growth period. Plants grown in well-watered condition showed more flavonoids and TNC and N concentration are more variable than half watered condition. Also, atmospheric CO_2 indirectly affects plant-pest relation, prevents pathogens and enhance the UV-B protection by altering the flavonoid concentration.

2.4 Adaptive response of plants on increased CO_2.

Singh *et al.* (2018) observed that the plant species *Parthenium hysterophorus*, under elevated CO_2 showed an increased effect on plant height and diameter, leaf fresh and dry weight, leaf moisture content, leaf length and leaf area, root length, leaf area index, specific leaf area, shoot fresh and dry weight, root fresh and dry weight and total dry biomass than the ambient condition. Photosynthetic rate and water use efficiency also increased. A reduction in stomatal conductance and transpiration in elevated condition than ambient was observed. These results show that under elevated CO_2 plants have enhanced intrinsic water use efficiency, biomass production and tissue carbon allocation showing good adaptability under changing climatic scenario, especially rising atmospheric CO_2.

Becker and Klaring (2015) studied two varieties of red lettuce grown in a growth chamber under elevated CO_2 (200ppm and 1000ppm) and observed that the head mass of plant increases simultaneously under high CO_2. At high CO_2, plants have a positive effect on flavonoid glycosides and some caffeic acid derivatives; the effects differ in these two varieties. The sugar concentration also increased under elevated CO_2. The CO_2 enriched atmosphere induces or gives high yield on red lettuce and rich in phenolic compounds.

Cha *et al*. (2017) reported that under elevated CO_2 *Quercus acutissima* had lower S/R ratio, but its leaf thickness was higher than Fraxinus rhynchophylla. Leaf area of *Q. acutissima* was higher in elevated CO_2. The specific leaf area (SLA) of both species were very low in elevated CO_2 condition. Under elevated CO_2, N concentration of leaf litter *Q. acutissima* was very low, and the C/N ratio was high. In *Q. acutissima* the P concentration was very low in elevated CO_2, but it was higher in *F. rhynchophylla*. In both species, Ca concentration was very low in elevated condition. Litter decaying was lower in elevated CO_2 than the ambient.

2.5 Biochemical Response of Plants under Elevated CO_2

Reddy *et al*. (2010) studied the positive and negative impact of rising CO_2 on photosynthesis in different species of higher plants. He found that CO_2 enriched atmosphere had a significant variance in physiological, chemical and molecular responsiveness in terrestrial plant species, which includes C_3, C_4 and Crassulacean Acid Metabolic Pathway (CAM). C_3 plants show a dramatical increase in carbon assimilation, growth and yield and show a positive response to photosynthetic acclimation. Carbonic Anhydrase (CA) was reduced in plants when exposed to elevated CO_2, but it also increased in some species. C_3 plants show both up and down regulations for photosynthetic capacity in enhanced CO_2 condition, and it differs with genetic and interactive environmental factors. C_4 plants show increased carbon uptake in an enriched atmosphere, and they show enhanced photosynthesis during drought and atmospheric vapour pressure deficit conditions. C_4 weeds also showed more response than C_4 crops. The response of CAM plants to CO_2 enriched atmosphere is little known compared to C_3 and C_4 plants. On marginal and semi-arid regions CAM plants show a significant increase in biomass production under CO_2 enriched atmosphere. The adaptive responses of plants to changing climate remain antithetical.

According to Watling *et al.* (2000), plants are grown under elevated CO_2 show lower Carboxylation Efficiency (CE) and CO_2 saturate rate of photosynthesis than the ambient. C isotopes increase in elevated CO_2 and bundle sheath leakiness was higher in elevated than the ambient. The ratio of quantum yield of CO_2 fixation to PS11 efficiency of plants grown under CO_2 enriched atmosphere was lower. Plants grown in elevated showed the decreased thickness of leaf bundle sheath than ambient.

Pritchard *et al.* (1999) observed that plants grown in elevated CO_2 changed their structure by the effects on primary and secondary meristems of shoot and root. Leaf area and anatomy of the plant were also changed. Increased cell division and cell expansion increased the growth of leaf thickness than wild species. Photosynthetic rate and transport capacity were increased in elevated CO_2. Plants grown in elevated CO_2showed increased leaf area per plant. Crop species showed increased response than tree, wild and non-woody species. Non-tree species, wild and non-woody species show a decrease in specific leaf area (SLA) in comparison with crop species. Plants in elevated CO_2 showed increased plant height, branching characters are changed and increased collar diameter and root length.

Jin *et al.* (2015), reported that plants grown in elevated CO_2 have more demand for phosphorus (P) for the photosynthesis simulation and growth responses. I have elevated CO_2 change P accretion by the changes in root morphology and an increase in rooting depth. The changes occurring in carbon flux change the quantity and composition of roots. Root exudates lead to P mobilization; they make changes in the biochemical environment and microbial activity of rhizosphere.

Qu *et al.* (2017), studied the effect of Sudden Heat Stock (SHS) on photosynthesis (PN) assimilation pathway under elevated CO_2 in plants using heat-tolerant (B76) and heat susceptible (B106) maize plants and pointed that B106 had an electrolyte leakage in SHS than B76 in the thermostability analysis of cell membrane. Photosynthesis of B76 was protected by elevated CO_2 from SHS through reducing stomatal conductance and transpiration and enhancing water use efficiency. The response of photosynthesis to SHS reduce the NADP-ME enzyme activity and reduce the transcript abundance. The SHS treatment increase starch depletion, accumulation of hexose and it suppresses the TCA cycle and C_4 assimilation pathway. Elevated CO_2 deviates the effect of SHS in citrate and related TCA cycle metabolites in B106, but in B76, the effect of elevated CO_2 is very small. Elevated CO_2 enhances starch in both heats tolerant and heat susceptible, but the combined effect of CO_2 and SHS on starch is significant. His findings indicate that heat stress tolerance is a more complicated trait and difficult to find the biochemical, physiological and molecular markers accurately and consistently predict heat stress tolerance.

Teng *et al.* (2006), pointed out that stomatal density and stomatal index of leaves and stomatal conductance and transpiration rate were decreased under elevated CO_2. Under a CO_2 enriched atmosphere, the number of chloroplast width and profile area and starch grain size and number were enhanced, but the number of grana thylakoid membranes decreased. The concentration of carbohydrates and plant hormones except abscisic acid increased and the concentration of mineral nutrients reduced. Changes occurred in chloroplast ultra-structure is a result of enhanced starch accumulation — the growth and development of Arabidopsis thaliana in elevated CO_2 enhanced foliar concentration of plant hormones. There is a decline in the concentration of mineral nutrient because of dilution by the enhanced concentration of carbohydrates and also decreased in stomatal conductance and transpiration rate.

Medlyn *et al.* (1999) a meta-analysis of photosynthesis stated that light-saturated photosynthesis (Amax) was strongly enhanced in elevated CO_2. A down-regulation of photosynthesis occurred in the same concentration of CO_2. The downregulation of parameters like potential electron transport rate (Jmax), the maximum rubisco activity (Vmax) would affect the biochemistry of photosynthesis and this link to the effect of elevated CO_2 and leaf Nitrogen (N) concentration. He concluded that the current model is best for modelling of photosynthesis in elevated CO_2.

According to Bowes (1991), C_3 plants shows enhancement in growth at elevated condition, but it is marginal in C_4 plants. The enhancement occurs in anatomically, morphologically, physiologically and biochemically. At the initial stage, there is an enhancement in its photosynthetic rate under elevated CO_2, thereafter it will be decrease. A reduction also occurs in rubisco activity of plants.

Xu *et al.* (2015) reported that under elevated CO_2 net photosynthetic rate (Anet) had a positive effect on C_3 plants, but in C_4 plants enhancement occurs water deficit condition. Down regulation of photosynthesis occurred due to a decrease in ATP: ADP ratio, diluted N, overly occurring photosynthetic accumulation under long term exposure of elevated CO_2, mainly in N and C sink limitation. There is a reduction in respiration in a CO_2 enriched atmosphere. Elevated CO_2 partially enhance the accumulation of antioxidants like polyphenols and ascorbate, and enhance semi-antioxidant enzyme. CO_2 enrichment decreases the N level and increases the quantity of total non-structural carbohydrate (TNC). Under elevated CO_2 plants mitigate the negative impacts of abiotic stress, but relatively better enhancement occurs in plant growth, photosynthesis, water use efficiency, enhanced antioxidant metabolism and decreased the photorespiration.

Graaff *et al.* (2006) observed that CO_2 enrichment promotes gross N immobilization. So the gross and net N mineralization were not affected, and the enhancement occurred in microbial C content and soil respiration. In short, the elevated CO_2 enhance overall above and below ground plant biomass and also increase the CO_2 respiration. When N-treatment will available the plants show good above and below ground enhancement in elevated CO_2 or the low availability of N; they show less enhancement and soil C content doesn't increase. Under elevated

CO_2 the N fixation was promoted only when the additional nutrients avail. The main motivator of C sequestration is soil C supply via soil growth, which is controlled by nutrient availability. In non-fertilized condition, their microbial N immobilization increases the plant growth to CO_2 enrichment. When the additional nutrients supply the enhanced soil C, and C sequestration will sustain long term under CO_2 enhancement.

Leakey *et al.* (2009) observed that the soybean plant grown in a CO_2 enriched atmosphere at field condition has an enhancement in its night-time respiration. The number of mitochondria was greater in the CO_2 enriched atmosphere. So there is a greater respiratory proportion, and leaf carbohydrates presence enhance the respiration of plants. In future, under CO_2 enriched atmosphere, foliar respiration was high, and this will leads to a reduction in plant carbon balance.

Saravanan and Karthi (2014) stated that the *Catharanthus roseus* shows the highest phenol, flavonoid, carbohydrate and tannin at 600ppm+rh and highest alkaloid content at 900ppm. In their biochemical analysis. Protein content was high in ambient than elevated condition. Plants under 900ppm show greater enhancement in fresh weight, shoot length, and the number of leaves, and at 600ppm recorded the highest root number, and 600+Rh shows the highest root length.

Janani *et al.* (2016) pointed out that *Azadirachta indica* (neem) is acclimatized the elevated CO_2 condition, but *Melia dubia* (Melia) is sensitive to elevated CO2. Photosynthesis, stomatal conductance, and transpiration rate of *Melia* were affected in CO_2 enriched atmosphere, and a decrease occurs in its carbohydrates, proteins, sugar, amino acids and phenols. The neem shows greater long term and short term responses in stomatal conductance and transpiration than *Melia*. And neem shows a positive response to changing climate.

Saravanan and Karthi (2017) stated that *Adhatoda vasica* shows higher alkaloid and flavonoid concentration in controlled elevated condition. And higher tannin and saponin rate was shows is 900ppm. The concentration of phenol was highest in ambient condition. The highest fresh weight, shoot length was showed in 900ppm, and the number of leaves showed in 600ppm+RH, and at 600ppm plants get the highest number of leaves, and longest root length.

MATERIALS AND METHOD

CHAPTER 3

MATERIALS AND METHODS

The present study entitled "Growth dynamics and physiological response of selected forestry species to CO_2 enriched atmosphere" was conducted at the Central Nursery, Forest Research Institute, Dehradun, Uttarakhand, during October 2018 to May 2019. The materials used and methodology adopted for was study was described in this Chapter.

3.1 Study area

The open-top chamber (OTC) facility with automated and controlled environmental conditions (CO_2, temperature, pressure, and humidity), was established at the Central Nursery of Forest Research Institute, (300 200 420 N, 770 590 590 E), Dehradun, was used to carry out the proposed study (Singh et al., 2018). The seedlings of *Terminalia chebula, Terminalia bellirica,* and *Terminalia arjuna* were exposed under elevated CO_2 (400 ppm and 800 ppm) atmosphere inside the OTC.

3.1.2 Structure of OTC

Each OTC structure is designed with square type, having 3m X 3m X 4m dimensions. The OTC is fabricated by GI/MS pipe and installed in the experimental field. The OTC is covered with polycarbonate sheets of 80-85% transmission level of light and reduced dilution effects of air within the chamber. Each chamber has a suitable door of 6ft and 3ft size. The upper portion of OTC is kept open so on to maintain natural condition of temperature and humidity.

3.1.3 Sensors on OTC

The sensors of temperature, humidity, and CO_2 in OTC are connected by four core shielded cable for obtaining data in the control room. The sensor box is fabricated with powder-coated MS sheet. The sensor box has the flexibility to adjust it on any height based on the plant height. The sensor was protected from natural hazards like rain, sunlight, wind etc.

3.1.4 CO_2 distribution

Pure CO_2 gas (99.9%) of commercial-grade was supplied to chambers through CO_2 gas cylinder with 47 kg capacity and maintained at the set level of CO_2 (400 ppm, 800 ppm), using manifold gas regulators, pressure pipelines, solenoid valves, rotameters, sampler, pump, CO_2 analyser, PC linked program logic control (PLC) and Supervisory Control and Data Acquisition (SCADA). Air compressor with 120L capacity is used to dilute the concentration of CO_2 gas for the uniformity of CO_2 inside the chamber.

The IR heater helps to increase 60C temperature inside OTC compared with the ambient. The ceramic heaters are designed with a reflector of 910mm X 120mm X 90 mm and operated on 240V and 1.5KVA capacity. Heater panel is consoled with three independent IR heater of size 245mm X 60mm connected in parallel having operated voltage 240VAC. The IR heater height can be adjusted according to plant height from the top of OTC.

The dehumidification process takes place by the dehumidifier unit that sucks the moisture from OTC. The humidification makes the entire OTC as dry.

A CO2 monitor is used for monitoring and controlling CO_2 gas in the OTC. The system was fully automatic and maintained the desired level of CO_2 throughout the experimental period. Data scanner, SCADA software, and PC are used to monitor and control the CO_2 concentration in each OTC.

The data scanner records a wide variety of energy and environmental measurements including temperature, relative humidity, AC/DC and voltage, differential pressure, time of use (light and motors), light intensity, water level, soil moisture, rainfall, wind speed and direction and pulse signals.

3.2 Trees Studied

3.2.1 *Terminalia arjuna*

Family: Combretaceae (Terminalia Family/Arjuna Family)

Common Names: Gujarat: Dhaula Sadar; Hindi: Arjun Koha; Kannada: Holematti: Maraty: Savimadat; Tamil: Kula Marutha; Malayalam: Neermaruth; Telugu: Thella Maddi.

3.2.2 *Terminalia bellirica*

Family: Combretaceae (Rangoon creeper family)

Synonyms: Myrobalanus bellirica

Local Names: Assamese: Bauri, Bhamora, Dubong, Silli; Bengali: Baherra; Guajarati: Baheda, Bahedan, Hero; Hindi: Bahera, Bharla, Bulla, Lechara, Sagona: Kannada: Tare, Santi, Tharo; Malayalam: Thanni; Marathi: Bahera, Balda, Vehala; Oriya: Bada, Thara; Punjabi: Bahera, Bayrah, Birha: Sanskrit: Akshavriksha, Baherukha; Tamil: Tani, Kattuelu-Pay, Thandri; Telugue: Thadi, Thandra.

Trade Name: Bahera, Bellaric myrobalan

3.2.3 *Terminalia chebula*

Family: Combretaceae

Local Names: Assamese: Halikara, Silicha; Bengali: Haritaki; Guajarati: Haradi, Hirde; Hindi: Harad, Harra, Harhar; Kannada: Allale, Arili, herrda; Malayalam: Kadukka; Marathi: Hirada, Habra; Oriya: Harada, Horitoki; Punjabi: Harar; Sanskrit: Abhaya, Amrita, Hemavathi, Jeevanthi, Sudha; Tamil: Kadakai, Illagucan; Telugu: Karaka.

Common name: Gall nut

Trade name: Chebulic myrobalan, Harad.

3.3 Preparation of potting media

A fine mixture of soil, sand, and FYM in the ratio of 1:1:1 was prepared. The soil and sand were sieved and cleaned from undesirable materials. The manure was not sieved but rubbed with hands to make it fine, and twigs and other impurities were removed.

3.3.1 Polybag / Pot filling

After preparation of mixture, it was filled in 36 polybags for planting the saplings of *Terminalia arjuna, Terminalia bellirica,* and *Terminalia chebula.*

Plate 1: Collection of plant materials and planting

The saplings of *Terminalia chebula, Terminalia bellirica,* and *Terminalia arjuna* were purchased from the Central nursery, Forest Research Institute, Dehradun. Only healthy and uniform saplings were selected a total of 36 saplings (12 each of *Terminalia chebula, Terminalia bellirica,* and *Terminalia arjuna*). The seedlings were collected on 29/09/2018 and was replanted in standard size polybags (22cmX21cm) on 01/10/2018 with proper soil mixture and watered. The poly bags were kept outside the OTC chambers for a few days for acclimatization or reduce potting stress. Then the pots with the seedlings were gradually exposed to the elevated CO_2 level chambers in OTC (400 ppm, 800 ppm) on 10/10/2018. Each concentration chambers had six saplings of each species in both 400 ppm and 800 ppm.

(a)

(b)

Plate 1: Plant in OTC at (a) 400ppm and (b) 800ppm before CO_2 application

3.3.2 Experimental materials and treatments

- Plant species - 3 numbers *(Terminalia chebula, Terminalia bellirica, and Terminalia arjuna*)
- Number of treatments -1 (CO_2)
- Level of CO_2 - Two level of CO_2 (400 ppm, 800 ppm)
- Number of replications - Six replication per species

Plate 2: Plants in OTC before harvesting (upper-400ppm, down-800ppm)

3.4 Measurement of parameters

3.4.1 Growth dynamics and morphological analysis

The study was carried out from October 2018 to June 2019. The growth dynamics and morphological behaviour were observed for each plant exposed in the treatments. The parameters such as plant height (cm), collar diameter (mm), number of leaves, leaf length and leaf width (cm), root weight (g), shoot weight (g), leaf weight (g), moisture content and root length were measured during the study. Plant height was measured using measuring scale/ meter scale and collar diameter with digital Vernier calliper (Williams, 1946). The leaf area was calculated using graph paper method by spreading the leaf on graph paper and tracing its outline. The number of squares lying within the leaf was counted and expressed in cm^2 (Pandey and Singh, 2011). The leaf area index was calculated as the leaf area per unit ground surface area (Williams, 1946). The specific leaf area was measured by taking an area of a fresh leaf divided by its oven-dry mass (Kvet *et al.,* 1971). Leaf weight ratio (LWR) was expressed as the dry weight of leaves to the total dry weight (Kvet *et al.,* 1971).The root-shoot ratio was calculated as the ratio of root dry weight to shoot dry weight.

Leaf Area Index (LAI - Williams, 1946)

LAI = Total leaf area of a plant / Ground area occupied by that plant

Leaf Area Ratio (LAR)

LAR = Leaf area per plant/ Plant dry weight

Leaf Weight Ratio (LWR - Kvet *et al.,* 1971)

LWR = Leaf dry weight/Plant dry weight

Specific Leaf Area (SLA - Kvet *et al.,* 1971)

SLA = Leaf area/Leaf weight

Specific Leaf Weight (SLW)

SLW = Leaf weight/Leaf area

Absolute Growth Rate (AGR)

$$AGR = h_2 - h_1/t_2 - t1$$

Where, t_1 & t_2 are the times and h_1 & h_2 are the plant heights.

Net Assimilation Rate (NAR – Williams, 1946)

$$NAR = [(W_2 - W_1)/ (t_2 - t_1)]*[(\log_e L_2 - \log_e L_1)/ (L_2 - L_1)]$$

Where, W_1 and W_2 are dry weights of whole plant at times t_1 and t_2 respectively

L_1 and L_2 are leaf weights or leaf area at t_1 and t_2 respectively

$t_1 - t_2$ are time interval in days

Relative Growth Rate (RGR – Williams, 1946)

$$RGR = \log_e W_2 - \log_e W_1 / t_2 - t_1$$

Where, W_1 and W_2 are dry weights of the whole plant at times t_1 and t_2 respectively

$t_1 - t_2$ are time interval in days

3.4.2 Measurement of physiological parameters

The portable photosynthetic system (LICOR-6400 XT, manufactured by LICOR, USA) was used to measure the physiological behaviour of plants. The readings were taken from 10 am to 12 pm on sunny days. The photosynthetic rate, transpiration rate (E), stomatal conductance (gs), Instantaneous water use efficiency (Pn/E), intrinsic water use efficiency (Pn/gs), Intercellular CO_2 Concentration (Ci), Carboxylation efficiency (Pn/Ci), and Mesophyll efficiency (Ci/gs) were observed using portable photosynthetic system to monitor and study the physiological response of plants to elevated CO_2.

(A) (B)

Plate 3: Portable photosynthesis system (A), Screen of instrument (B)

The Instantaneous WUE was computed as the ratio of CO_2 assimilation through photosynthesis (Pn) and water lost using transpiration (E) (Medranoa *et al.,* 2015) although intrinsic WUE was estimated as the ratio of photosynthetic rate to stomatal conductance (Pn/gs) (Warrier *et al.,* 2013). Intrinsic carboxylation efficiency (Pn/Ci) was computed as the ratio of Pn to intercellular CO_2 concentration (Ci) while intrinsic Mesophyll efficiency (Ci/gs) calculated as the ratio of intercellular CO_2 concentration (Ci) to gs (Warrier *et al.,* 2013).

46

Plate 4: Measuring Night leaf respiration

Plate 5: Measuring Photosynthesis

3.5 Biomass and carbon estimation

The biomass is estimated from different plant parts. The saplings from each treatment were uprooted and separated as root, shoot, and leaf parts after eight months of planting. The uprooted roots were cleaned with distilled water to remove soil particles adhering on root hairs. The fresh weight of root, shoot, and leaves were taken and then subsequently subjected to oven drying. The samples were oven-dried at 650C until a constant weight was reached and then weighed. The oven-dried weight was subtract from fresh weight to get moisture contents. Moisture percentage was also calculated. The biomass was expressed in gram (g) (Wu *et al.,* 2013). The organic carbon was estimated with the soil organic carbon analysis (Walkley and. Black, 1934).

3.6 Biochemical analysis

The biochemical parameters such as chlorophyll, protein, proline, carbohydrate, nutrient analysis, phenols, and ascorbic acid were conducted at the chemical laboratory on Ecology, Climate Change and Forest Influence Division, Forest Research Institute, Dehradun.

Chlorophyll (DMSO method) and carotenoid

Ascorbic acid (spectrophotometer method)

Protein (Bradford dye)

Total sugar (DuBois phenol sulphuric acid method)

Proline (Bait's method)

Organic carbon (Walkey and black method, 1934)

Phosphorous – molybdate blue method

Potassium- flame photometer

Total nitrogen (Kjeldahl method)

3.7 Mitigation efficiency estimation

Carbon concentration in different plant parts was estimated by the combustion method

3.7.1 Carbon stock in different components (Wang and Feng, 1995)

Biomass components (leaves, stem and root) of plant species and their carbon concentration were multiplied to estimate carbon stock in each component.

3.7.2 CO_2 mitigation

CO_2 mitigation by the tree was estimated by multiplying the values of carbon stock by the factor, 3.66.

3.7.3 Total amount of carbon sequestrated in plant component

Total carbon sequestration in plant components was estimated by adding long-lived carbon storage in plant components and the carbon storage due to substitution biomass for coal. Total carbon sequestration was expressed in Mg ha^{-1}.

4. Statistical analysis

Statistical analysis of obtained data will be done with the help of suitable statistical tool to investigate variations of recorded parameters.

49

RESULTS

CHAPTER 4

RESULTS

4.1 Morphological analysis

4.1.2 Response of elevated CO_2 on plant height

Table 1: Response of elevated CO_2 on plant height at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and* *Terminalia* chebula

	Treatments	
Species	400ppm	800ppm
T.arjuna	28.03 ± 0.69	32.36 ± 0.43
T.bellirica	26.65 ± 0.68	37.94 ± 0.66
T.chebula	52.24 ± 1.17	60.75 ± 0.79)

Plants were grown in elevated CO_2 (800 ppm) condition respond better compared to those plants which were in ambient conditions (400 ppm).In the present study plant height of *Terminalia arjuna* was significantly increased under elevated CO_2 condition (32.36 ± 0.43) over ambient condition (28.03 ± 0.69). Increase in the plant height was ~14 % from the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was ~34% in stress (elevated CO_2) condition than ambient. In this species during elevated CO_2 condition, it was recorded higher (37.94 ± 0.66) compared to the control (26.65 ± 0.68) while *Terminalia chebula* showed an increase in the plant height in elevated condition was (60.75 ± 0.79) over ambient condition (52.24 ± 1.17) ~15% of increase was shown. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula* and *Terminalia arjuna*.

4.1.2 Response of elevated CO_2 on leaf length

Table 2: Response of elevated CO_2 on leaf length at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia* bellirica *and Terminalia* chebula

Species	Treatments	
	400ppm	800ppm
T.arjuna	10.23 ± 0.53	11.62 ± 0.47
T.bellirica	12.99 ± 0.48	14.57 ± 0.60
T. chebula	11.28 ± 0.40	12.13 ± 0.36

In this study, leaf length of *Terminalia arjuna* was significantly increased in elevated CO_2 by 11.62 ± 0.47 than ambient condition 10.23 ± 0.53. It is approximately showed an increase of 12.74%. The leaf length of *Terminalia bellirica* increased dramatically in elevated CO_2 by 14.57 ± 0.60 compared to ambient 12.99 ± 0.48. In the case of *Terminalia bellirica*, there is an increase of 11.5%. In this study leaf length of *Terminalia chebula* was significantly high in the elevated condition of CO_2 by 12.13 ± 0.36 over ambient 400ppm 11.28 ± 0.40. The response is 7.26% of the increase in elevated CO_2. In this study under stressed condition *Terminalia arjuna* responded much more than other species- *Terminalia bellirica and Terminalia chebula.*

4.1.3 Response of elevated CO_2 on leaf width

Table 3: Response of elevated CO_2 on leaf width at ambient (400ppm) and elevated (800ppm) conditions of Terminalia arjuna, *Terminalia* bellirica *and Terminalia* chebula

	Treatments	
Species	400ppm	800ppm
T.arjuna	2.77 ± 0.25	3.1 ± 0.21
T.bellirica	4.88 ± 0.26	5.73 ± 0.35
T.chebula	6.12 ± 0.32	6.32 ± 0.24

In the present study, *Terminalia arjuna* plant grown under elevated CO_2 has significant growth in leaf width by 3.1 ± 0.21 concerning ambient (2.77 ± 0.25). The response was significant and higher than approximately 11.63% from ambient 400ppm. *Terminalia bellirica* showed a rapid and significant increase in elevated CO_2 by 5.73 ± 0.35 over the ambient condition of CO_2 (4.88 ± 0.26). The increase is approximately 16.01% than ambient 400ppm. The plant *Terminalia chebula* showed an increase in elevated CO_2 condition by 6.32 ± 0.24 compared to ambient 400ppm 6.12 ± 0.32. The increase is approximately higher than 3.21% to elevated CO_2. Plant *Terminalia bellirica* showed a significant and rapid increase in leaf width compared to the other two species of *Terminalia arjuna and Terminalia chebula.*

4.1.4 Response of elevated CO_2 on stem diameter/ collar diameter

Table 4:Response of elevated CO_2 on stem diameter at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia* bellirica *and Terminalia* chebula

	Treatments	
Species	400ppm	800ppm
T.arjuna	7.34 ± 0.32	7.47 ± 0.28
T.bellirica	5.09 ± 0.26	6.08 ± 0.55
T.chebula	6.99 ± 0.46	9.37 ± 0.53

The current study showed the increasing stem diameter of *Terminalia arjuna* at the stressed condition of elevated CO_2 by 7.47 ± 0.28 over the ambient condition of 400ppm (7.34 ± 0.32), which is 1.75% of increase occur on leaf collar diameter at the stressed condition. The plant *Terminalia bellirica* showed an increase on elevated CO_2 by 6.08 ± 0.55 over ambient 400ppm 5.09 ± 0.26. The increase in collar diameter is approximately 17.72%. The rapid increase occurred in elevated condition subjected *Terminalia chebula* by 9.37 ± 0.53 over the ambient condition of CO_2 is 6.99 ± 0.46. The increase of collar diameter is approximately 29.09% in elevated CO2 in *Terminalia chebula* Plants. Terminalia chebula was showing a dramatic increase to elevated CO_2 than the other two species of *Terminalia bellirica and Terminalia arjuna.*

4.1.5 Response of elevated CO_2 on leaf number

Table 5: Response of elevated CO_2 on number of leaves at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula*

	Treatments	
Species	400ppm	800ppm
T.arjuna	23.08 ± 1.15	24.81 ± 1.12
T.bellirica	5.07 ± 0.39	6.60 ± 0.61
T.chebula	9.55 ± 0.55	10.087 ± 0.79

The current study on *Terminalia arjuna* showed an increase in number of leaves under elevated CO_2 by 24.81 ± 1.12 over ambient CO_2 condition by 23.08 ± 1.15. The increase of number of leaves in elevated CO_2 is approximately 7.22% than ambient condition. The number of leaves in *Terminalia bellirica* grown under elevated CO_2 was increased by 6.60 ± 0.61 over *Terminalia bellirica* grown in the ambient condition of CO_2 is 5.07 ± 0.39. The increase in *Terminalia bellirica* in the stressed condition of CO_2 is approximately 26.25%. *Terminalia chebula* plants grown in elevated condition showed a significant increase by 10.087 ± 0.79 than ambient condition grown *Terminalia chebula* plant. The increase was approximately 5.44% in *Terminalia chebula* under elevated CO_2. *Terminalia bellirica* showed higher response for the number of leaves grown under the elevated condition of CO_2 than other two species of *Terminalia arjuna and Terminalia chebula.*

4.1.6 Response of elevated CO_2 on branch numbers

Table 6: Response of elevated CO_2 on number of branches at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula*

Species	Treatments	
	400ppm	800ppm
T.arjuna	2.19 ± 0.55	2.22 ± 0.47
T. bellirica	0.44 ± 0.31	0.65 ± 0.37
T.chebula	5.73 ± 0.74	5.9 ± 0.80

The present study showed an increase in branch number of *Terminalia arjuna* plants grown in elevated CO_2 by 2.22 ± 0.47 over ambient 400ppm condition (2.19 ± 0.55). The increase in the number of leaves showed by *Terminalia arjuna* was approximately 1.58 % than ambient. The number of branches in *Terminalia bellirica* grown under elevated CO_2 increased by 0.65 ± 0.37 over *Terminalia bellirica* grew in the ambient condition of CO_2 (0.44 ± 0.31). The increase in *Terminalia bellirica* in the stressed condition of CO_2 is approximately 38.53%. *Terminalia chebula* plants grown in elevated condition showed a significant increase by 5.9 ± 0.80 than ambient condition grown *Terminalia chebula* plant 5.73 ± 0.74. The increase was approximately 2.86% in Terminalia chebula under elevated CO_2. *Terminalia bellirica* showed higher response for number of branches grown under the elevated condition of CO_2 than other two species of *Terminalia arjuna and Terminalia chebula.*

4.1.7 Response of elevated CO_2 on root length

Table 7: Response of elevated CO_2 on root length at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

Species	Treatments	
	400ppm	800ppm
T. arjuna	41.5 ± 0.99	57 ± 1.39
T. bellirica	30.1 ± 1.17	41.57 ± 1.54
T.chebula	28.15 ± 1.12	34.1 ± 1.11

In the present study, the root length of *Terminalia arjuna* significantly increased under elevated CO_2 condition (57 ± 1.39) over ambient condition (41.5 ± 0.99). Increase in the root length was approximately 31.47% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was ~32.02% in stress (elevated CO_2) condition than ambient. In this species during elevated CO_2 condition, it was recorded higher (41.57 ± 1.54) compared to the control (30.1 ± 1.17). While *Terminalia chebula* showed an increase in root length in elevated condition (34.1 ± 1.11) over ambient condition (28.15 ± 1.12) an increase of about 119.11%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

4.1.8 Response of elevated CO_2 on total leaf area

Table 8: Response of elevated CO_2 on total leaf area at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

	Treatments	
Species	400ppm	800ppm
T.arjuna	532.63 ± 5.18	745.59 ± 5.11
T.bellirica	237.72 ± 2.73	446.75 ± 5.76
T.chebula	425.1 ± 2.55	621.65 ± 7.44

The current study showed higher leaf area of *Terminalia arjuna* at the stressed condition of elevated CO_2 (745.59 ± 5.11) over the ambient condition of 400ppm (532.63 ± 5.18), which is 27.97% of increase on total leaf area at the stressed condition. *Terminalia bellirica* showed an increase in elevated CO_2 by (446.75 ± 5.76) over ambient 400ppm (237.72 ± 2.73). The increase of leaf area was approximately 61.07%. The rapid increase occurred in the elevated condition in *Terminalia chebula* (621.65 ± 7.44) over the ambient condition of CO_2 is (425.1 ± 2.55). The increase of leaf area was approximately 37.55% in elevated CO_2 in *Terminalia chebula* Plants. *Terminalia bellirica* was showing a dramatic increase to elevated CO2 than other two species *Terminalia chebula and Terminalia arjuna*.

4.1.9 Response of elevated CO_2 on leaf area index

Table 9: Response of elevated CO_2 on leaf area index at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

Species	Treatments	
	400ppm	800ppm
T.arjuna	1.12 ± 0.23	1.41 ± 0.26
T.bellirica	0.503 ± 0.12	0.94 ± 0.265
T.chebula	0.89 ± 0.11	1.31 ± 0.34

In the present study leaf area index of *Terminalia arjuna* significantly increased under elevated CO_2 condition (1.41 ± 0.26) over ambient condition (1.12 ± 0.23). Increase in the leaf area index was 22.67% from the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was ~61.07% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (0.94 ± 0.265) compared to the control (0.503 ± 0.12) while *Terminalia chebula* showed an increase in the leaf area index in elevated condition (1.31 ± 0.34) over ambient condition (0.89 ± 0.11) an increase of about 38.18%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

4.1.10 Response of elevated CO_2 on leaf area ratio

Table 10: Response of elevated CO_2 on leaf area ratio at ambient (400ppm) and elevated (800ppm) conditions of Terminalia arjuna, *Terminalia* bellirica *and Terminalia* chebula

	Treatments	
Species	400ppm	800ppm
T.arjuna	25.57 ± 1.074	32.37± 1.11
T.bellirica	12.09 ± 0.75	20.98 ± 1.506
T.chebula	20.77 ± 0.68	28.85 ± 1.58

In the present study, *Terminalia arjuna* plants grown under elevated CO_2 have a significant leaf area ratio by (32.37± 1.11) concerning ambient 400ppm (25.57 ± 1.074). The response was significant and higher than approximately 23.49% from ambient 400ppm. *Terminalia bellirica* showed rapid and significant increase in elevated CO_2 by (20.98 ± 1.506) over ambient condition of CO_2 is (12.09 ± 0.75). The increase is approximately 53.79% than the ambient 400ppm. *Terminalia chebula* showed an increase in elevated CO_2 condition by (28.85 ± 1.58) compared to ambient 400ppm (20.77 ± 0.68). The increase is approximately higher than 32.55% to elevated CO_2. *Terminalia bellirica* showed a significant and rapid increase in leaf area ratio compared to the other two species of *Terminalia arjuna and Terminalia chebula.*

4.1.11 Response of elevated CO_2 on leaf weight ratio

Table 11: Response of elevated CO_2 on leaf area index at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* *arjuna*, *Terminalia* *bellirica and* *Terminalia* *chebula*

	Treatments	
Species	400ppm	800ppm
T.arjuna	0.306 ± 0.0607	0.337 ± 0.112
T. bellirica	0.296 ± 0.142	0.327 ± 0.102
T.chebula	0.29 ± 0.055	0.335 ± 0.102

In the present study *Terminalia arjuna* grown in ambient 400ppm has a significant leaf weight ratio by (0.337 ± 0.112) over elevated CO_2 (0.306 ± 0.0607). The response was significant and higher than approximately 23.49% than elevated CO_2. *Terminalia bellirica* showed a rapid and significant increase in ambient condition of CO_2 by (0.327 ± 0.102) over elevated CO2 (0.296 ± 0.142). The increase was approximately 9.9852% than elevated CO_2. *Terminalia chebula* showed an increase in elevated CO_2 condition by (0.335 ± 0.102) compared to ambient 400ppm (0.29 ± 0.055). The increase was approximately higher by 11.63% to elevated CO_2. *Terminalia chebula* showed a significant and rapid increase in leaf area ratio compared to the other two species of *Terminalia arjuna and Terminalia chebula*, which showed a rapid decline in leaf weight ratio.

4.1.12 Response of elevated CO_2 on specific leaf area

Table 12: Response of elevated CO_2 on specific leaf area at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna,* Terminalia bellirica *and Terminalia* chebula

Species	Treatments	
	400ppm	800ppm
T.arjuna	77.136 ± 1.91	105.36 ± 1.826
T.bellirica	37.26 ± 1.29	69.88 ± 2.409
T.chebula	69.38 ± 0.98	92.16 ± 3.13

In this case, *Terminalia arjuna* plant is grown under elevated CO_2 a significant specific leaf area by (105.36 ± 1.826) concerning ambient 400ppm (77.136 ± 1.91). The response was significant and higher than approximately 30.93% from ambient 400ppm. The *Terminalia bellirica* showed a rapid and significant increase in elevated CO_2 by (69.88 ± 2.409) over the ambient condition of CO_2 is (37.26 ± 1.29). The increase is approximately 60.89% than ambient 400ppm. The plant *Terminalia chebula* shows an increase in elevated CO_2 condition by (92.16 ± 3.13) compared to ambient 400ppm (69.38 ± 0.98). The increase is approximately higher than 28.19% to elevated CO_2. Plant *Terminalia bellirica* showed a significant and rapid increase in significant leaf area compared to the other two species of *Terminalia arjuna and Terminalia chebula.*

4.1.13 Response of elevated CO_2 on specific leaf weight

Table 13: Response of elevated CO_2 on specific leaf weight at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

Species	Treatments	
	400ppm	800ppm
T. arjuna	0.013 ± 0.026	0.0097± 0.016
T. bellirica	0.0097± 0.016	0.106 ± 0.075
T.chebula	0.0144± 0.013	0.0147 ± 0.039

In this study, *Terminalia arjuna* grown under ambient 400ppm has a specific leaf weight by (0.013 ± 0.026) over elevated CO_2 (0.0097± 0.016). The response was significant and higher than approximately 35.32% than elevated CO_2. The *Terminalia bellirica* showed a rapid and significant increase in elevated CO_2 by (0.106 ± 0.075) over ambient condition of CO_2 (0.0097± 0.016). The increase is approximately 35.32% than ambient 400ppm. Terminalia chebula showed an increase in elevated CO_2 condition by (0.0147 ± 0.039) compared to ambient 400ppm (0.0144± 0.013). The increase was higher by 1.63% to ambient. *Terminalia bellirica* showed significant and rapid increase in leaf area compared to other two species of *Terminalia arjuna and Terminalia chebula*. They showed significant reduction in specific leaf weight.

4.1.14 Response of elevated CO_2 on absolute growth rate

Table 14: Response of elevated CO_2 on absolute growth rate at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica and *Terminalia* chebula

Species	Treatments	
	400ppm	800ppm
T.arjuna	0.113 ± 0.083	0.171 ± 0.065
T.bellirica	0.055 ± 0.065	0.082 ± 0.094
T.chebula	0.046± 0.074	0.083 ± 0.062

In this study, *Terminalia arjuna* grown under elevated CO_2 has an absolute growth rate by 0.171 ± 0.065 concerning ambient 400ppm (0.113 ± 0.083). The response was significant and higher by 40.93% than ambient 400ppm. *Terminalia bellirica* showed a rapid and significant increase in elevated CO_2 by (0.082 ± 0.094)) over the ambient condition of CO_2 (0.055 ± 0.065). The increase was 39.07% higher than ambient 400ppm. *Terminalia chebula* shows an increase in elevated CO_2condition by 0.083 ± 0.062 compared to ambient 400ppm (0.046± 0.074). The increase was approximately higher by 57.75% than ambient CO_2. *Terminalia chebula* showed a significant and rapid increase in absolute growth rate compared to the other two species of *Terminalia arjuna and Terminalia bellirica.*

4.1.15 Response of elevated CO_2 on net assimilation rate

Table 15: Response of elevated CO_2 on net assimilation rate at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

	Treatments	
Species	400ppm	800ppm
T.arjuna	0.24± 0.0041	0.28± 0.066
T.bellirica	0.055± 0.065	0.23± 0.072
T. chebula	0.0180± 0.004	0.187± 0.077

In this case *Terminalia arjuna* plant grown under elevated CO_2 has net assimilation rate by 0.28± 0.066 concerning ambient 400ppm (0.24± 0.0041). The response was significant and higher by 15.38% than ambient 400ppm. *Terminalia bellirica* showed a rapid and significant increase in elevated CO_2 by 0.23± 0.072 over the ambient condition of CO_2 (0.055± 0.065). The increase is approximately 119.44% than ambient 400ppm. *Terminalia chebula* showed an increase in elevated CO_2 condition by 0.187± 0.077 compared to ambient 400ppm (0.0180± 0.004). The increase was higher by 166.6% than ambient CO_2. *Terminalia bellirica* showed a significant and rapid increase in net assimilation rate compared to the other two species of *Terminalia arjuna and Terminalia chebula*.

4.1.16 Response of elevated CO_2 on relative growth rate

Table 16: Response of elevated CO_2 on relative growth rate at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

Species	Treatments	
	400ppm	800ppm
T.arjuna	0.24± 0.0041	0.28± 0.066
T.bellirica	0.055± 0.065	0.23± 0.072
T.chebula	0.0180± 0.004	0.187± 0.077

In this study, *Terminalia arjuna* plant grown under elevated CO_2 has a relative growth rate by 0.28± 0.066 concerning ambient 400ppm (0.24± 0.0041). The response was significant and higher by 15.38% than ambient 400ppm. *Terminalia bellirica* showed a rapid and significant increase in elevated CO_2 by 0.23± 0.072 over the ambient condition of CO_2 (0.055± 0.065). The increase was 119.44% higher than ambient 400ppm. *Terminalia chebula* showed an increase in elevated CO_2 condition by 0.187± 0.077 compared to ambient 400ppm (0.018 ± 0.004). The increase was higher by 166.6% than ambient CO_2. *Terminalia chebula* showed a significant and rapid increase in relative growth rate compared to the other two species of *Terminalia arjuna and Terminalia bellirica*.

4.1.17 Response of elevated CO_2 on root shoot ratio

Table 17: Response of elevated CO_2 on root-shoot ratio at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

	400ppm	800ppm
T.arjuna	0.602 ± 0.129	0.616 ± 0.205
T.bellirica	1.008 ± 0.503	0.974 ± 0.219
T.chebula	1.004 ± 0.076	0.81 ± 0.111

In this study, *Terminalia arjuna* grown under elevated CO_2 has root shoot ratio by 0.616 ± 0.205 concerning ambient 400ppm (0.602 ± 0.129). The response was significant and higher by 2.24% than ambient 400ppm. *Terminalia bellirica* showed a significant increase in ambient condition of CO_2 by 1.008 ± 0.503 over elevated CO_2 (0.974 ± 0.219). The increase was 3.44% higher than elevated CO_2. *Terminalia chebula* showed an increase in ambient 400ppm condition by 1.004 ± 0.076 compared to elevated CO_2 (0.81 ± 0.111). The increase was approximately 21.39% higher than elevated CO_2. *Terminalia arjuna* showed a significant and rapid increase in root shoot ratio compared to the other two species of *Terminalia chebula and Terminalia bellirica*, which showed a rapid decline in root shoot ratio at elevated CO_2.

4.2 Biomass and Moisture content

4.2.1 Response of elevated CO_2 on fresh weight

Table 18: Response of elevated CO_2 on fresh weight at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula*

	Leaf	Stem	Root
T.arjuna-800	15.71 ± 0.5	16.06 ± 0.74	25.7 ± 0.79
T.arjuna-400	15.49 ± 0.51	15.526 ± 0.65	20.85 ± 0.7
T.bellirica-800	16.28 ± 0.68	10.84 ± 0.9	28.36 ± 1.24
T.bellirica-400	15.99 ± 1.02	8.11 ± 0.98	25.25 ± 1.48
T.chebula-800	17.12 ± 0.86	13.92 ± 0.8	23.9 ± 0.87
T.chebula-400	16.83 ± 0.69	10.813 ± 0.54	23.45± 0.59

Leaves: In the present study, the fresh weight of leaves of *Terminalia arjuna* significantly increased under elevated CO_2 condition (15.71 ± 0.508) over ambient condition (15.49 ± 0.519). Increase in leaf fresh weight was approximately 1.45% than ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was approximately 1.84% in stress (elevated CO_2) condition than ambient. In this species at elevated CO_2 condition, it was higher (16.28 ± 0.683) compared to the control (15.99 ± 1.022) while *Terminalia chebula* showed an increase in the fresh leaf weight in elevated condition (17.12 ± 0.86) over ambient condition (16.83 ± 0.695) an increase of about 1.707%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

Stem: Fresh weight of a stem of *Terminalia arjuna* significantly increased under elevated CO_2 condition (16.06 ± 0.742) over ambient condition (15.526 ± 0.659). Increase in fresh stem weight was approximately 3.39% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was approximately 28.76% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (10.84 ± 0.905) compared to the control (8.116 ± 0.985) while *Terminalia chebula* showed an increase in the fresh stem weight in elevated condition (13.92 ± 0.801) over ambient condition (10.813 ± 0.547) an increase of about 25.12 %. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

Roots: Fresh weight of root of *Terminalia arjuna* significantly increased under elevated CO_2 condition (25.703 ± 0.797) over ambient condition (20.85 ± 0.70009). Increase in the fresh root weight was approximately 20.83% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 11.59% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (28.36 ± 1.24) compared to the control (25.25 ± 1.48) while *Terminalia chebula* showed an increase in the fresh root weight in elevated condition (23.9 ± 0.871) over ambient condition (23.45± 0.591) an increase of 2.109%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

4.2.2 Response of elevated CO_2 on Dry weight

Table 19: Response of elevated CO_2 on dry weight at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

	Leaf	Stem	Root
T.arjuna-800	7.18 ± 0.25	7.08 ± 0.59	8.31 ± 0.54
T.arjuna-400	7.07 ± 0.39	6.87 ± 0.62	8.29 ± 0.6
T.bellirica-800	6.44 ± 0.3	5.05 ± 0.54	11.2 ± 0.79
T.bellirica-400	6.46 ± 0.49	3.87 ± 0.63	10.2 ± 0.71
T.chebula-800	6.75 ± 0.97	6.19 ± 0.85	9.97 ± 0.83
T.chebula-400	5.69 ± 0.52	4.5 ± 0.21	10.04 ± 0.4

Leaves: In the present study, the dry weight of leaves of *Terminalia arjuna* significantly increased under elevated CO_2 condition (7.18 ± 0.254) over ambient condition (7.075 ± 0.39). Increase in the leaf dry weight was approximately 1.51% from the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was approximately 2.51% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (6.44 ± 0.301) compared to the control (6.28 ± 0.492) while *Terminalia chebula* showed an increase in the leaf dry weight in elevated condition (6.75 ± 0.97) over ambient condition (5.69 ± 0.529) an increase of about 17.04%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna.*

Stem: Dry weight of a stem of *Terminalia arjuna* significantly increased under elevated CO_2 condition (7.08 ± 0.59) over ambient condition (6.87 ± 0.62). Increase in the stem dry weight 2.93% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was approximately 26.45% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (5.05 ± 0.54) compared to the control (3.87 ± 0.631) while *Terminalia chebula* showed an increase in the stem dry weight in elevated condition (6.19 ± 0.854) over ambient condition (4.5 ± 0.211) an increase of about 9.3%. Among these species *Terminalia bellirica* showed a better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

Roots: Dry weight of root of *Terminalia arjuna* significantly increased under elevated CO_2 condition (8.31 ± 0.54) over ambient condition (8.29 ± 0.602). Increase in the root dry weight 0.28% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was approximately 31.61% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (11.2 ± 0.79) compared to the control (10.2 ± 0.71) while *Terminalia chebula* showed an increase in dry weight in ambient condition (10.045 ± 0.406) over elevated condition (9.97 ± 0.83) an increase of about 9.3%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia arjuna*, and there is a decline in *Terminalia chebula* under elevated CO_2.

4.2.3 Response of elevated CO_2 on moisture content

Table 20: Response of elevated CO_2 on moisture content at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia* bellirica *and Terminalia* chebula

	Leaf	Stem	Root
T.arjuna-800	54.88 ± 0.78	54.66 ± 1.49	67.65 ± 0.85
T.arjuna-400	56.02 ± 0.71	55.8 ± 1.53	60.36 ± 1.2
T.bellirica-800	59.8 ± 1.37	54.67 ± 2.93	61.42 ± 1.2
T.bellirica-400	57.67 ± 1.73	50.68 ± 2.22	56.56 ± 1.63
T.chebula-800	61.21 ± 1.2	55.8 ± 0.97	58.43 ± 0.66
T.chebula-400	66.26 ± 0.95	58.005 ± 0.79	56.75 ± 1.04

Leaves: Moisture content (MC) of leaves of *Terminalia arjuna* decreased under elevated CO_2 condition (54.882 ± 0.783) over ambient condition (56.022 ± 0.713). Increase in the MC of leaves was approximately 2.05% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was approximately 3.4% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (59.808 ± 1.376) compared to the control (57.678 ± 1.735) while *Terminalia chebula* showed an increase in the MC of leaves in ambient condition (66.264 ± 0.952) over elevated condition (61.213 ± 1.205) an increase of about 5.72%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia arjuna*, and there is a decline in *Terminalia chebula*.

Stem: Moisture content (MC) of stems of *Terminalia arjuna* significantly increased under ambient condition (55.809 ± 1.537) over elevated CO_2 condition

(54.663 ± 1.498). Increase in the stem MC was 2.07% higher than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was approximately 7.59% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (54.679 ± 2.933) compared to the control (50.68 ± 2.224) while *Terminalia chebula* showed an increase in the stem MC in ambient condition (58.005 ± 0.798) over elevated condition (55.804 ± 0.974) an increase of about 3.86%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula* and *Terminalia arjuna*.

Root: Moisture content (MC) of roots of *Terminalia arjuna* was significantly increased under elevated CO_2 condition (67.65 ± 0.851) over ambient condition (60.367 ± 1.202). Increase in the MC of the root was 11.38% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 8.24% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (61.426 ± 1.209) compared to the control (56.565 ± 1.632) while *Terminalia chebula* showed an increase in the MC of the root in elevated condition (58.43 ± 0.666) over ambient condition (56.759 ± 1.048) an increase of about 2.89%. Among these species *Terminalia arjuna* showed better results in stress condition followed by *Terminalia chebula and Terminalia bellirica*.

4.3 Physiological Analysis

4.3.1 Response of elevated CO_2 on Photosynthetic Rate (Pn)

Table 21: Response of elevated CO_2 on Photosynthetic rate at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia* bellirica *and Terminalia* chebula

	Winter	Spring	Summer
T.arjuna-800	7.65 ± 0.29	10.07 ± 0.37	26.91 ± 3.895
T.arjuna-400	6.77 ± 0.53	8.86 ± 0.38	21.51 ± 2.44
T.bellirica-800	7.62 ± 0.25	7.44 ± 0.18	14.76 ± 3.26
T.bellirica-400	5.39 ± 0.5	6.78 ± 0.39	11.66 ± 3.25
T.chebula-800	7.15 ± 0.17	7.83 ± 0.43	17.4 ± 3.3
T.chebula-400	4.75 ± 0.31	5.39 ± 0.4	7.55 ± 0.87

Winter (December-January): Photosynthetic rate (Pn) of *Terminalia arjuna* in winter significantly increased under elevated CO_2 condition (7.65 ± 0.29) over ambient condition (6.77 ± 0.53). Increase in Pn was approximately 12.06% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 34.27% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (7.62 ± 0.25) compared to the control (5.39 ± 0.503) while *Terminalia chebula* showed an increase in the Pn in elevated condition (7.15 ± 0.17) over ambient condition (4.75 ± 0.31) an increase of about 40.36%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna*.

Spring (February-March): Photosynthetic rate (Pn) of *Terminalia arjuna* in spring sign, defiantly increased under elevated CO_2 condition (10.07 ± 0.37) over ambient condition (8.86 ± 0.387). Increase in Pn was approximately 12.74% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 9.23% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (7.44 ± 0.18) compared to the control (6.78 ± 0.39) while *Terminalia chebula* showed an increase in the Pn in elevated condition (7.83 ±, 0.43) over ambient condition (5.39 ± 0.403) an increase of about 36.77%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna.*

Summer (April-May): Photosynthetic (Pn) of *Terminalia arjuna* in summer significantly increased under elevated CO_2 condition (26.91 ± 3.895) over ambient condition (21.51 ± 2.44). Increase in Pn was 22.29% of the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was approximately 23.46% in stress (elevated CO_2) condition than ambient. In this species during elevated CO_2 condition it was higher (14.76 ± 3.26) compared to the control (11.66 ± 3.25) while *Terminalia chebula* showed an increase in Pn in elevated condition (17.4 ± 3.3) over ambient condition (7.55 ± 0.875) an increase of about 78.95%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna.*

4.3.2 Response of elevated CO_2 on Stomatal Conductance (gs)

Table 22: Response of elevated CO_2 on stomatal conductance at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

	Winter	Spring	Summer
T.arjuna-800	0.0906 ± 0.0042	0.0831 ± 0.0033	0.122 ± 0.0202
T.arjuna-400	0.126 ± 0.017	0.038 ± 0.0054	0.194 ± 0.022
T.bellirica-800	0.1006 ± 0.012	0.0722± 0.503	0.122 ± 0.015
T.bellirica-400	0.125 ± 0.016	0.067 ± 0.0053	0.185 ± 0.02
T.chebula-800	0.081 ± 0.0069	0.0501 ±0.00601	0.119 ± 0.032
T.chebula-400	0.1007 ± 0.014	0.055 ± 0.009	0.144 ± 0.024

Winter: Stomatal conductance (gs) of *Terminalia arjuna* in winter significantly increased under ambient condition (0.126 ± 0.017) over elevated CO_2 condition (0.0906 ± 0.0042). Increase in gs was approximately 12.06% over the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 21.63% in ambient than stress (elevated CO_2) condition. In this species, under ambient condition, it was higher (0.125 ± 0.016) compared to the elevated condition (0.1006 ± 0.012) while *Terminalia chebula* showed an increase in gs in ambient condition (0.1007 ± 0.014) over elevated condition (0.081 ± 0.0069) an increase of about 21.68%. Among these species, *Terminalia chebula* showed better results in ambient condition followed by *Terminalia bellirica and Terminalia arjuna.*

Spring: Stomatal conductance (gs) of *Terminalia arjuna* in spring significantly increased under elevated CO_2 condition (0.0831 ± 0.0033) over ambient condition (0.038 ± 0.0054). Increase in gs was 74.38% over the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 7.47% in stress (elevated CO_2) condition than ambient. In this species under the elevated condition, it was higher (0.0722± 0.503) compared to the ambient CO_2 (0.067 ± 0.0053) while *Terminalia chebula* showed an increase in the gs in ambient condition (0.055 ± 0.009) over elevated condition (0.0501 ±0.00601) an increase of about 9.32%. Among these species, *Terminalia arjuna* showed better results in stress condition followed by *Terminalia bellirica*, but *Terminalia chebula* showed better response under ambient.

Summer: Stomatal conductance (gs) of *Terminalia arjuna* in summer significantly increased under ambient condition (0.194 ± 0.022) over elevated CO_2 condition (0.122 ± 0.0202). Increase in gs was 45.56% over the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 41.04% in ambient than stress (elevated CO_2) condition. In this species under the ambient condition, it was higher (0.185 ± 0.02) compared to the elevated CO_2 (0.122 ± 0.015) while *Terminalia chebula* showed an increase in gs ambient condition (0.144 ± 0.024) over elevated condition (0.119 ± 0.032) an increase of about 19.01%. Among these species, *Terminalia arjuna* showed better results in ambient condition followed by *Terminalia bellirica and Terminalia chebula*.

4.3.3 Response of elevated CO_2 on Intercellular CO_2 Concentration (Ci)

Table 23: Response of elevated CO_2 on intercellular CO_2 concentration at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

	Winter	Spring	Summer
T.arjuna-800	203.74 ± 5.87	171.44 ± 8.806	255.66 ± 23.89
T.arjuna-400	287.14 ± 10.101	199.28 ± 10.88	261.83 ± 39.94
T.bellirica-800	239.54 ± 15.74	154.81 ± 16.38	261.83 ± 39.94
T.bellirica-400	307.94 ± 3.88	210.36 ± 13.21	285.66 ± 36.88
T.chebula-800	221.32 ± 12.71	164.68 ± 10.77	276.83 ± 45.21
T.chebula-400	300.87 ± 9.06	237.91 ± 22.23	273 ± 9.81

Winter: Intercellular CO_2 Concentration (Ci) of *Terminalia arjuna* in winter significantly increased under ambient condition (287.14 ± 10.101) over elevated CO_2 condition (203.74 ± 5.87). Increase in Ci was 33.98%, than the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 24.98% in ambient than stress (elevated CO_2) condition. In this species under the ambient condition, it was higher (307.94 ± 3.88) compared to the elevated CO_2 (239.54 ± 15.74) while *Terminalia chebula* showed an increase in the Ci ambient condition (300.87 ± 9.06) over elevated condition (221.32 ± 12.71) an increase of about 30.46%. Among these species, *Terminalia arjuna* showed better results in ambient condition followed by *Terminalia bellirica* and *Terminalia chebula.*

Spring: Intercellular CO_2 Concentration (Ci) of *Terminalia arjuna* in spring significantly increased under ambient condition (199.28 ± 10.88) over elevated CO_2 condition (171.44 ± 8.806). Increase in Ci was approximately 15.01% than the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 30.42% in ambient than stress (elevated CO_2) condition. In this species under ambient condition, it was higher (210.36 ± 13.21) compared to the elevated CO_2 (154.81 ± 16.38) while *Terminalia chebula* showed an increase in the Ci ambient condition (237.91 ± 22.23) over elevated condition (164.68 ± 10.77) an increase of about 36.37%. Among these species *Terminalia chebula* showed better results in ambient condition followed by *Terminalia bellirica and Terminalia arjuna.*

Summer: Intercellular CO_2 Concentration (Ci) of *Terminalia arjuna* in summer significantly increased under ambient condition (261.83 ± 39.94) over elevated CO_2 condition (255.66 ± 23.89). Increase in Ci was 2.38% from the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 8.7% in ambient than stress (elevated CO_2) condition. In this species under the ambient condition it was higher (285.66 ± 36.88) compared to the elevated CO_2 (261.83 ± 39.94) while *Terminalia chebula* showed an increase in Ci elevated condition (276.83 ± 45.21) over ambient condition (273 ± 9.81), an increase of about 1.39%. Among these species, *Terminalia chebula* showed better results in stress condition and other *Terminalia bellirica, and Terminalia arjuna* are showed a good response at ambient condition.

4.3.4 Response of elevated CO_2 on Transpiration

Table 24: Response of elevated CO_2 on transpiration rate at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica and *Terminalia* chebula

	Winter	Spring	Summer
T.arjuna-800	2.42 ± 0.104	2.75 ± 0.071	4.29 ± 0.53
T.arjuna-400	1.89 ± 0.242	3.006 ± 0.265	6.305 ± 0.47
T.bellirica-800	2.738 ± 0.1005	2.28 ± 0.157	5.2 ± 0.801
T.bellirica-400	1.93 ± 0.21	1.33 ± 0.119	6.14 ± 0.38
T.chebula-800	2.251 ± 0.121	3.205 ± 0.202	4.513 ± 0.75
T.chebula-400	1.62 ± 0.17	2.37 ± 0.34	4.30 ± 0.061

Winter: Transpiration (E) of *Terminalia arjuna* in winter significantly increased under elevated CO_2 condition (2.42 ± 0.104) over ambient condition (1.89 ± 0.242). Increase in E was approximately 24.59% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 34.33% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (2.738 ± 0.1005) compared to the control (1.93 ± 0.21) while *Terminalia chebula* showed an increase in the E in elevated condition (2.251 ± 0.121) over ambient condition (1.62 ± 0.17), an increase of about 32.55%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

Spring: Transpiration (E) of *Terminalia arjuna* in spring significantly increased under ambient condition (3.006 ± 0.265) over elevated CO_2 condition (2.75 ± 0.071). Increase in E was 8.71% from the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 56.63% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition it was higher (2.28 ± 0.157) compared to the control (1.33 ± 0.119) while *Terminalia chebula* showed an increase in E in elevated condition (3.205 ± 0.202) over ambient condition (2.37 ± 0.34) an increase of about 29.8%. Among these species *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and in Terminalia arjuna,* better response showed in ambient condition.

Summer: Transpiration (E) of *Terminalia arjuna* in summer significantly increased under ambient condition (6.305 ± 0.47) over elevated CO_2 condition (4.29 ± 0.53). Increase in E was 37.96% than the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 16.57% in ambient than stress (elevated CO_2) condition. In this species, under the ambient condition it was recorded higher (6.14 ± 0.38) compared to the elevated CO_2 (5.2 ± 0.801) while *Terminalia chebula* showed an increase in E in elevated condition (4.513 ± 0.75) over ambient condition (4.30 ± 0.061), an increase of about 4.76%. Among these species, *Terminalia arjuna* showed better results in ambient condition followed by *Terminalia bellirica* and the *Terminalia chebula* result under elevated CO_2.

4.3.5 Response of elevated CO_2 on Instantaneous water use efficiency

Table 25: Response of elevated CO_2 on instantaneous water use efficiency at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

	Winter	Spring	Summer
T.arjuna-800	3.169 ± 0.242	3.66 ± 0.227	6.964 ± 0.749
T.arjuna-400	3.736 ± 0.357	3.045 ± 0.326	3.516 ± 0.437
T.bellirica-800	2.789 ± 0.14	3.322 ± 0.267	3.798 ± 0.8004
T.bellirica-400	2.843 ± 0.192	5.194 ± 0.387	1.925 ± 0.472
T.chebula-800	3.236 ± 0.296	2.483 ± 0.282	4.44 ± 0.689
T.chebula-400	3.017 ± 0.288	2.33 ± 0.28	1.79 ± 0.24

Winter: Instantaneous water use efficiency (Pn/E) of *Terminalia arjuna* in winter significantly increased under ambient condition (3.736 ± 0.357) over elevated CO_2 condition (3.169 ± 0.242). Increase in Pn/E was 16.54% than the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 2.13% in ambient than stress (elevated CO_2) condition. In this species, under the ambient condition, it was higher (2.843 ± 0.192) compared to the elevated CO_2 condition (2.789 ± 0.14) while *Terminalia chebula* showed an increase in Pn/E in elevated condition (3.236 ± 0.296) over ambient condition (3.017 ± 0.288) which was increase of about 7.05%. Among these species, *Terminalia chebula* showed better results in stress condition, and *Terminalia bellirica and Terminalia arjuna* showed good response under ambient.

Spring: Instantaneous water use efficiency (Pn/E)) of *Terminalia arjuna* in spring significantly increased under elevated CO_2 condition (3.66 ± 0.227) over ambient condition (3.045 ± 0.326). Increase in Pn/E was 18.5% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 43.94% in ambient than stress (elevated CO_2) condition. In this species, under ambient condition, it was higher (5.194 ± 0.387) compared to the elevated CO_2 condition (3.322 ± 0.267) while *Terminalia chebula* showed an increase in Pn/E in elevated condition was (2.483 ± 0.282) over ambient condition (2.33 ± 0.28) which was increase of about 6.23%. Among these species *Terminalia arjuna* showed better results in stress condition followed by *Terminalia chebula*, the *Terminalia bellirica* showed good response under ambient.

Summer: Instantaneous water use efficiency (Pn/E) of *Terminalia arjuna* in summer significantly increased under elevated CO_2 condition (6.964 ± 0.749) over ambient condition (3.516 ± 0.437). Increase in Pn/E was 65.95% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 65.49% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (3.798 ± 0.8004) compared to the control (1.925 ± 0.472) while *Terminalia chebula* showed an increase in Pn/E in elevated condition was (4.44 ± 0.689) over ambient condition (1.79 ± 0.24) an increase of about 85.07%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna.*

4.3.6 Response of elevated CO_2 on intrinsic water use efficiency

Table 26: Response of elevated CO_2 on intrinsic water use efficiency at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* b*ellirica and Terminalia* chebula

	Winter	Spring	Summer
T.arjuna-800	84.67 ± 0.92	121.369 ± 1.264	263.09 ± 4.927
T.arjuna-400	56.246 ± 1.435	242.206 ± 3.09	118.468 ± 2.75
T.bellirica-800	75.829 ± 0.739	107.767 ± 2.055	151.946 ± 5.186
T.bellirica-400	45.52 ± 0.76	104.348 ± 2.241	47.457 ± 2.84
T.chebula-800	91.783 ± 1.93	163.73 ± 2.395	274.672 ± 7.76
T.chebula-400	50.467 ± 1.446	105.781 ± 2.58	72.185 ± 1.775

Winter: Intrinsic water use efficiency (Pn/gs) of *Terminalia arjuna* in winter significantly increased under elevated CO_2 condition (84.67 ± 0.92) over ambient condition (56.246 ± 1.435). Increase in Pn/gs was 40.35% over the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 43.91% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (75.829 ± 0.739) compared to the control (45.52 ± 0.76) while *Terminalia chebula* showed an increase in Pn/gs in elevated condition (91.783 ± 1.93) over ambient condition (50.467 ± 1.446) an increase of about 58.09%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna.*

Spring: Intrinsic water use efficiency (Pn/gs) of *Terminalia arjuna* in spring significantly increased under ambient condition (242.206 ± 3.09) over elevated CO_2

84

condition (121.369 ± 1.264). Increase in Pn/gs was 66.47% from the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 3.22% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (107.767 ± 2.055) compared to the control (104.348 ± 2.241) while *Terminalia chebula* showed an increase in Pn/gs in elevated condition (163.73 ± 2.395) over ambient condition (105.781 ± 2.58) an increase of about 43%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica*, and *Terminalia arjuna* showed good response under ambient.

Summer: Intrinsic water use efficiency (Pn/gs) of *Terminalia arjuna* in summer significantly increased under elevated CO_2 condition (263.09 ± 4.927) over ambient condition (118.468 ± 2.75). Increase in Pn/gs was 75.81% over the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 104.8% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (151.946 ± 5.186) compared to the control (47.457 ± 2.84) while *Terminalia chebula* showed an increase in Pn/gs in elevated condition (274.672 ± 7.76) over ambient condition (72.185 ± 1.775) which was an increase of about 116.75%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna.*

4.3.7 Response of elevated CO_2 on carboxylation efficiency

Table 27: Response of elevated CO_2 on carboxylation efficiency at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

	Winter	Spring	Summer
T.arjuna-800	0.0237 ± 0.024	0.045 ± 0.0349	0.0823 ± 0.07
T.arjuna-400	0.0376 ± 0.022	0.059 ± 0.0345	0.112 ± 0.094
T.bellirica-800	0.0319 ± 0.0198	0.059 ± 0.053	0.0813 ± 0.123
T.bellirica-400	0.01745 ± 0.0223	0.0333 ± 0.040	0.0523 ± 0.0929
T.chebula-800	0.0329 ± 0.03)	0.0479 ± 0.032	0.075 ± 0.087
T.chebula-400	0.0157 ± 0.0119	0.0241 ± 0.0392	0.0279 ± 0.037

Winter: Carboxylation efficiency (Pn/Ci) of *Terminalia arjuna* in winter significantly increased under ambient condition (0.0376 ± 0.022) over elevated CO_2 condition (0.0237 ± 0.024). Increase in Pn/Ci was 46.66% from the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 58.33% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (0.0319 ± 0.0198) compared to the control (0.01745 ± 0.0223) while *Terminalia chebula* showed an increase in Pn/Ci in elevated condition (0.0329 ± 0.03) over ambient condition (0.0157 ± 0.0119) an increase of about 72.34%. Among these species *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica* and *Terminalia arjuna* showed better response under ambient.

Spring: Carboxylation efficiency (Pn/Ci) of *Terminalia arjuna* in spring significantly increased under ambient condition (0.059 ± 0.0345) over elevated CO_2 condition (0.045 ± 0.0349). Increase in Pn/Ci was approximately 26.92% than the elevated condition. However, in the case of *Terminalia bellirica* the percent increase was 56.52% in stress (elevated CO_2) condition than ambient. In this species, under elevated CO_2 condition it was higher (0.059 ± 0.053) compared to the control (0.0333 ± 0.040) while *Terminalia chebula* showed an increase in Pn/Ci in elevated condition was (0.0479 ± 0.032) over ambient condition (0.0241 ± 0.0392) an increase of about 64.78%. Among these species *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna* showed better response under ambient.

Summer: Carboxylation efficiency (Pn/Ci) of *Terminalia arjuna* in summer significantly increased under ambient condition (0.112 ± 0.094) over elevated CO_2 condition (0.0823 ± 0.07). Increase in Pn/Ci was 30.92% than the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 43.41% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition it was higher (0.0813 ± 0.123) compared to the control (0.0523 ± 0.0929) while *Terminalia chebula* showed an increase in Pn/Ci in elevated condition (0.075 ± 0.087) over ambient condition (0.0279 ± 0.037) an increase of about 91.54%. Among these species *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna* showed a better response under ambient.

4.3.8 Response of elevated CO_2 on mesophyll efficiency

Table 28: Response of elevated CO_2 on mesophyll efficiency at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* b*ellirica and Terminalia* chebula

	Winter	Spring	Summer
T.arjuna-800	2404.855 ± 9.814	2072.927 ± 6.01	2463.71 ± 14.87
T.arjuna-400	2558.696 ± 5.091	5366.45 ± 13.009	1475.844 ± 8.65
T.bellirica-800	2381.223 ± 3.77	2236.096 ± 11.55	2109.03 ± 11.71
T.bellirica-400	2687.11 ± 9.905	3184.3 ± 11.21	1599.81 ± 9.73
T.chebula-800	2756.647 ± 6.017	3436.28 ± 11.05	3342.59 ± 21.89
T.chebula-400	3233.73 ± 12.52	4417.166 ± 12.7	2761.8 ± 12.32

Winter: Mesophyll efficiency (Ci/gs) of *Terminalia arjuna* in winter significantly increased under ambient condition (2558.696 ± 5.091) over elevated CO_2 condition (2404.855 ± 9.814). Increase in Ci/gs was 6.19% from the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 12.07% in ambient than stress (elevated CO_2) condition. In this species, under the ambient condition, it was higher (2687.11 ± 9.905) compared to the elevated CO_2 condition (2381.223 ± 3.77) while *Terminalia chebula* showed an increase in Ci/gs in ambient condition (3233.73 ± 12.52) over elevated condition (2756.647 ± 6.017) an increase of about 15.92%. Among these species, *Terminalia chebula* showed better results in ambient condition followed by *Terminalia bellirica and Terminalia arjuna.*

Spring: Mesophyll efficiency (Ci/gs) of *Terminalia arjuna* in spring significantly increased under ambient condition (5366.452 ± 13.009) over elevated CO_2 condition (2072.927 ± 6.01). Increase in Ci/gs was 88.54% than the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 34.98% in ambient than stress (elevated CO_2) condition. In this species, under ambient condition was recorded higher (3184.301 ± 11.214) compared to the elevated CO2 condition (2236.096 ± 11.55) while *Terminalia chebula* showed an increase in Ci/gs in ambient condition (4417.166 ± 12.7) over elevated condition (3436.284 ± 11.059) an increase of about 24.97%. Among these species *Terminalia arjuna* showed better results in ambient condition followed by *Terminalia bellirica and Terminalia chebula.*

Summer: Mesophyll efficiency (Ci/gs) of *Terminalia arjuna* in summer significantly increased under elevated CO_2 condition (2463.719 ± 14.875) over ambient condition (1475.844 ± 8.65). Increase in Ci/gs was 50.15% from the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 27.45% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition it was higher (2109.032 ± 11.711) compared to the control (1599.81 ± 9.737) while *Terminalia chebula* showed an increase in Ci/gs in elevated condition (3342.595 ± 21.89) over ambient condition (2761.807 ± 12.324) an increase of about 19.02%. Among these species, *Terminalia arjuna* showed better results in stress condition followed by *Terminalia bellirica and Terminalia chebula.*

4.3.9 Response of elevated CO_2 on night leaf respiration

Table 29: Response of elevated CO_2 on night leaf respiration at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* *arjuna, Terminalia* *bellirica and Terminalia* *chebula*

	Winter	Spring	Summer
T.arjuna-800	-1.319 ± 0.181	-1.261 ± 0.104	-0.966 ± 0.17
T.arjuna-400	-1.086 ± 0.172	-0.865 ± 0.161	-2.36 ± 0.288
T.bellirica-800	-1.279 ± 0.244	-0.757 ± 0.23	-1.018 ± 0.23
T.bellirica-400	-1.22 ± 0.125	-0.923 ± 0.347	-2.66 ± 0.615
T.chebula-800	-1.06 ± 0.096	-0.53 ± 0.1750	-1.48 ± 0.234
T.chebula-400	-1.2007 ± 0.144	-0.284 ± 0.2177	-2 ± 0.206

Winter: Night Leaf Respiration (A) of *Terminalia arjuna* in winter significantly increased under ambient condition (-1.086 ± 0.172) over elevated CO_2 condition (-1.319 ± 0.181). Increase in A was 19.37% than the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 4.7% in ambient than stress (elevated CO_2) condition. In this species, under the ambient condition it was higher (-1.22 ± 0.125) compared to the elevated CO_2 condition (-1.279 ± 0.244) while *Terminalia chebula* showed an increase in A in elevated condition (-1.06 ± 0.096) over ambient condition (-1.2007 ± 0.144) an increase of about 12.38%. Among these species *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna* showed a better response under ambient.

Spring: Night Leaf Respiration (A) of *Terminalia arjuna* in spring significantly increased under ambient condition (-0.865 ± 0.161) over elevated CO_2 condition (-1.261 ± 0.104). Increase in A was approximately 37.73% over the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was approximately 20.35% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition it was higher (-0.757 ± 0.23) compared to the control (-0.923 ± 0.347) while *Terminalia chebula* showed an increase in A in ambient condition (-0.284 ± 0.2177) over elevated condition (-0.53 ± 0.1750) an increase of about 60.44%. Among these species *Terminalia chebula* showed better results in ambient condition followed by *Terminalia arjuna* and *Terminalia bellirica* showed better response under elevated condition

Summer: Night Leaf Respiration (A) of *Terminalia arjuna* in summer significantly increased under elevated CO_2 condition (-0.966 ± 0.17) over ambient condition (-2.36 ± 0.288). Increase in A was 84.33% from the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 89.91% in stress (elevated CO_2) condition than ambient. In this species, during elevated CO_2 condition, it was higher (-1.018 ± 0.23) compared to the control (-2.66 ± 0.615) while Terminalia chebula showed an increase in A in elevated condition (-1.483 ± 0.234) over ambient condition (-2 ± 0.206) an increase of about 29.88%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

4.4 Mitigation Response

4.4.1 Response of elevated CO_2 on Carbon sequestration

Table 30: Response of elevated CO_2 on carbon sequestration at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

T.arjuna-800	16.6 ± 0.66
T.arjuna-400	16.04 ± 0.69
T.bellirica-800	20.31 ± 1.01
T.bellirica-400	12.15 ± 1.02
T.chebula-800	15.22 ± 0.78
T.chebula-400	11.98 ± 0.55

Carbon sequestration of *Terminalia arjuna* was significantly increased under elevated CO_2 condition (16.6 ± 0.66) over ambient condition (16.04 ± 0.69). Increase in sequestration was 3.43% from the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 50.31% in stress (elevated CO_2) condition than ambient. In this species during elevated CO_2 condition it was higher (20.31 ± 1.01) compared to the control (12.15 ± 1.02) while *Terminalia chebula* showed an increase in the sequestration in elevated condition (15.22 ± 0.78) over ambient condition (11.98 ± 0.55) an increase of about 23.8%. Among these species *Terminalia chebula* showed better results in stress condition followed by *Terminalia bellirica and Terminalia arjuna.*

4.4.2 Response of elevated CO_2 on Carbon partitioning

Table 31: Response of elevated CO_2 on carbon partitioning at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia* bellirica *and Terminalia* chebula

	Leaf	Stem	Root
T.arjuna-800	32.42 ± 0.54	29.96 ± 1.15	37.61 ± 1.2
T.arjuna-400	29.49 ± 0.77	31.83 ± 0.87	38.66 ± 0.69
T.bellirica-800	14.42 ± 0.98	25.56 ± 0.066	60.01 ± 0.98
T.bellirica-400	32.45 ± 1.18	17.86 ± 1.51	49.67 ± 1.21
T.chebula-800	29.62 ± 1.28	26.61 ± 1.01	43.76 ± 1.17
T.chebula-400	27.15 ± 0.92	22.23 ± 0.59	50.6 ± 0.85

Leaves: Carbon partitioning of leaves of *Terminalia arjuna* was increased under elevated CO_2 condition (32.42 ± 0.54) over ambient condition (29.49 ± 0.77). Increase in partitioning was 9.4 % of the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 76.92% in ambient than stress (elevated CO_2) condition. In this species, under the ambient condition, it was higher (32.45 ± 1.18) compared to the elevated CO_2 condition (14.42 ± 0.983) while *Terminalia chebula* showed an increase in partitioning in elevated condition (29.62 ± 1.28) over ambient condition (27.15 ± 0.92) an increase of about 8.7%. Among these species, *Terminalia arjuna* showed better results in stress condition followed by *Terminalia chebula and Terminalia bellirica* there is carbon partitioning high in ambient condition.

Stem: Carbon partitioning of the stem of *Terminalia arjuna* increased under ambient condition (31.83 ± 0.87) over elevated CO_2 condition (29.96 ± 1.157). Increase in partitioning was 6.05 % from the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 35.47% in stress (elevated CO_2) condition than ambient. In this species, under elevated CO_2 condition, it was higher (25.56 ± 0.066) compared to the control (17.86 ± 1.51) while *Terminalia chebula* showed an increase in partitioning in elevated condition (26.61 ± 1.01) over ambient condition (22.23 ± 0.59) an increase of about 17.92%. Among these species *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula.*

Root: Carbon partitioning of roots of *Terminalia arjuna* was increased under ambient condition (38.66 ± 0.69) over elevated CO_2 condition (37.61± 1.202). Increase in partitioning was 2.75% than the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 18.83% in stress (elevated *CO2*) condition than ambient. In this species, under elevated *CO2* condition, it was higher (60.014 ± 0.98) compared to the control (49.67 ± 1.21) while *Terminalia chebula* showed an increase in partitioning in ambient condition (50.604 ± 0.853) over elevated condition (43.76 ± 1.17) an increase of about 14.48%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna* and they showed good response under ambient condition.

4.4.3 Response of elevated CO_2 on Carbon mitigation

Table 32: Response of elevated CO_2 on carbon mitigation at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

	Leaf	Stem	Root
T.arjuna-800	1202.34 ± 2.18	1209.09 ± 7.78	1420.26 ± 7.09
T.arjuna-400	1155.48 ± 2.89	1173.83 ± 8.2	1417.19 ± 7.87
T.bellirica-800	1099.46 ± 4.82	1850.44 ± 11.82	4842.58 ± 16.32
T.bellirica-400	1102.73 ± 7.88	662.18 ± 10.62	1699.21 ± 9.31
T.chebula-800	1154.65 ± 8.22	1056.02 ± 7.71	1703.36 ± 7.63
T.chebula-400	932.43 ± 6.65	770.62 ± 3.91	1764.11 ± 3.05

Leaves: Carbon mitigation of leaves of *Terminalia arjuna* was increased under elevated CO_2 condition (1202.34 ± 2.18) over ambient condition (1155.48 ± 2.89). Increase in mitigation was approximately 7.49% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 0.293% in ambient than stress (elevated CO_2) condition. In this species, under ambient it was higher (1102.73 ± 7.88) compared to the elevated CO_2 condition (1099.46 ± 4.82) while *Terminalia chebula* showed an increase in mitigation in elevated condition (1154.65 ± 8.22) over ambient condition (932.43 ± 6.65) an increase of about 21.29%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia arjuna,* but there is a decline in *Terminalia bellirica* under elevated condition.

Stem: Carbon mitigation of stem of *Terminalia arjuna* was increased under elevated CO_2 condition (1209.09 ± 7.78) over ambient condition (1173.83 ± 8.2). Increase in mitigation was 2.95% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 94.58% in stress (elevated CO2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (1850.44 ± 11.82) compared to the control (662.18 ± 10.62) while *Terminalia chebula* showed an increase in mitigation in elevated condition (1056.02 ± 7.71) over ambient condition (770.62 ± 3.91) an increase of about 31.24%. Among these species *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna*.

Root: Carbon mitigation of roots of *Terminalia arjuna* was increased under elevated CO_2 condition (1420.26 ± 7.095) over ambient condition (1417.19 ± 7.87). Increase in mitigation was 0.021% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 96.11% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (4842.58 ± 16.32) compared to the control (1699.21 ± 9.31) while *Terminalia chebula* showed an increase in mitigation in ambient condition (1764.11 ± 3.05) over elevated condition (1703.36 ± 7.63) an increase of about 3.5%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia arjuna,* but in *Terminalia chebula* there was a decline under a stressed condition.

4.4.4 Response of elevated CO_2 on Carbon stocks

Table 33: Response of elevated CO_2 on carbon stocks at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

	Leaf	Stem	Root
T.arjuna-800	328.5 ± 1.14	330.35 ± 4.071	388.05 ± 3.7
T.arjuna-400	315.7 ± 1.51	320.71 ± 4.28	387.21 ± 4.11
T.bellirica-800	300.4 ± 2.52	505.58 ± 6.18	1323.11 ± 8.53
T.bellirica-400	301.29 ± 4.12	180.92 ± 5.55	464.26 ± 4.87
T.chebula-800	315.47 ± 4.3	288.53 ± 4.031	465.39 ± 3.98
T.chebula-400	265.72 ± 3.17	209.97 ± 2.008	468.69 ± 2.78

Leaves: Carbon stock of leaves of *Terminalia arjuna* was increased under elevated CO_2 condition (328.5 ± 1.14) over ambient condition (300.4 ± 2.52). Increase in carbon stock was 3.95% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 0.29% in ambient than stress (elevated CO_2) condition. In this species, under ambient condition it was higher (301.29± 4.12) compared to the elevated CO_2 condition (300.4 ± 2.52) while *Terminalia chebula* showed an increase in carbon stock in elevated condition

(315.47 ± 4.3009) over ambient condition (265.72 ± 3.17) an increase of about 27.78%. Among these species *Terminalia chebula* showed better results in stress condition followed by *Terminalia arjuna* but in *Terminalia bellirica* results a decline in elevated condition was observed.

Stem: Carbon stock of stem of *Terminalia arjuna* was increased under elevated CO_2 condition (330.35 ± 4.07) over ambient condition (320.71 ± 4.28). Increase in carbon stock was approximately 2.96% over the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 94.85% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (505.58 ± 6.18) compared to the control (180.92± 5.52) while *Terminalia chebula* showed an increase in carbon stock in elevated condition (288.53 ± 4.031) over ambient condition (209.97 ± 2.008) an increase of about 31.51%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

Roots: Carbon stock of roots of *Terminalia arjuna* was increased under elevated CO_2 condition (388.05 ± 3.7) over ambient condition (387.21 ± 4.11). Increase in carbon stock was 0.216% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 96.1% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (1323.11 ± 8.53) compared to the control (464.26 ± 4.87) while *Terminalia chebula* showed an increase in carbon stock in ambient condition (468.69 ± 2.784) over elevated condition (465.39 ± 3.98) an increase of about 0.706%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

4.5 Biochemical analysis

4.5.1 Response of elevated CO_2 on Total chlorophyll

Table 34: Response of elevated CO_2 on total chlorophyll at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

T.arjuna-800	0.26 ± 0.0605
T.arjuna-400	0.18 ± 0.077
T.bellirica-800	0.25 ± 0.0103
T.bellirica-400	0.16 ± 0.101
T.chebula-800	0.37 ± 0.069
T.chebula-400	0.252 ± 0.08

Total chlorophyll (µl/ml) of *Terminalia arjuna* significantly increased under elevated CO_2 condition (0.26 ± 0.0605) over ambient condition (0.18 ± 0.077). Increase in the total chlorophyll was 36.91% over the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 40.76% in stress (elevated CO2) condition than ambient. In this species during elevated CO_2 condition, it was higher (0.25 ± 0.0103) compared to the control (0.16 ± 0.101) while *Terminalia chebula* showed an increase in total chlorophyll in elevated condition (0.37 ± 0.069) over ambient condition (0.252 ± 0.08) an increase of about 38.74%. Among these species *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

4.5.2 Response of elevated CO_2 on Total carotenoid

Table 35: Response of elevated CO_2 on total carotinoid at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

T.arjuna-800	4.45 ± 0.28
T.arjuna-400	3.47± 0.29
T.bellirica-800	3.87 ± 0.27
T.bellirica-400	2.59 ± 0.37
T.chebula-800	7.70 ± 0.41
T.chebula-400	6.47 ± 0.30

Total carotenoid of *Terminalia arjuna* was significantly increased under elevated CO_2 condition (4.45 ± 0.28) over ambient condition (3.47± 0.29). Increase in the total carotenoid was 24.73% from the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 41.73% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition it was higher (3.87 ± 0.27) compared to the control (2.59 ± 0.37) while *Terminalia chebula* showed an increase in total carotenoid in elevated condition (7.70 ± 0.41) over ambient condition (6.47 ± 0.30) an increase of about 17.25%. Among these species *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

4.5.3 Response of elevated CO_2 on Ascorbic Acid

Table 36: Response of elevated CO_2 on ascorbic acid at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

T.arjuna-800	90.69 ± 1.04
T.arjuna-400	81.45 ± 1.47
T.bellirica-800	34.13 ± 0.61
T.bellirica-400	22.43 ± 1.09
T.chebula-800	61.48 ± 1.28
T.chebula-400	57.22 ± 1.36

The ascorbic acid content of *Terminalia arjuna* increased under elevated CO_2 condition (90.69 ± 1.04) over ambient condition (81.45 ± 1.47). Increase in the Ascorbic acid was 10.74% over the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 41.35% in stress (elevated CO_2) condition than ambient. In this species, under elevated CO_2 condition, it was higher (34.13 ± 0.61) compared to the control (22.43 ± 1.09) while *Terminalia chebula* showed an increase in ascorbic acid in elevated condition (61.48 ± 1.28) over ambient condition (57.22 ± 1.36) an increase of about 7.18%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

4.5.4 Response of elevated CO_2 on Protein

Table 37: Response of elevated CO_2 on protein at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia chebula*

T.arjuna-800	0.24 ± 0.016
T.arjuna-400	0.096 ± 0.0041
T.bellirica-800	0.16 ± 0.014
T.bellirica-400	0.068 ± 0.0073
T.chebula-800	0.21 ± 0.007
T.chebula-400	0.107 ± 0.0023

Protein content of *Terminalia arjuna* was significantly increased under elevated CO_2 condition (0.24 ± 0.016) over ambient condition (0.096 ± 0.0041). Increase in the Protein content was 85.13% than the ambient condition. However, in case of *Terminalia bellirica* the percentage increase was 83.23% in stress (elevated CO_2) condition than ambient. In this species during elevated CO_2 condition it was higher (0.16 ± 0.014) compared to the control (0.068 ± 0.0073) while *Terminalia chebula* showed an increase in Protein content in elevated condition (0.21 ± 0.007) over ambient condition (0.107 ± 0.0023) an increase of about 68.33%. Among these species *Terminalia arjuna* showed better results in stress condition followed by *Terminalia chebula and Terminalia bellirica.*

4.5.5 Response of elevated CO_2 on Total sugars

Table 38: Response of elevated CO_2 on total sugars at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

T.arjuna-800	31.63 ± 0.81
T.arjuna-400	13.6 ± 1.36
T.bellirica-800	24.82 ± 0.98
T.bellirica-400	11.71 ± 1.34
T.chebula-800	45.98 ± 1.12
T.chebula-400	12.48 ± 0.99

Total sugars content of *Terminalia arjuna* significantly increased under elevated CO_2 condition (31.63 ± 0.81) over ambient condition (13.6 ± 1.36). Increase in total sugars content was approximately 79.69% of the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 71.8% in stress (elevated CO_2) condition than ambient. In this species during elevated CO_2 condition it was higher (24.82 ± 0.98) compared to the control (11.71 ± 1.34) while *Terminalia chebula* showed an increase in total sugars content in elevated condition (45.98 ± 1.12) over ambient condition (12.48 ± 0.99) an increase of about 114.6%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia arjuna and Terminalia bellirica.*

4.5.6 Response of elevated CO_2 on Proline

Table 39: Response of elevated CO_2 on proline at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* b*ellirica and Terminalia chebula*

T.arjuna-800	0.00044 ± 0.0107
T.arjuna-400	0.004785 ± 0.012594
T.bellirica-800	0.025± 0.046
T.bellirica-400	0.039 ± 0.074
T.chebula-800	0.0013 ± 0.017
T.chebula-400	0.029 ± 0.102

Proline content decreased with elevated CO_2. Proline content of *Terminalia arjuna* increased under ambient condition (0.004785 ± 0.012594) over elevated CO2 condition (0.00044 ± 0.0107). Increase in proline content was 166.17% from the elevated condition. However, in the case of *Terminalia bellirica* the percentage increase was 42.28% in ambient than stress (elevated CO_2) condition. In this species under the ambient condition, it was higher (0.039 ± 0.074) compared to the elevated CO_2 condition (0.025± 0.046) while *Terminalia chebula* showed an increase in proline content in ambient condition (0.029 ± 0.102) over elevated condition (0.0013 ± 0.017) an increase of about 114.6%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia arjuna and Terminalia chebula*.

4.5.7 Response of elevated CO_2 on Organic carbon

Table 40: Response of elevated CO_2 on organic carbon content at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

	Leaf	Stem	Root
T.arjuna-800	47.21 ± 0.27	51.803 ± 1.03	42.16 ± 1.4
T.arjuna-400	42.89 ± 0.33	46.94 ± 0.51	38.96 ± 1.33
T.bellirica-800	25.802 ± 1.309	42.95 ± 1.14	45.48 ± 0.257
T.bellirica-400	51.13 ± 0.65	28.99 ± 1.24	43.55 ± 0.37
T.chebula-800	37.37 ± 1.22	40.29 ± 0.692	43.89 ± 0.57
T.chebula-400	33.44 ± 1.003	37.306 ± 0.419	39.102 ± 0.41

Leaves: Organic carbon content of leaves of *Terminalia arjuna* significantly increased under elevated CO_2 condition (47.21 ± 0.27) over ambient condition (42.89 ± 0.33). Increase in the OC was 9.59% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 65.86% in ambient than stress (elevated CO_2) condition. In this species, at the ambient condition, it was higher (51.13 ± 0.65) compared to the elevated CO_2 condition (25.802 ± 1.309) while *Terminalia chebula* showed an increase in OC content in elevated condition (37.37 ± 1.22) over ambient condition (33.44 ± 1.003) an increase of about 11.07%. Among these species, *Terminalia chebula* showed better results in stress condition followed by *Terminalia arjuna*, but *Terminalia bellirica* leaf showed a decline of OC under the stressed state.

Stem: Organic carbon content of stems of *Terminalia arjuna* significantly increased under elevated CO_2 condition (51.803 ± 1.031) over ambient condition (46.94 ± 0.518). Increase in t OC content was 9.83% from the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 38.81% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO2 condition, it was higher (42.95 ± 1.14) compared to the control (28.99 ± 1.24) while *Terminalia chebula* showed an increase in OC content in elevated condition was (40.29 ± 0.692) over ambient condition (37.306 ± 0.419) an increase of about 7.71%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

Roots: Organic carbon content of roots of *Terminalia arjuna* significantly increased under elevated CO_2 condition (42.16 ± 1.402) over ambient condition (38.96 ± 1.335). Increase in OC content was 7.87% from the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 12.28% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (45.48 ± 0.257) compared to the control (43.55 ± 0.37) while *Terminalia chebula* showed an increase in OC content in elevated condition (43.89 ± 0.57) over ambient condition (39.102 ± 0.41) an increase of about 11.54%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia chebula and Terminalia arjuna.*

4.6 Nutrient Analysis

4.6.1 Response of elevated CO_2 on potassium

Table 41: Response of elevated CO_2 on potassium at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

T.arjuna-800	22 ± 1.63
T.arjuna-400	17.83 ± 1.22
T.bellirica-800	16.66 ± 0.87
T.bellirica-400	19 ± 0.57
T.chebula-800	14.5 ± 0.4
T.chebula-400	13.33 ± 0.73

Leaf potassium content of *Terminalia arjuna* significantly increased under elevated CO_2 condition (22 ± 1.63) over ambient condition (17.83 ± 1.22). Increase in potassium content was 20.93% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 13.12% in ambient condition than stress (elevated CO_2) condition. In this species under the ambient condition, it was higher (19 ± 0.57) compared to the elevated CO_2 condition (16.6 ± 0.87) while *Terminalia chebula* showed an increase in potassium content in elevated condition (14.5 ± 0.41) over ambient condition (13.33 ± 0.73) an increase of about 8.63%. Among these species, *Terminalia arjuna* showed better results in stress condition followed by *Terminalia chebula,* but *Terminalia bellirica* showed reduction at the stressed condition.

107

4.6.2 Response of elevated CO_2 on Phosphorous

Table 42: Response of elevated CO_2 on phosphorous at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

T.arjuna-800	0.59 ± 0.114
T.arjuna-400	0.518 ± 0.109
T.bellirica-800	0.79 ± 0.25
T.bellirica-400	0.45 ± 0.24
T.chebula-800	0.405 ± 0.585
T.chebula-400	0.635 ± 0.69

Leaf phosphorus content of *Terminalia arjuna* significantly increased under elevated CO_2 condition (0.59 ± 0.114) over ambient condition (0.518 ± 0.109). Increase in leaf phosphorous was approximately 14.54% than the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 54.83% in stress (elevated CO_2) condition than ambient. In this species, under elevated CO_2 condition, it was higher (0.79 ± 0.25) compared to the control (0.45 ± 0.24) while *Terminalia chebula* showed an increase in leaf phosphorous in ambient condition (0.635 ± 0.69) over elevated condition (0.405 ± 0.585) an increase of about 44.23%. Among these species, *Terminalia bellirica* showed better results in stress condition followed by *Terminalia arjuna*, but *Terminalia chebula* showed decline under elevated condition.

4.6.3 Response of elevated CO_2 on Total Nitrogen

Table 43: Response of elevated CO_2 on total nitrogen at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

T.arjuna-800	2.125 ± 1.068
T.arjuna-400	3.07 ± 0.6
T.bellirica-800	4.095 ± 0.54
T.bellirica-400	1.05 ± 0.63
T.chebula-800	0.145 ± .05
T.chebula-400	0.185 ± .33

Total nitrogen content of *Terminalia arjuna* significantly increased under ambient condition (3.07 ± 0.6) over elevated CO_2 condition (2.125 ± 1.068). Increase in total nitrogen was 36.38% of the ambient condition. However, in the case of *Terminalia bellirica* the percentage increase was 118.36% in stress (elevated CO_2) condition than ambient. In this species, at elevated CO_2 condition, it was higher (4.095 ± 0.54) compared to the control (1.05 ± 0.63) while *Terminalia chebula* showed an increase in total nitrogen in ambient condition (0.185 ± .33) over elevated condition (0.145 ± .05) an increase of about 24.24%. Among these species *Terminalia bellirica* showed better results in stress condition, but *Terminalia chebula and Terminalia arjuna* are showed reduction under a stressed condition.

Table 44: Statistical analysis of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

Parameter	F	p	S/NS	F	P	S/NS	F	p	S/NS
	Value	Value		Value	Value		Value	Value	
	Treatment			Species			Treatment* species		
Plant Height (cm)	16.51	<0.01	S	96.162	<0.01	S	1.122	0.347	NS
Leaf Length (cm)	11.77	<0.01	S	10.802	<0.01	S	0.382	0.688	NS
Leaf width(cm)	12.22	<0.01	S	148.151	<0.01	S	0.664	0.527	NS
collar diameter (cm)	1.50	0.24	NS	12.448	<0.01	S	0.61	0.554	NS
Number of Leaves	0.47	0.50	NS	26.569	<0.01	S	0.008	0.992	NS
Number of Branches	0.52	0.48	NS	39.483	<0.01	S	0.108	0.899	NS
Root Length (cm)	12.44	0.00	NS	12.593	<0.01	S	2.08	0.154	NS
Fresh Weight -Leaf (g)	0.27	0.61	NS	0.262	0.773	NS	0.019	0.981	NS
Fresh Weight -Stem (g)	0.87	0.36	NS	14.109	<0.01	S	0.147	0.865	NS
Fresh Weight -Root (g)	2.94	0.10	NS	1.275	0.303	NS	0.505	0.612	NS
Dry Weight -Leaf (g)	2.23	0.15	NS	0.606	0.556	NS	1.554	0.238	NS
Dry Weight -Stem (g)	0.71	0.41	NS	4.568	0.025	NS	0.137	0.873	NS
Dry Weight - Root (g)	0.02	0.89	NS	1.06	0.367	NS	0.466	0.635	NS
Moisture Content - Leaves (%)	1.41	0.25	NS	0.70	0.51	NS	2.828	0.086	NS
Moisture Content -Stem (%)	0.09	0.77	NS	0.258	0.775	NS	0.018	0.982	NS
Moisture Content - Root (%)	8.64	<0.01	S	1.18	0.33	NS	0.516	0.605	NS
Total Leaf Area - cm^2	7.45	0.01	NS	4.767	0.022	NS	0.593	0.563	NS

Leaf Area Index	7.45	0.01	NS	4.767	0.022	NS	0.593	0.563	NS
Leaf Area Ratio	4.55	0.05	NS	3.354	0.058	NS	0.574	0.573	NS
Shoot Leaf Area	1.32	0.27	NS	2.877	0.082	NS	1.196	0.325	NS
Shoot Leaf Weight	32.97	<0.01	S	68.784	<0.01	S	38.154	<0.01	S
Absolute growth Rate	9.22	<0.01	S	24.285	<0.01	S	0.002	0.998	NS
Net Assimilation Rate	3.07	0.097	NS	12.002	<0.01	S	0.083	0.921	NS
Relative Growth Rate	3.07	0.097	NS	12.002	<0.01	S	0.083	0.921	NS
Root Shoot Ratio	1.15	0.30	NS	4.313	0.03	NS	0.888	0.429	NS
Photosynthetic Rate - Winter (Pn)	160.53	<0.01	S	12.052	<0.01	S	4.057	0.035	NS
Stomatal Conductance - Winter (gs)	2.80	0.11	NS	1.748	0.202	NS	0.224	0.802	NS
intercellular CO2 Concentration - Winter (Ci)	94.85	<0.01	S	6.314	<0.01	S	0.666	0.526	NS
Transpiration Rate - Winter - E	50.02	<0.01	S	4.894	0.02	NS	1.455	0.259	NS
Instantaneous Water Use Efficiency - Winter (Pn/E)	1.78	0.20	NS	4.19	0.03	NS	2.68	0.096	NS
Intrinsic Water Use Efficiency - Winter (Pn/gs)	43.63	<0.01	S	3.095	0.07	NS	2.175	0.142	NS
Carboxylation Efficiency - Winter (Pn/Ci)	154.83	<0.01	S	6.198	<0.01	S	0.776	0.475	NS
Mesophyll Efficiency - Winter (Ci/gs)	4.16	0.06	NS	2.999	0.075	NS	0.007	0.993	NS
Photosynthetic Rate - Spring (Pn)	30.27	<0.01	S	25.479	<0.01	S	3.627	0.047	NS
Stomatal Conductance - Spring (gs)	9.39	<0.01	S	1.654	0.219	NS	5.302	0.015	NS
Intercellular CO2 Concentration - Spring (Ci)	9.94	<0.01	S	0.453	0.643	NS	0.249	0.783	NS
Transpiration Rate - Spring - E	9.70	<0.01	S	18.066	<0.01	S	4.014	0.036	NS

Instantaneous Water Use Efficiency - Spring (Pn/E)	1.90	0.19	NS	23.245	<0.01	S	13.239	<0.01	S
Intrinsic Water Use Efficiency - Spring (Pn/gs)	2.15	0.16	NS	6.227	<0.01	S	7.457	<0.01	S
Carboxylation Efficiency - Spring (Pn/Ci)	21.75	<0.01	S	5.595	0.013	NS	1.02	0.381	NS
Mesophyll Efficiency - Spring(Ci/gs)	32.14	<0.01	S	2.954	0.078	NS	7.573	<0.01	S
Photosynthetic Rate - Summer (Pn)	3.79	0.07	NS	4.331	0.029	NS	1.569	0.235	NS
Stomatal Conductance - Summer (gs)	0.55	0.47	NS	4.079	0.035	NS	2.317	0.127	NS
intercellular CO_2 Concentration - Summer (Ci)	0.15	0.70	NS	0.466	0.635	NS	0.527	0.599	NS
Transpiration Rate - Summer - E	0.84	0.37	NS	3.652	0.047	NS	3.135	0.068	NS
Instantaneous Water Use Efficiency - Summer (Pn/E)	4.89	0.04	NS	1.227	0.317	NS	1.097	0.355	NS
Intrinsic Water Use Efficiency - Summer (Pn/gs)	2.43	0.14	NS	0.734	0.494	NS	0.914	0.419	NS
Carboxylation Efficiency - Summer (Pn/Ci)	2.09	0.17	NS	2.087	0.153	NS	1.746	0.203	NS
Mesophyll Efficiency - Summer (Ci/gs)	0.44	0.51	NS	3.361	0.058	NS	0.015	0.986	NS
Night Leaf Respiration - Winter	1.78	0.21	NS	1.007	0.394	NS	6.096	0.015	NS
Night Leaf Respiration - Spring	0.69	0.42	NS	5.251	0.023	NS	6.997	0.01	NS
Night Leaf Respiration - Summer	15.35	<0.01	S	0.687	0.522	NS	2.167	0.157	NS
Ascorbic Acid	15.48	<0.01	S	244.519	<0.01	S	1.049	0.38	NS
Protein	68.28	<0.01	S	5.225	0.023	NS	0.925	0.423	NS
Total Sugar	129.26	<0.01	S	11.308	<0.01	S	10.5	<0.01	S

Proline	4.80	0.05	NS	6.058	0.015	NS	0.963	0.409	NS
Total Chlorophyll	120.01	<0.01	S	54.246	<0.01	S	2.026	0.175	NS
Total Carotenoid	50.17	<0.01	S	207.647	<0.01	S	0.319	0.733	NS
Organic Carbon - Leaves (%)	15.10	<0.01	S	15.066	<0.01	S	44.884	<0.01	S
Organic Carbon - Stem (%)	28.39	<0.01	S	35.72	<0.01	S	6.171	0.014	NS
Organic Carbon - Root (%)	4.54	0.06	NS	2.372	0.136	NS	0.285	0.757	NS
Nitrogen	3.75	0.08	NS	20.68	<0.01	S	11.591	<0.01	S
Phosphorous	0.80	0.39	NS	0.435	0.657	NS	7.678	<0.01	S
Potassium	0.29	0.60	NS	3.535	0.062	NS	1.008	0.394	NS
Carbon Sequestration	9.13	<0.01	S	2.96	0.077	NS	3.2	0.065	NS
Carbon Partitioning-Leaves (%)	3.38	0.08	NS	5.516	0.014	NS	15.12	<0.01	S
Carbon Partitioning-Stem (%)	0.78	0.39	NS	5.491	0.014	NS	0.481	0.626	NS
Carbon Partitioning-Root (%)	0.29	0.60	NS	15.181	<0.01	S	5.7	0.012	NS
Carbon Mitigation-Leaves	2.23	0.15	NS	0.595	0.562	NS	1.562	0.237	NS
Carbon Mitigation- Stem	8.47	<0.01	S	3.476	0.053	NS	6.26	<0.01	S
Carbon Mitigation- Root	23.06	<0.01	S	28.49	<0.01	S	26.766	<0.01	S
Carbon stock- Leaves	2.23	0.15	NS	0.595	0.562	NS	1.562	0.237	NS
Carbon stock- Stem	8.47	<0.01	S	3.476	0.053	NS	6.26	<0.01	S
Carbon stock-Root	23.06	<0.01	S	28.49	<0.01	S	26.766	<0.01	S

S= Significant, NS= Non-significant

DISCUSSION

CHAPTER 5

DISCUSSION

Results from this study illustrate that plants exposed to elevated CO_2 (800ppm) show positive responses compared to ambient CO_2 (400ppm). The study was done in the open-top chamber and the species *Terminalia arjuna, Terminalia chebula,* and *Terminalia bellirica.*

5.1 Adaptive behaviour of plants exposed to elevated CO_2 concentration

Photosynthetic rate of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula* is increased in elevated CO_2 than ambient in all seasons (fig:1). The rate of increase of photosynthesis is due to increase of ribulose 1,5- bisphosphate, which helps to CO_2 fixation, (Makino and Mae,1999) the availability of carbon makes higher the activities of rubisco. Generally, elevated CO_2 contribute a fall in stomatal conductance (gs) (Medlyn *et al.*, 2001 and Gao *et al.*, 2015) and the transpiration rate (Teng *et al.*, 2009 and Katul *et al.*, 2010). Due to some climatic factors interaction, the stomatal conductance might be increased. The gs increased by short term CO_2 conception (Zinta *et al.*, 2014). Stomatal conductance was high in elevated CO_2 due to the rapid opening of guard cells at high CO_2. Under elevated CO_2 plant-water relationship increased, it helps to increase water use efficiency of plants if the turgor pressure of plant increase it will improve the growth process (Sharma *et al.*, 2018). From the present study, stomatal conductance was lower in winter season for the three species at elevated CO_2 than ambient CO_2, and at spring season gs was high in elevated CO_2, but in summer season gs was higher in two species (*Terminalia arjuna* and *Terminalia bellirica*) under ambient CO_2 than elevated CO_2 (fig:2). The transpiration rate was higher in winter season at elevated CO_2 than ambient for three species, but in spring *Terminalia arjuna* shows higher transpiration rate at ambient CO_2 than elevated CO_2, and in summer season transpiration was higher in ambient CO_2 than elevated CO_2 except for *Terminalia chebula* (fig:4). Carboxylation efficiency and mesophyll efficiency are higher in elevated CO_2 at the summer season compared to ambient CO_2, but the *Terminalia arjuna* shows high carboxylation efficiency at ambient than elevated CO_2 (fig:7). Mesophyll efficiency was higher in elevated CO_2 in summer than ambient CO_2 (fig:8). Both instantaneous water use efficiency and intrinsic water use efficiency are higher in elevated CO_2 than ambient at summer season (fig: 5&6). Sharma *et al.* (2018), reported the photosynthetic rate, stomatal conductivity, transpiration rate, water use efficiency are increased with elevated CO_2, and the night leaf respiration is declined concerning elevated CO_2. Singh *et al.* 2018, observed that Pn and WUE are increased with increasing CO_2, and gs and E are decreased (Teng *et al.*, 2006). Leaky *et al.* (2009) reported night time respiration increases with elevated CO_2 the respiratory proportions are seen highly, and they enhance night respiration, and the mitochondria number is higher in these plants. The night leaf respiration was higher in elevated CO_2 in summer season (fig:9).

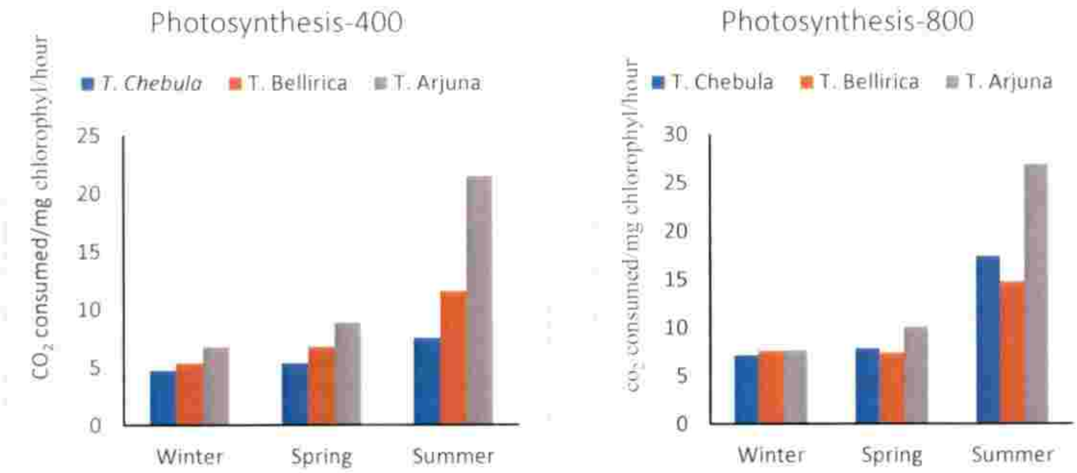

Figure 1: Response of elevated CO_2 on photosynthetic rate of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula*

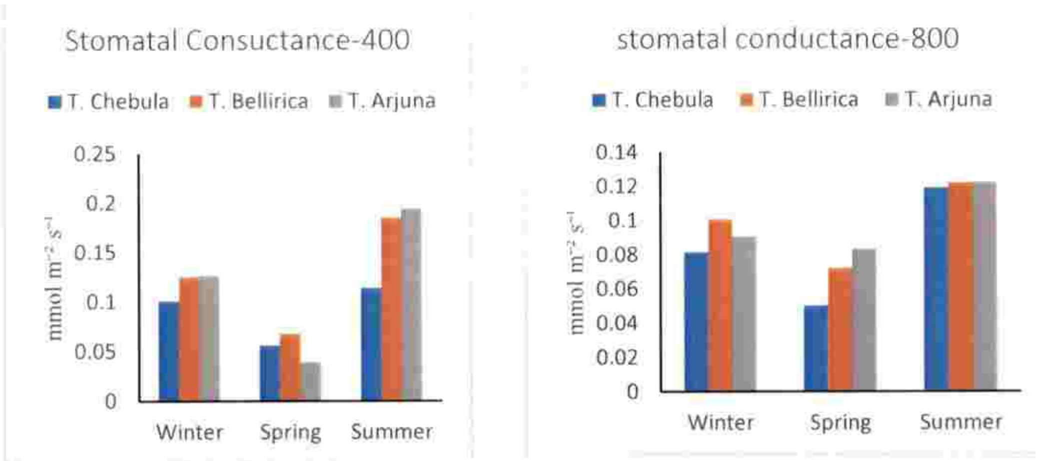

Figure 2: Response of elevated CO_2 on stomatal conductance to *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia* c*hebula*

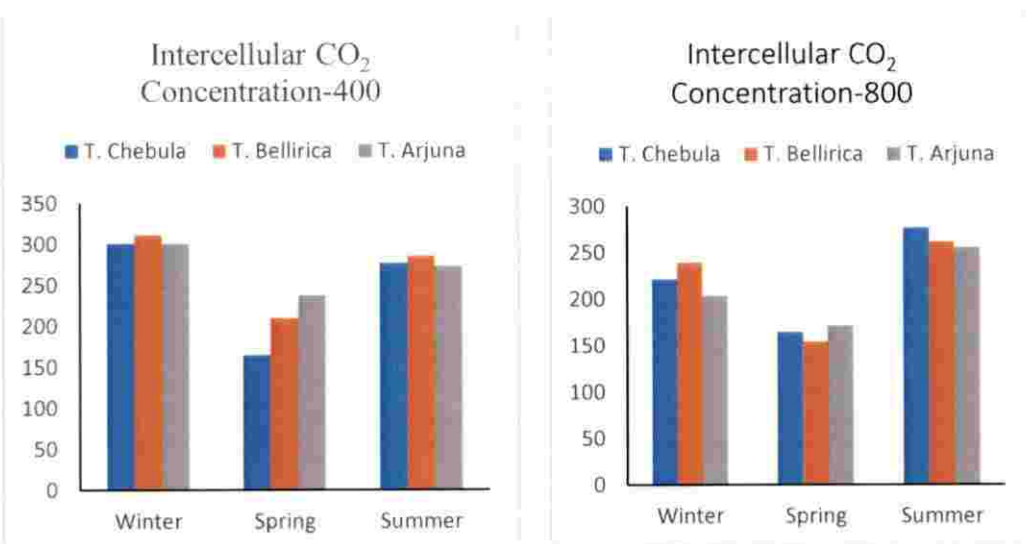

Figure 3: Response of elevated CO_2 on intercellular CO_2 concentration to *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia* c*hebula*

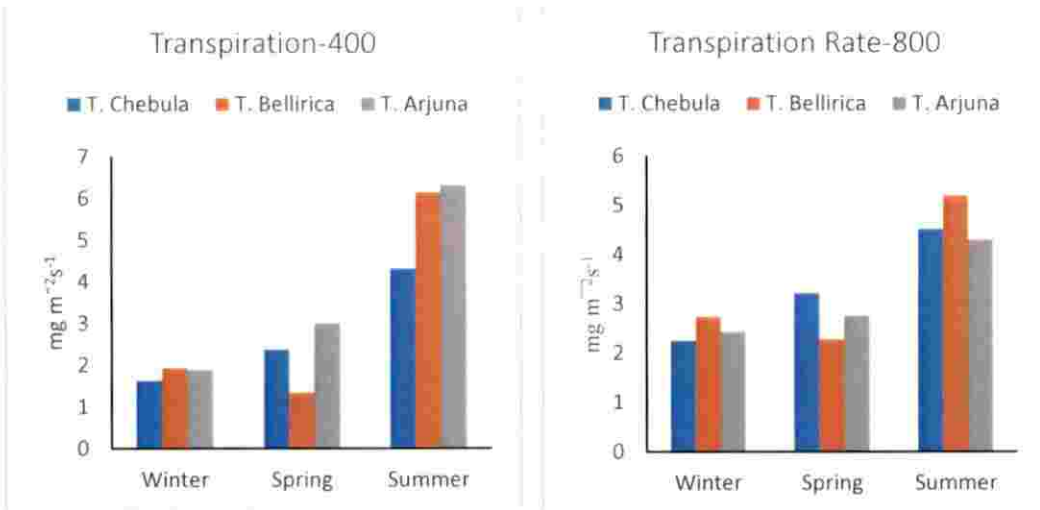

Figure 4: Response of elevated CO_2 on transpiration rate of *Terminalia arjuna, Terminalia* bellirica *and Terminalia chebula*

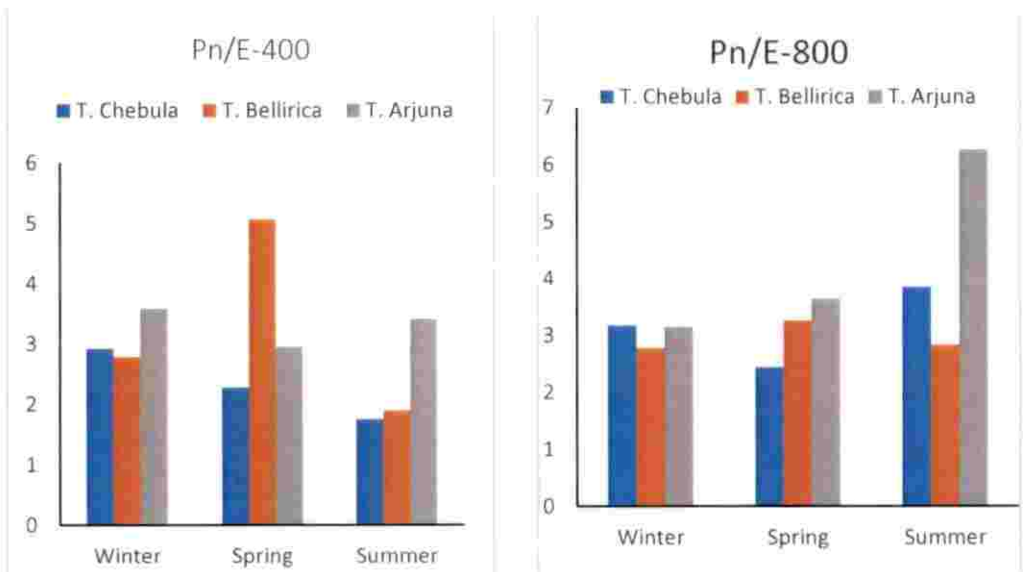

Figure 5: Response of elevated CO_2 on instantaneous water use efficiency of *Terminalia arjuna, Terminalia* bellirica *and Terminalia chebula*

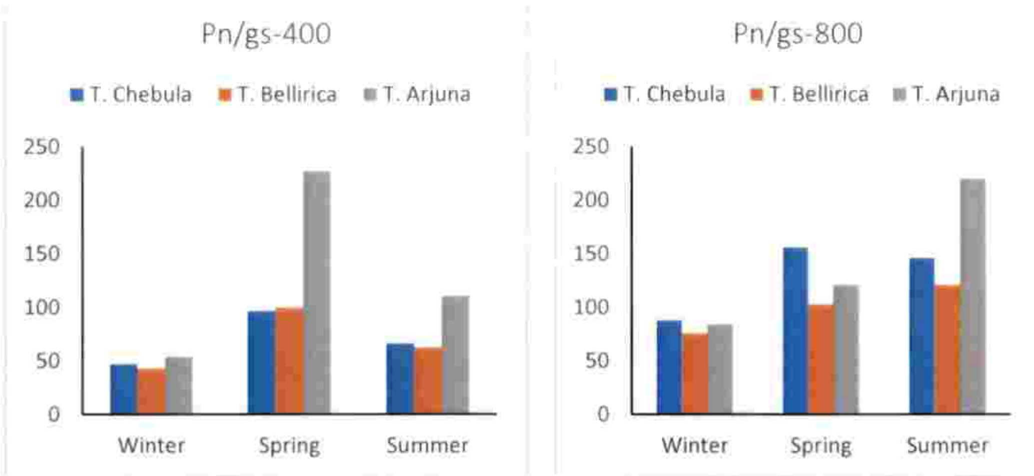

Figure 6: Response of elevated CO_2 on intrinsic water use efficiency of *Terminalia arjuna, Terminalia* bellirica *and Terminalia* chebula

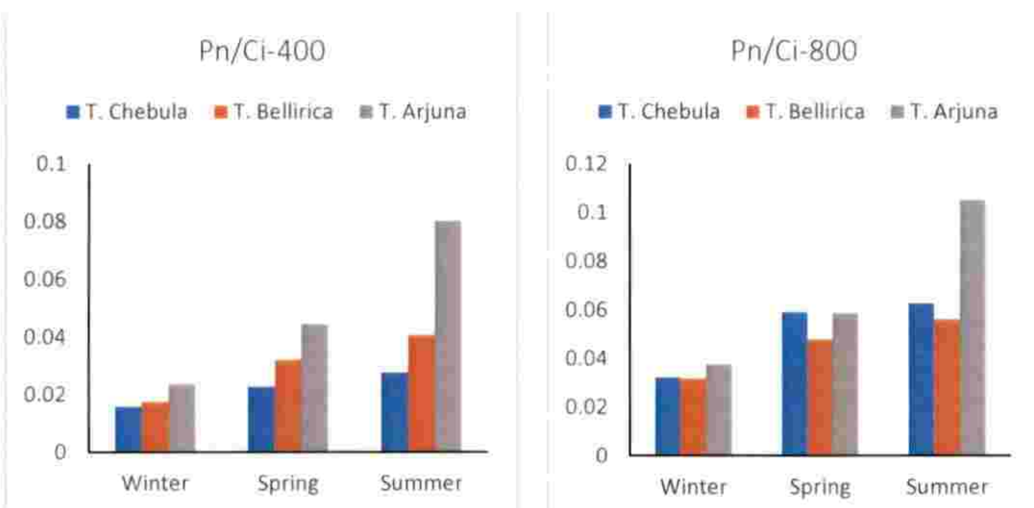

Figure 7: Response of elevated CO_2 on carboxylation efficiency of *Terminalia arjuna, Terminalia* bellirica *and Terminalia* chebula

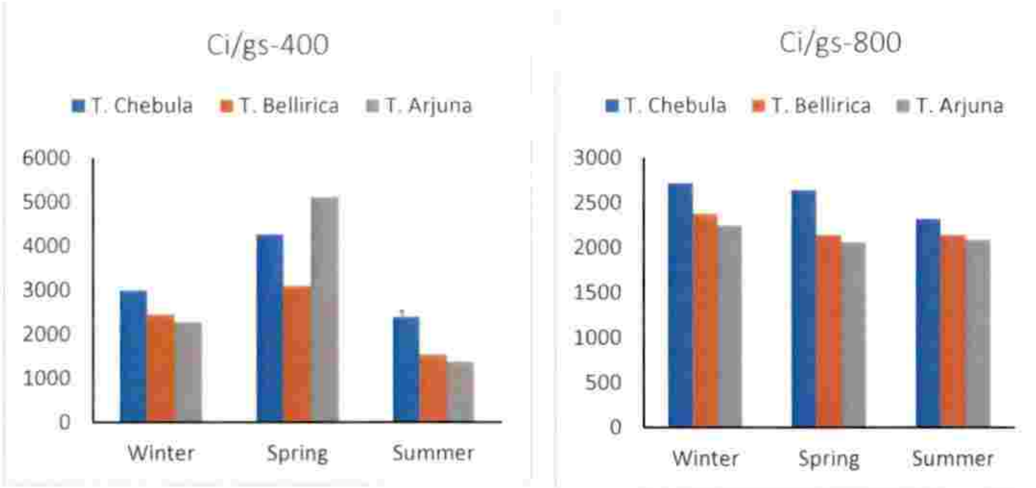

Figure 8: Response of elevated CO_2 on mesophyll efficiency of *Terminalia arjuna, Terminalia* b*ellirica and Terminalia* chebula

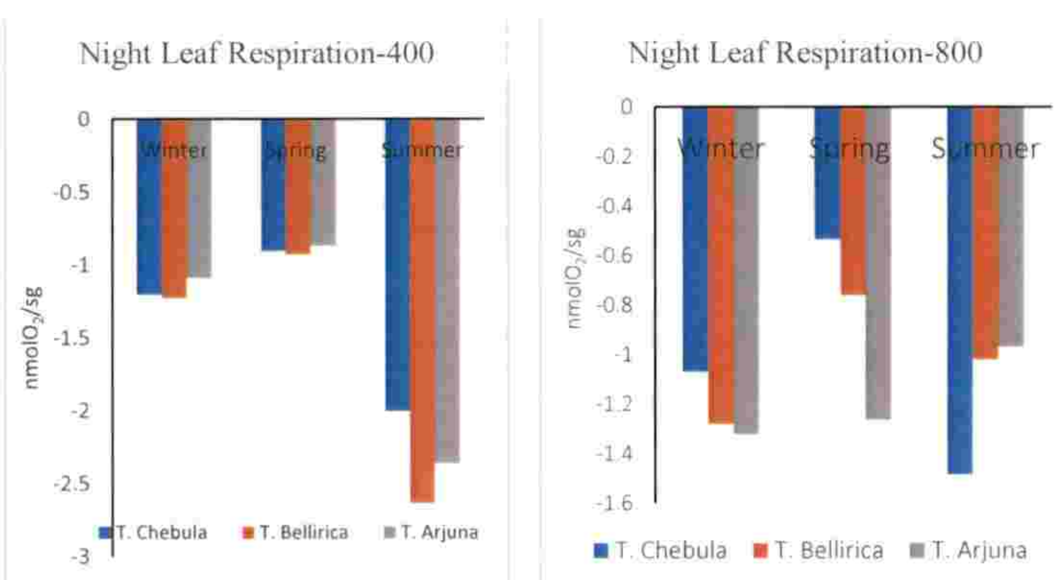

Figure 9: Response of elevated CO_2 on night leaf respiration of *Terminalia arjuna, Terminalia* b*ellirica and Terminalia* chebula

Elevated CO_2 always shows an increasing trend in plant height. The major reason for increased plant height as the increase of photosynthetic rate concerning elevated CO_2. Other growth parameters (leaf length, leaf width, collar diameter, the number of laves) are also increased in elevated CO_2 than ambient CO_2. Elevated CO_2 plays a role as fertilizer and helps to improve and accelerate plant growth and its functions (Rae *et al.,* 2007). For the present study plant height, leaf length, leaf width, collar diameter, number of leaves, number of branches, root length, leaf area, leaf area index (fig:10-fig:18) of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula* are shows significantly increasing trend concerning elevated CO_2. The rapid growth of leaf area occur at elevated CO_2 leads to increasing in transpiration rate of the plant (Morson and Gifford, 1984).

Biomass production was higher in this study at elevated CO_2 than ambient CO_2. Roots carbon allocation was higher than stem and leaf (Singh *et al.,* 2018 and, Lin and Wang, 1998) and higher in elevated CO_2 than ambient CO_2. Carbon allocation to leaves, stem, and roots are enhanced, and the plants become taller and produce their maximum of biomass. The rising of CO_2 enhance leaf photosynthesis and above-ground dry weight biomass (Ziska, 2001). Fresh as well as dry weight of leaf, stem and root (fig: 27&28) of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula* are increased in elevated CO_2 than ambient in this study, and the moisture content (fig: 29) of Terminalia bellirica is higher in elevated CO_2 than ambient, and the other two show a reduction in moisture content at elevated CO_2. Singh *et al.* (2018) also got the same result as increased plant height collar diameter, fresh and dry weight (leaf, stem, and root), moisture content, leaf area, root length, leaf area index, specific leaf area, total dry biomass (Sharma *et al.,* 2018), are increased with elevated CO_2. Rozema *et al.* (1993) said that leaf area per plant and leaf are increased in initial stages of CO_2 distribution after that leaf area ratio and specific leaf area are decreases (Cha *et al.* (2017)).

Plate 7: *T.arjuna* Plant (left-400ppm, right-800ppm)

Plate 8: *T.bellirica* (left-400ppm, right- 800ppm)

Plate 9: T.chebula plant (left-400ppm, right- 800ppm)

Figure 10: Response of elevated CO_2 on plant height at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia* c*hebula*

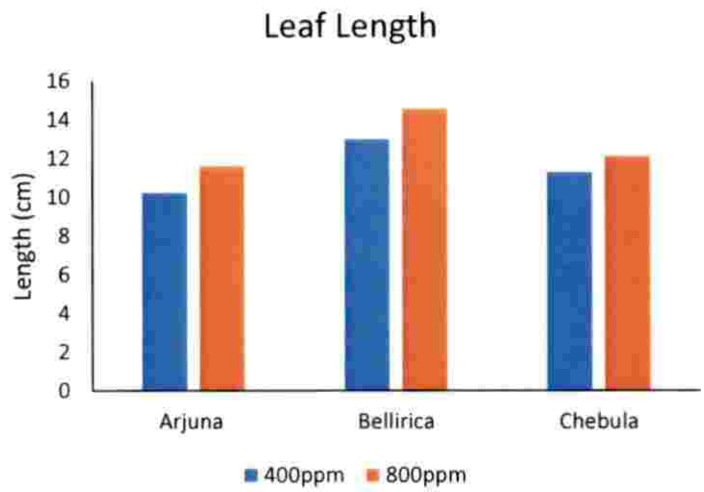

Figure 11: Response of elevated CO_2 on leaf length at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* *arjuna, Terminalia* bellirica *and Terminalia* chebula

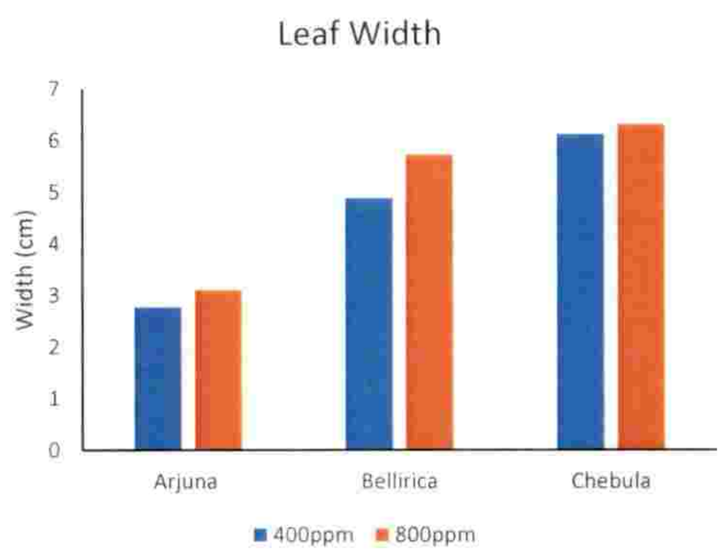

Figure 12: Response of elevated CO_2 on leaf width at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* *arjuna, Terminalia* bellirica *and Terminalia* chebula

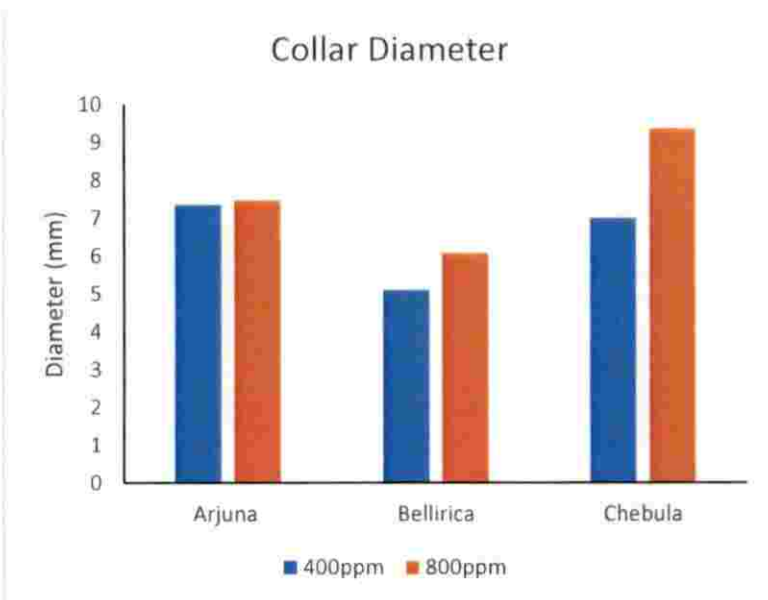

Figure 13: Response of elevated CO_2 on stem diameter at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

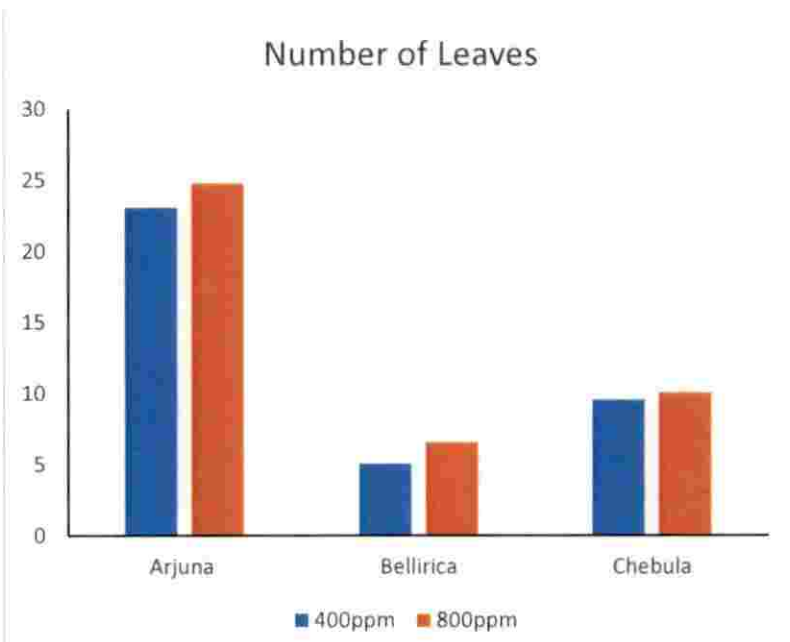

Figure 14: Response of elevated CO_2 on leaf number of plant at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

125

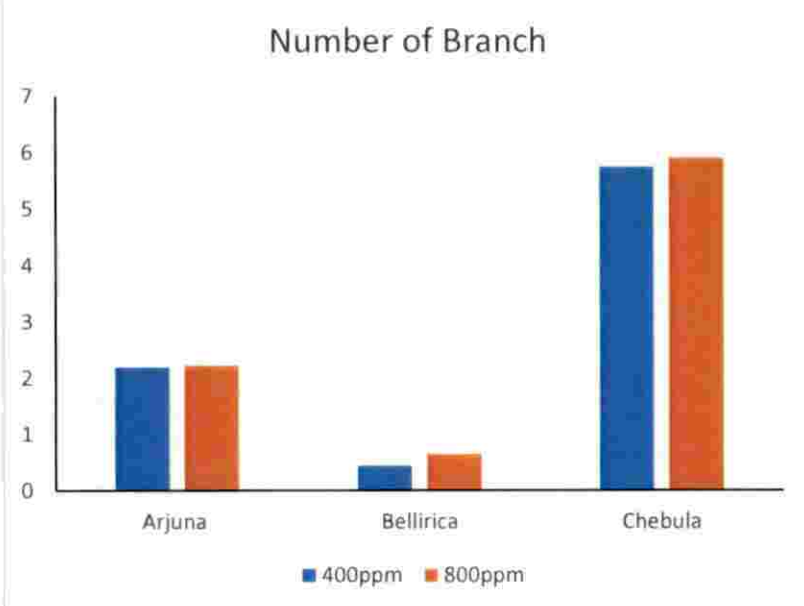

Figure 15: Response of elevated CO_2 on branch number of plant at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia* c*hebula*

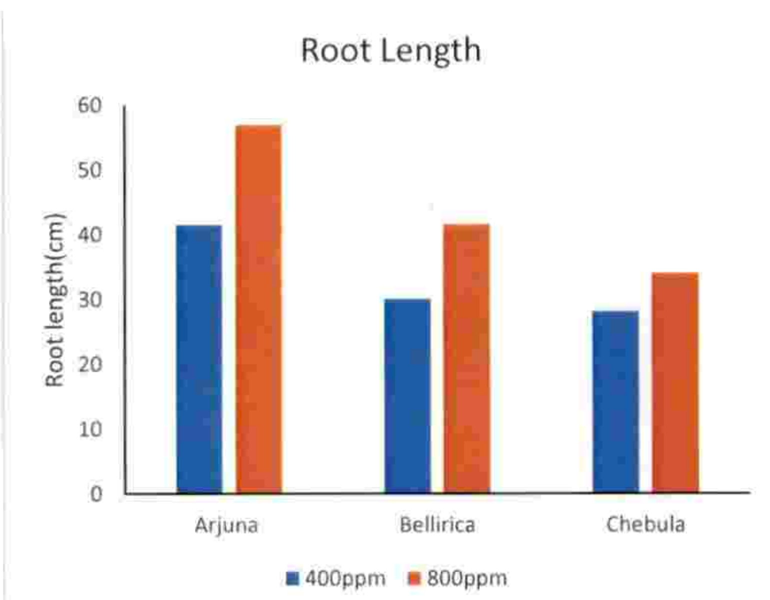

Figure 16: Response of elevated CO_2 on root length at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* a*rjuna, Terminalia* bellirica *and Terminalia* c*hebula*

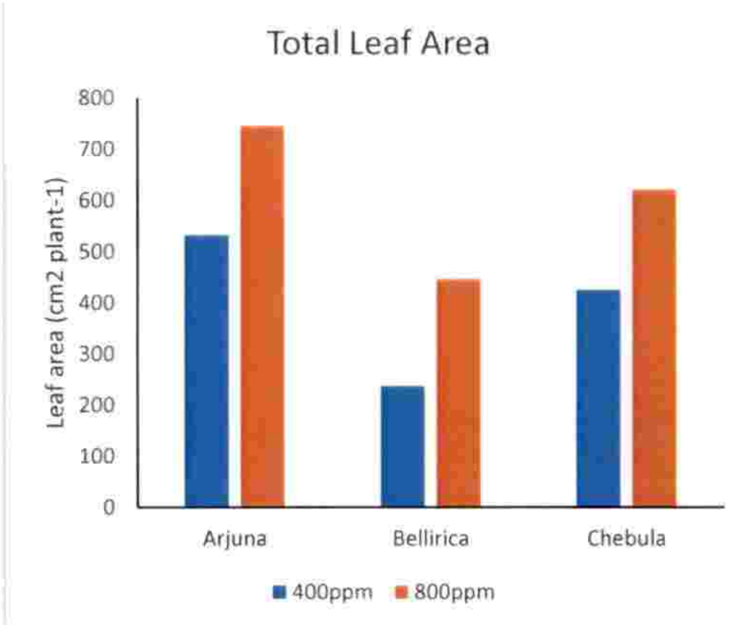

Figure 17: Response of elevated CO_2 on total leaf area at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

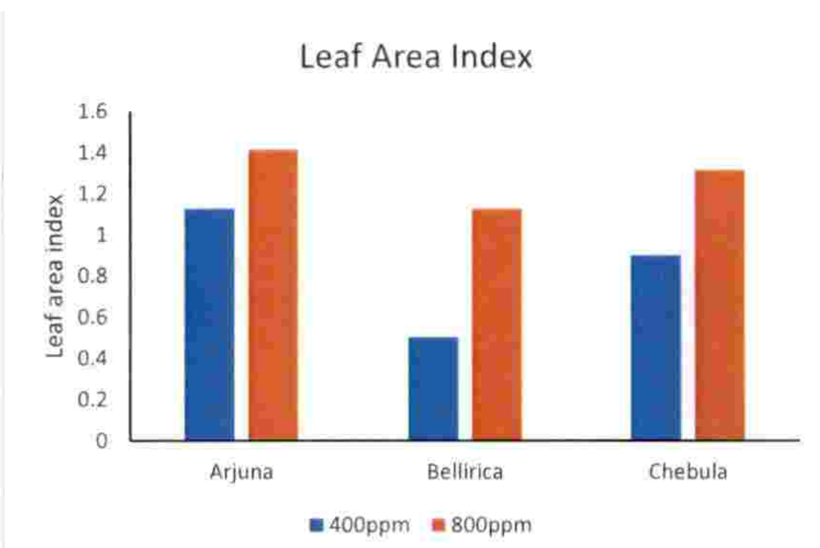

Figure 18: Impact of elevated CO_2 on leaf area index of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

127

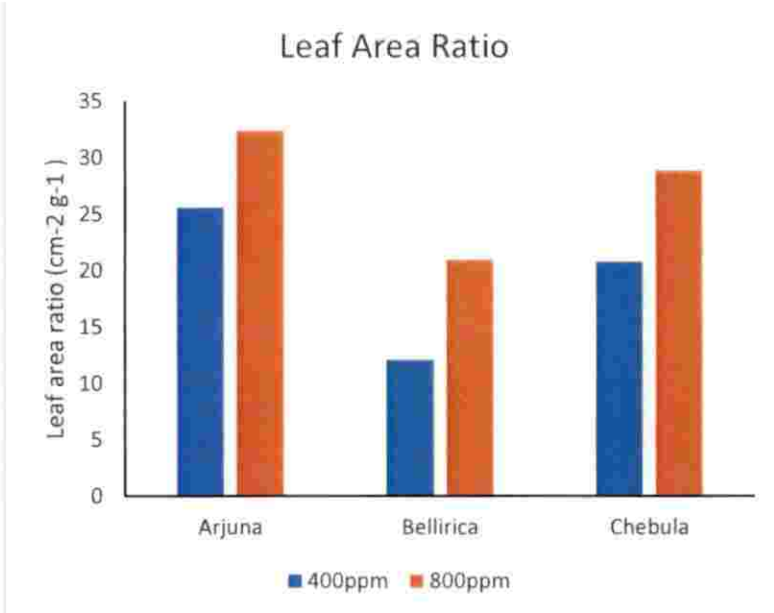

Figure 19: Impact of elevated CO_2 on leaf area ratio of *Terminalia* a*rjuna,* *Terminalia* b*ellirica and Terminalia* c*hebula*

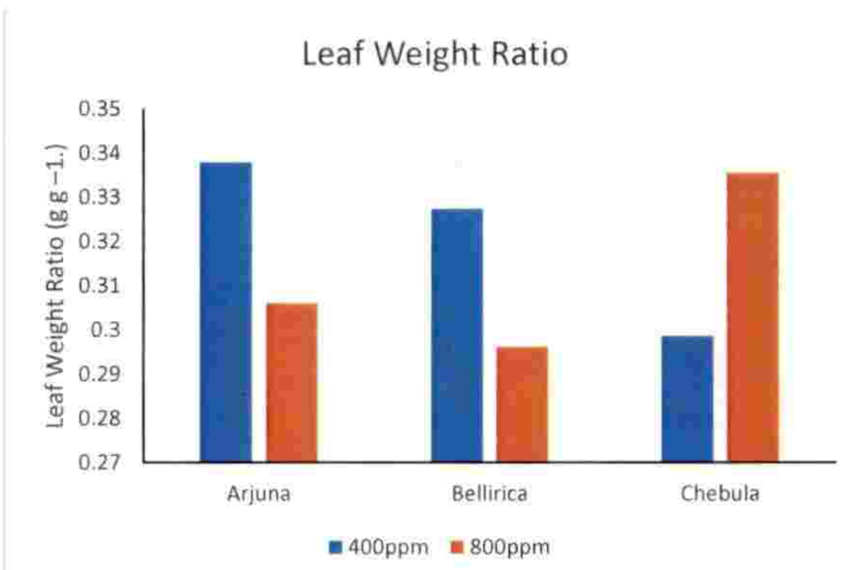

Figure 20: Impact of elevated CO_2 on leaf weight ratio of *Terminalia* a*rjuna,* *Terminalia* b*ellirica and Terminalia* c*hebula*

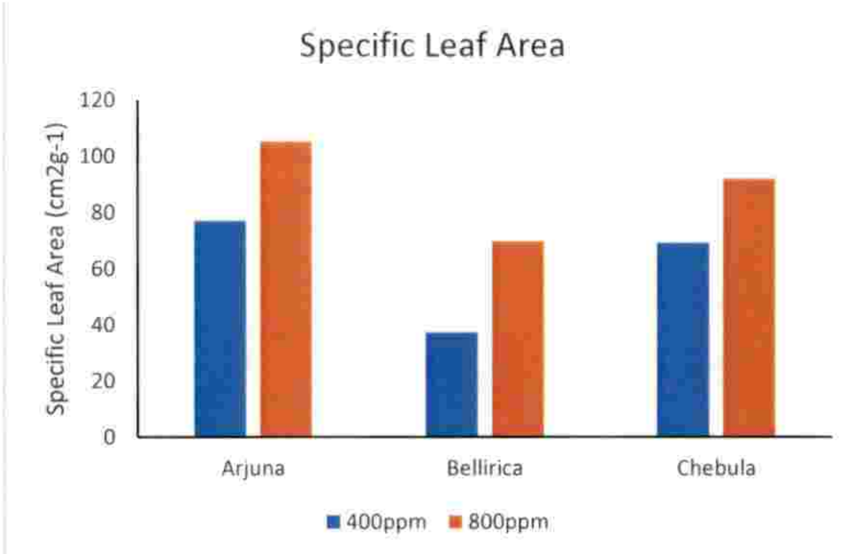

Figure 21: Impact of elevated CO_2 on SLA of *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia* c*hebula*

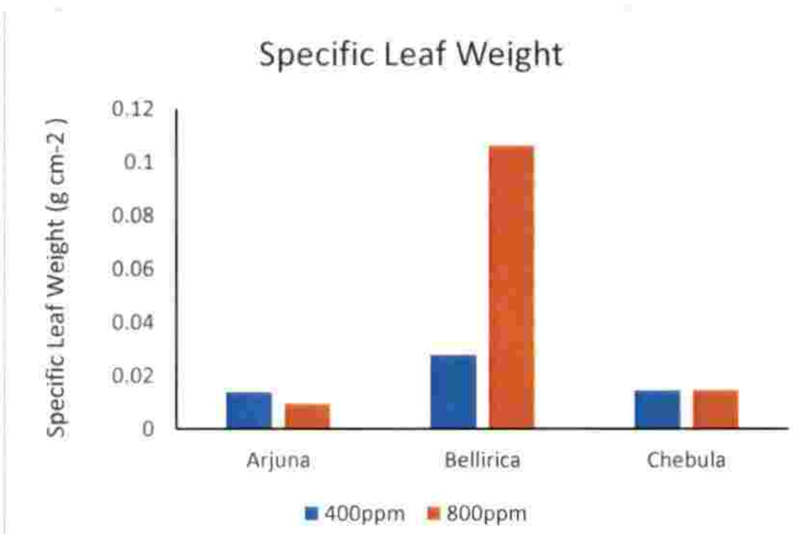

Figure 22: Impact of elevated CO_2 on specific leaf weight of *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia* c*hebula*

129

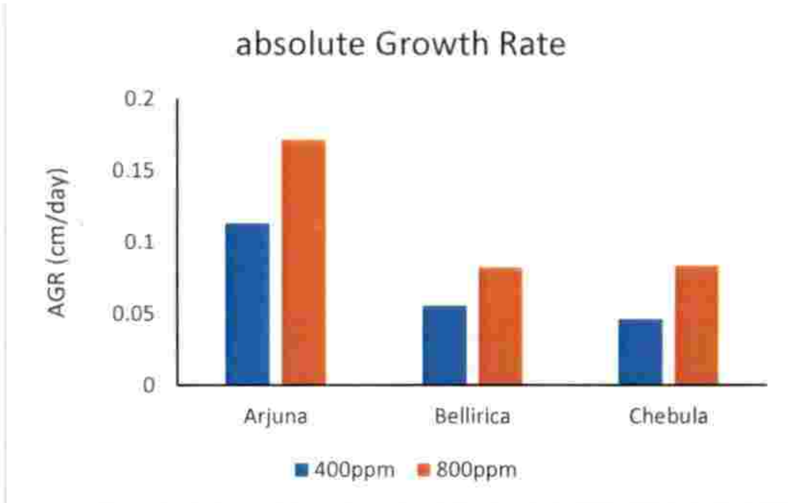

Figure 23: Impact of elevated CO_2 on AGR of *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia* c*hebula*

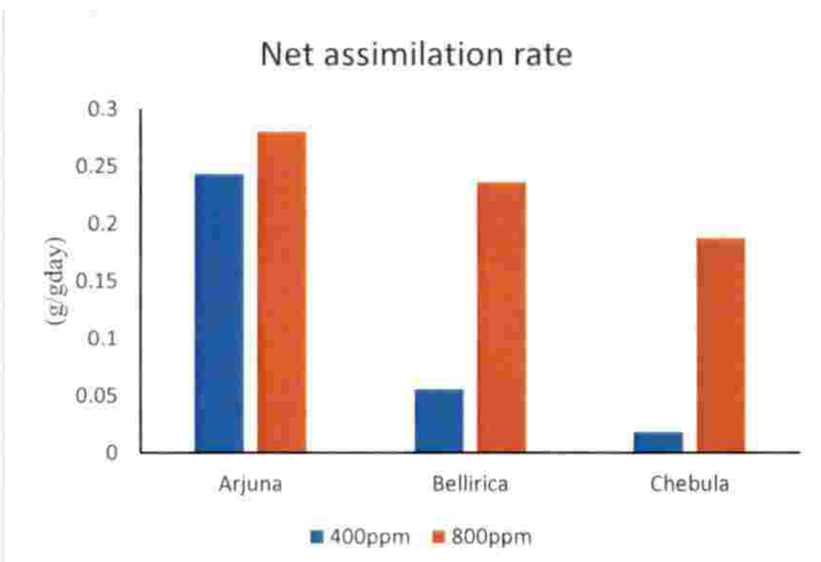

Figure 24: Impact of elevated CO_2 on NAR of *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia* c*hebula*

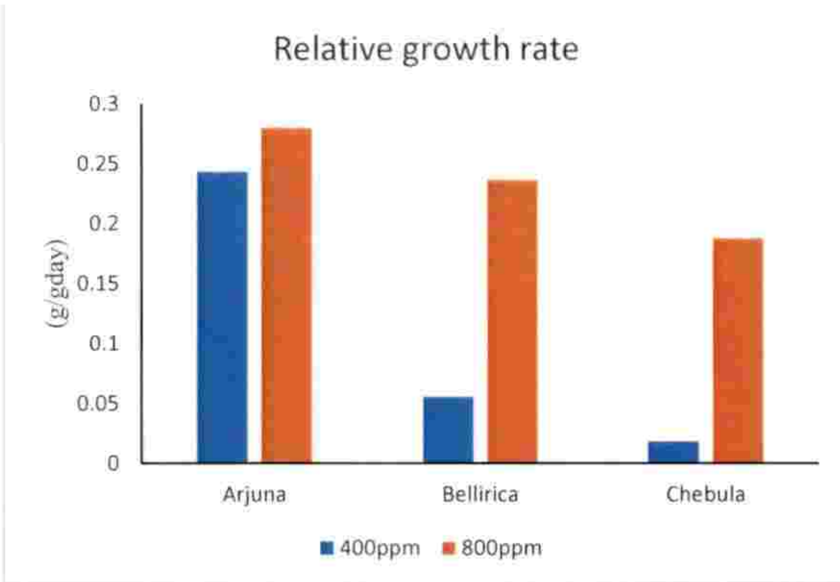

Figure 25: Impact of elevated CO_2 on relative growth rate of *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia* c*hebula*

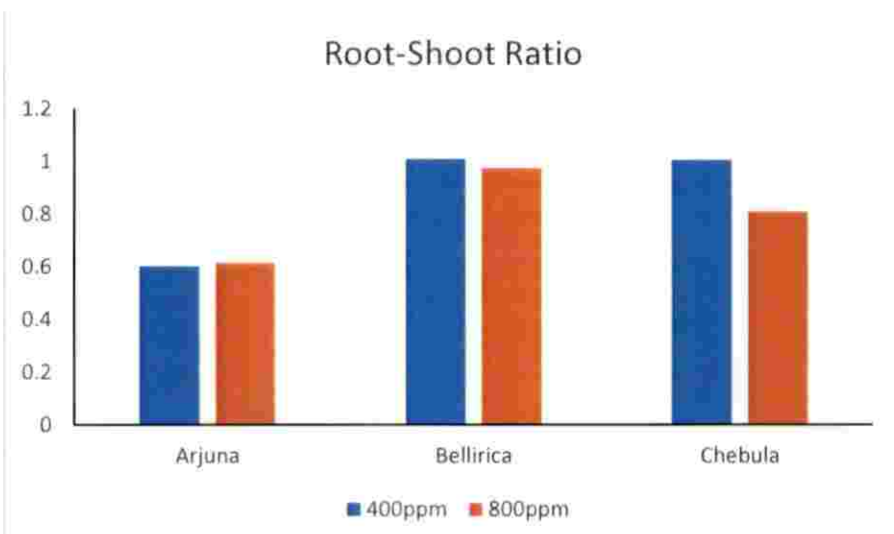

Figure 26: Impact of elevated CO_2 on RSR of *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia* c*hebula*

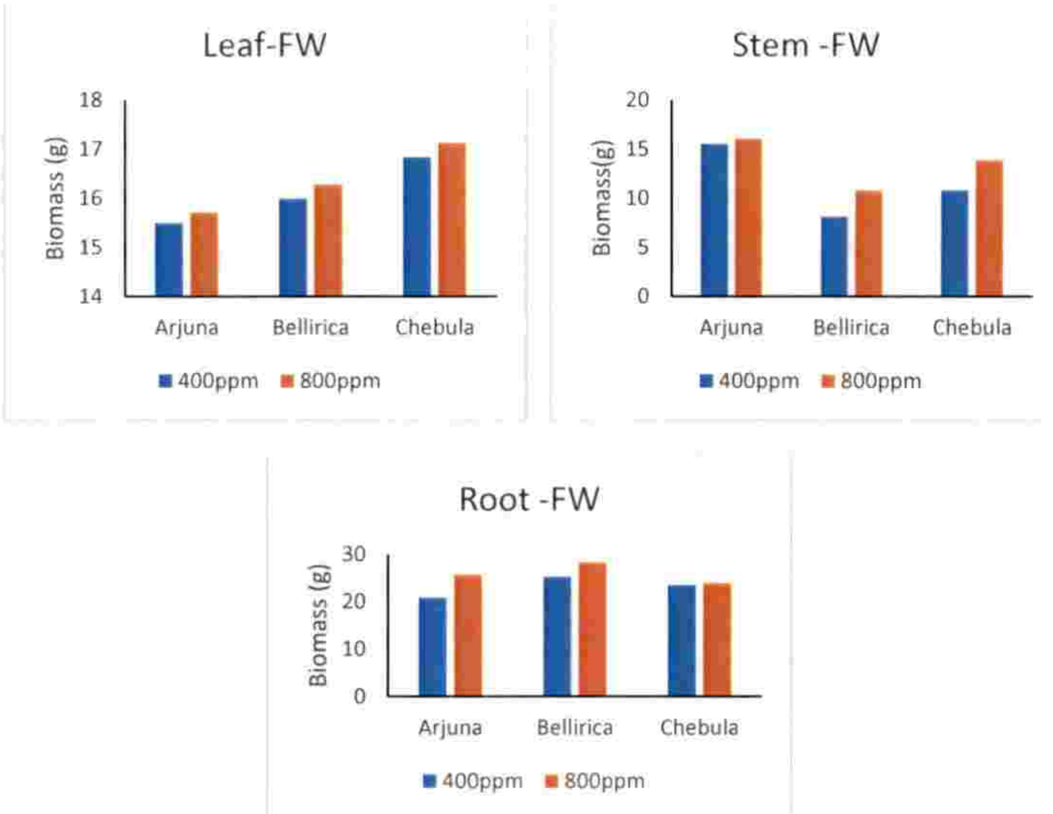

Figure 27: Impact of elevated CO_2 on various plant parts fresh weight (Leaves, Stem, and Root) of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula*

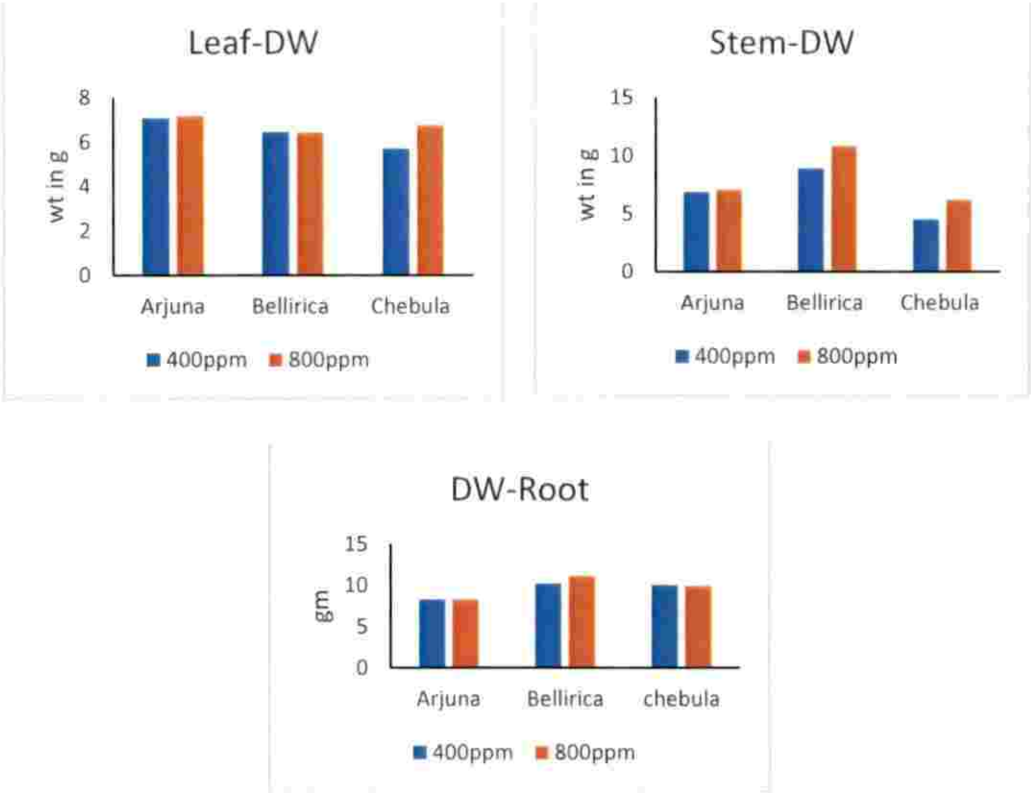

Figure 28: Impact of elevated CO_2 on various plant parts biomass (Leaves, Stem, and Root) of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula*

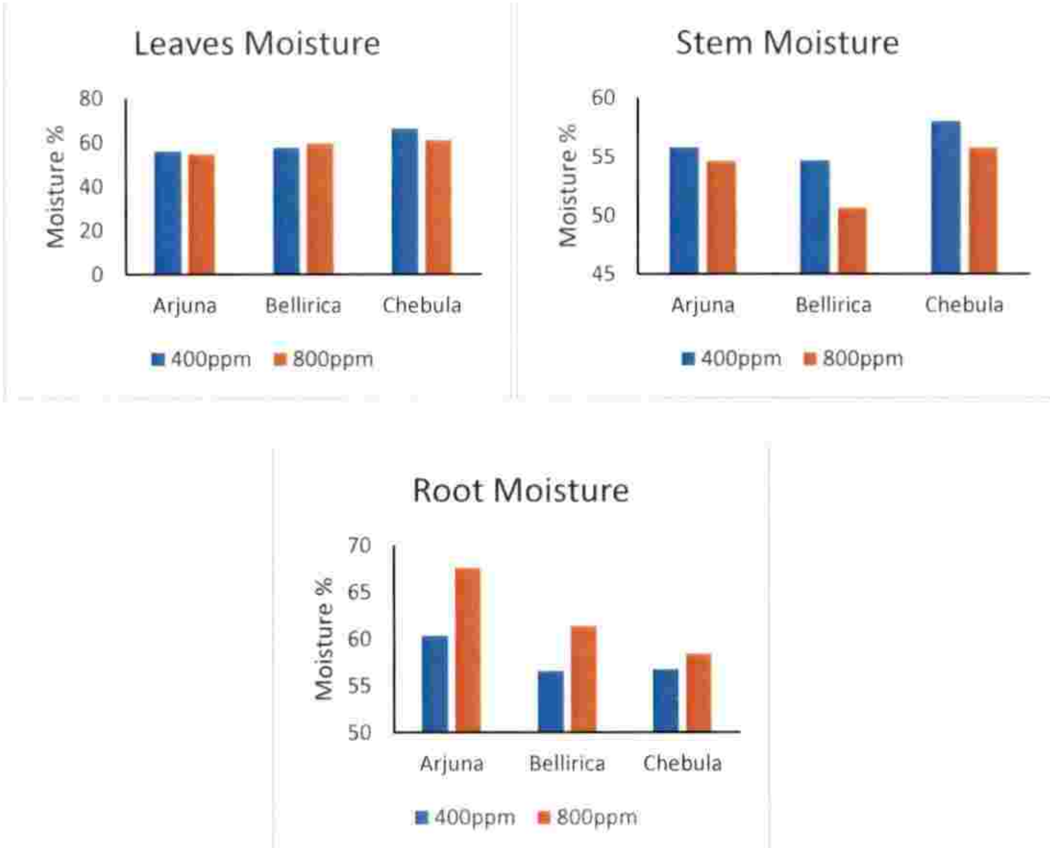

Figure 29: Impact of elevated CO_2 on various plant part Moisture content (Leaves, Stem, and Root) of *Terminalia* a*rjuna, Terminalia* b*ellirica and Terminalia chebula*

5.2 Mitigation efficiency of plants exposed to elevated CO_2 concentration

Under elevated CO_2 plants capture or sequestrate more carbon than ambient CO_2. With my results *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula* are shown a significant increase in carbon sequestration in elevated CO_2 than ambient CO_2 (fig: 30). The total sum amount of carbon partitioned by the plant was 100 (fig: 31). Carbon stock and carbon mitigation of all parts (leaf, stem and root) of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula* are higher in elevated CO_2 except Terminalia bellirica leaf than ambient (fig: 32&33).

Terminalia arjuna, Terminalia bellirica and *Terminalia chebula* plants store more carbon in elevated CO_2 condition than ambient CO_2.

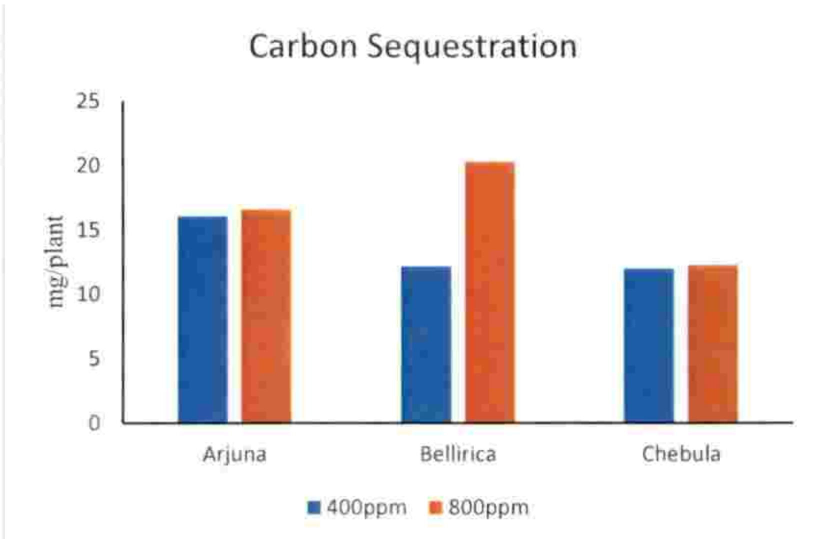

Figure 30: Response of elevated CO_2 on carbon sequestration at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

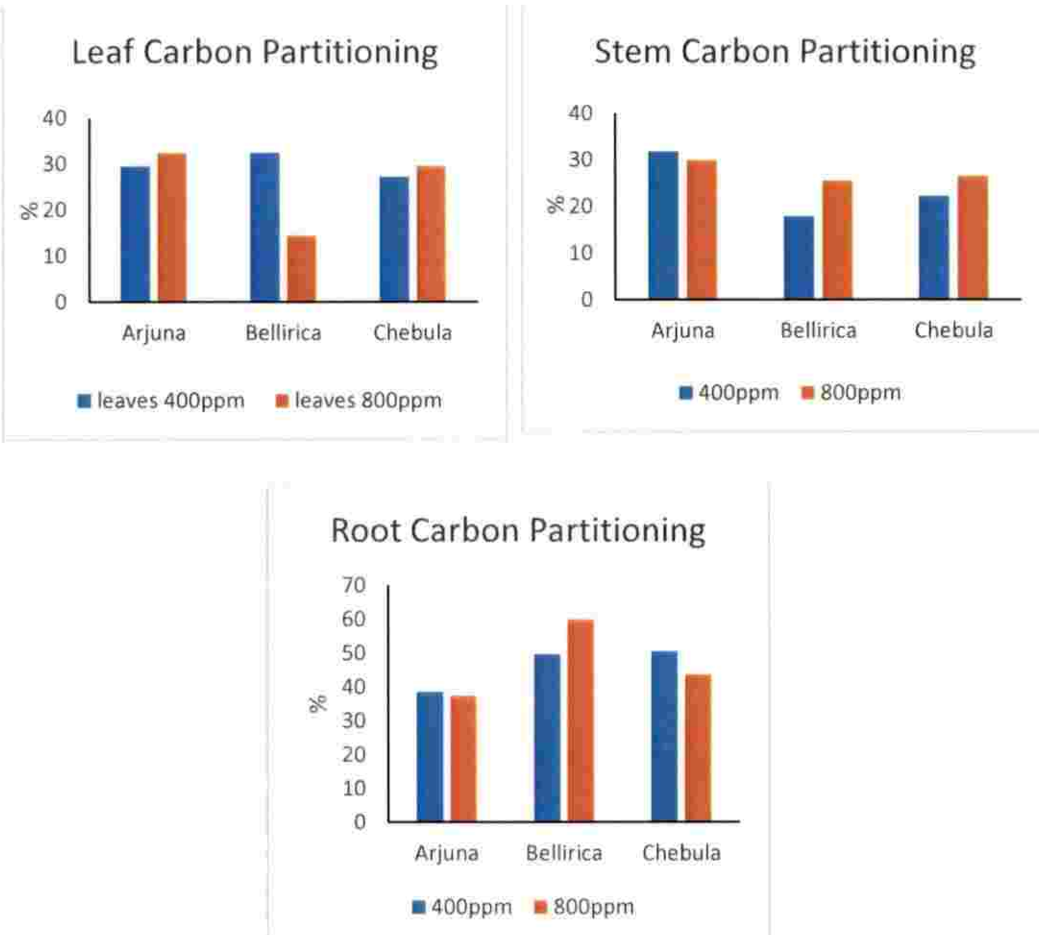

Figure 31: Response of elevated CO_2 on carbon partitioning at ambient (400ppm) and elevated (800ppm) conditions on various parts of (leaf, stem, and root) of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula*

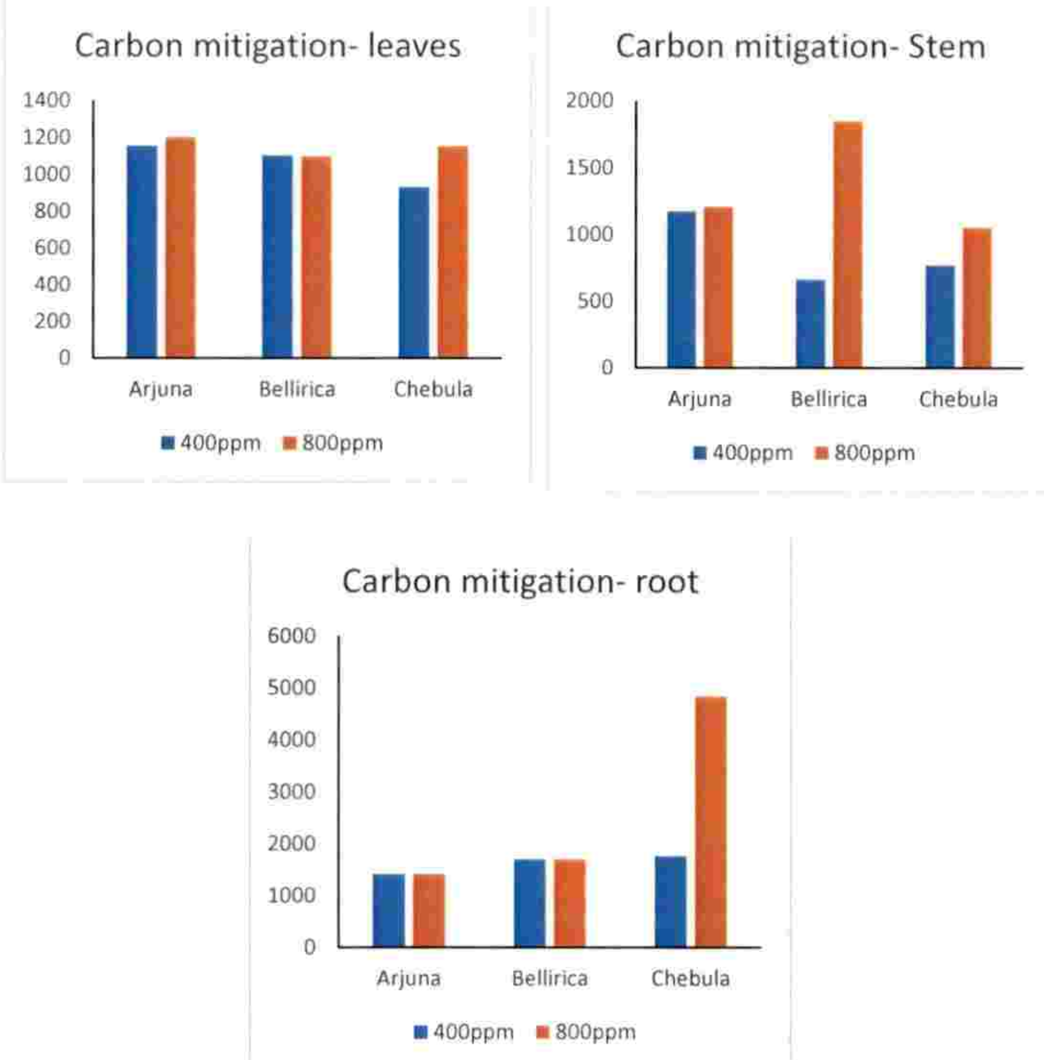

Figure 32: Response of elevated CO_2 on carbon mitigation at ambient (400ppm) and elevated (800ppm) conditions on various parts of (leaf, stem, and root) of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula*

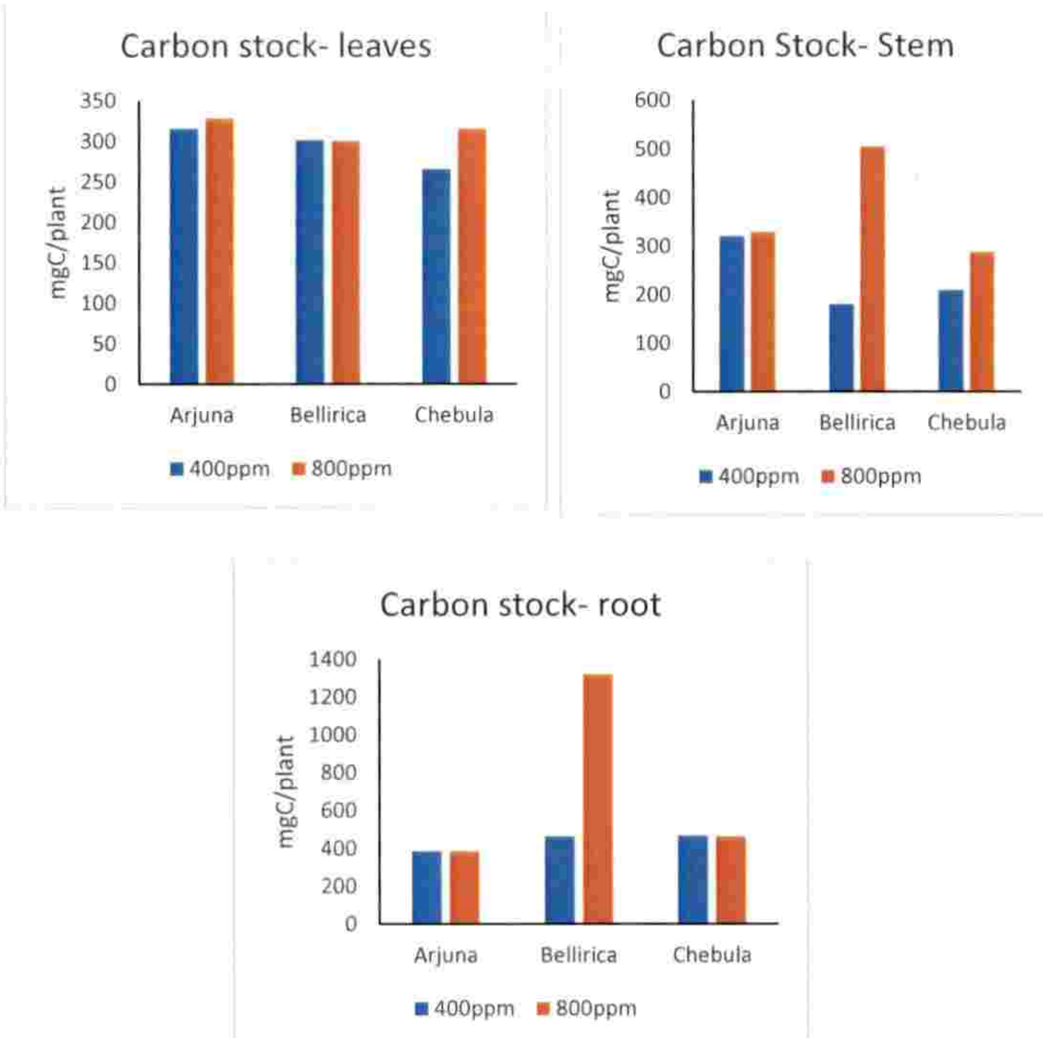

Figure 33: Response of elevated CO_2 on carbon stocks at ambient (400ppm) and elevated (800ppm) conditions on various parts of (leaf, stem, and root) of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula*

5.3 Biochemical response of plants grown under elevated CO_2 concentration

Chlorophyll component is one of the most important biological pigment and light-harvesting component. The lack of chlorophyll is a large indicator for diseases, industrial pollution and temperature extremes (Hendry and Grime, 1993). The reduction of chlorophyll affects plant growth, photosynthetic activities (Jeong *et al.*, 2018). Ibrahim *et al.* (2014) founded that chlorophyll content and sugar are increased with elevated CO_2. Xu *et al.* (2015) estimated the ascorbic acid and other antioxidants are enhanced at elevated CO_2 than ambient. In this study chlorophyll and carotenoid contents, total sugars, ascorbic acid and protein contents of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula* are significantly increased under elevated CO_2 than ambient CO_2 (fig: 34-38). Janani *et al.* (2016), stated protein, sugar, other carbohydrates, amino acids, and phenols of Melia gets reduced under elevated CO_2. Saravanan and Kathy (2014) also observed protein was decreased with elevated CO_2. Mafakhaeri *et al.* (2010) founded that the proline content increase leads to a decrease of chlorophyll content occur and the photosynthetic rate. Stomatal conductivity and transpiration also get reduced. Proline was good stress indicator under elevated CO_2 proline content was decreased than ambient CO_2 (fig: 39) in the present study. Hence, plants grown under elevated CO_2 has less stress, even a higher presence of CO_2.

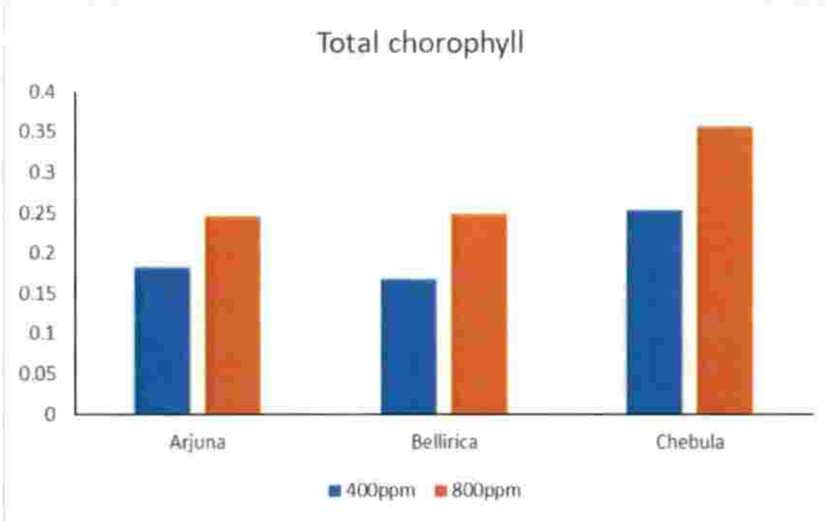

Figure 34: Response of elevated CO_2 on total chlorophyll at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

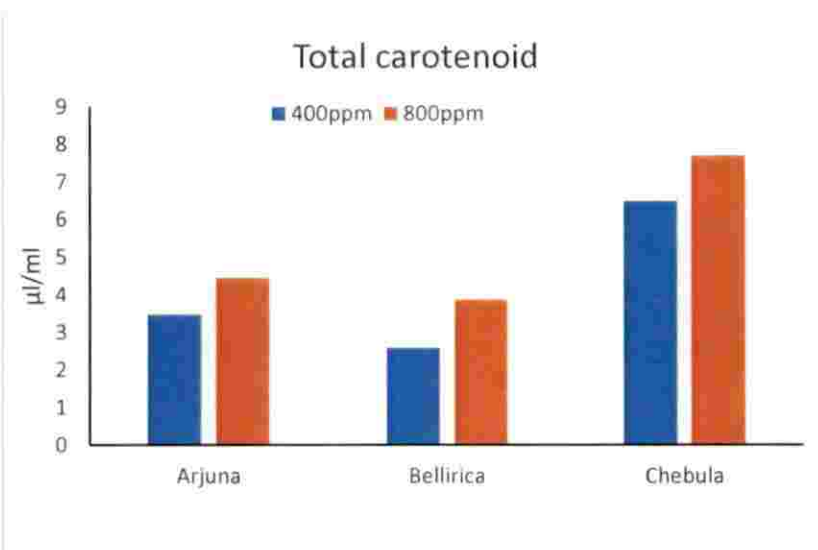

Figure 35: Response of elevated CO_2 on total carotenoid at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

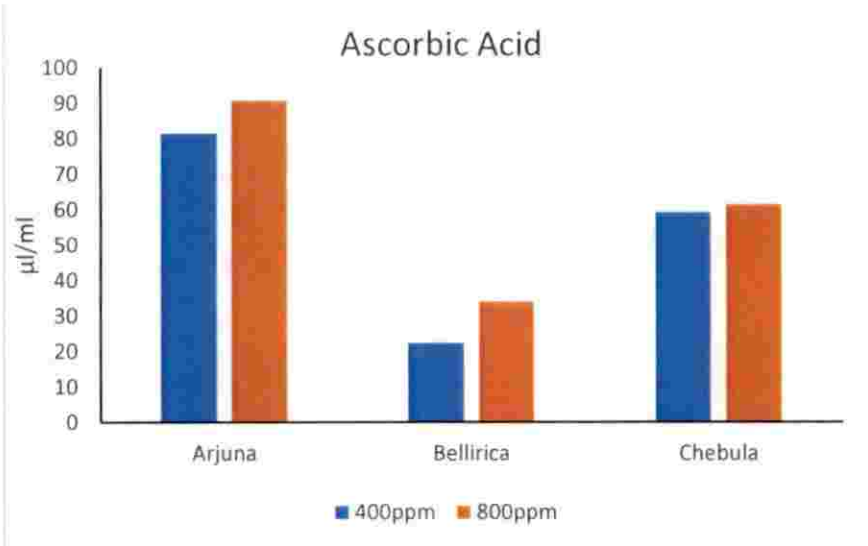

Figure 36: Response of elevated CO_2 on ascorbic acid at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

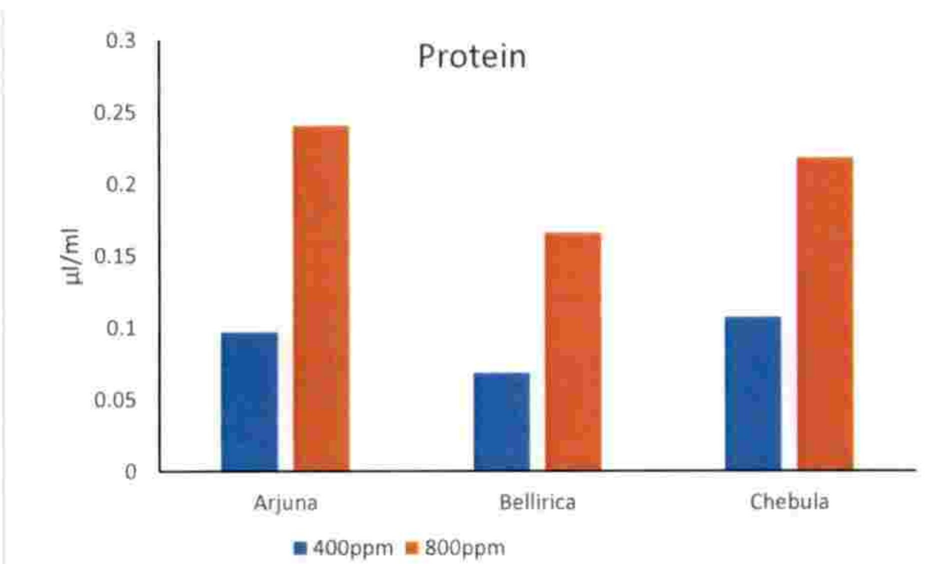

Figure 37: Response of elevated CO_2 on protein at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

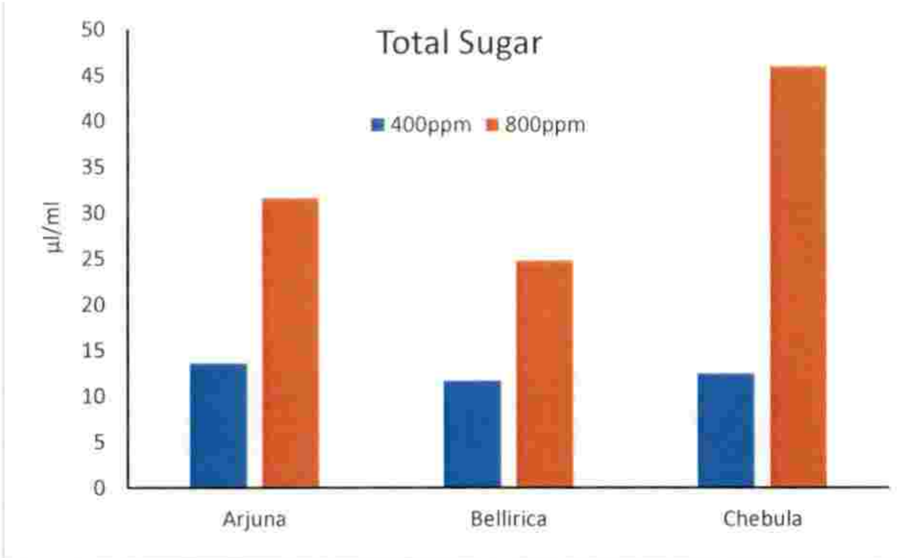

Figure 38: Response of elevated CO_2 on total sugar at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

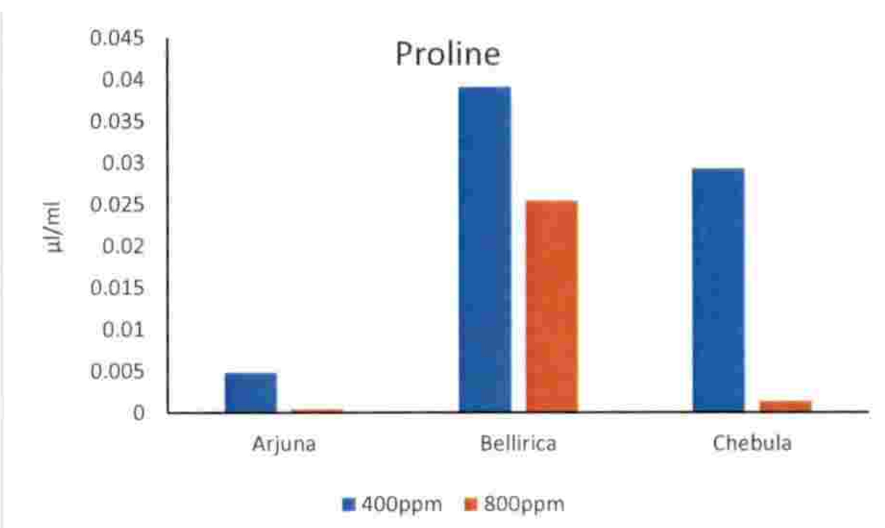

Figure 39: Response of elevated CO_2 on proline at ambient (400ppm) and elevated (800ppm) conditions of *Terminalia* arjuna, *Terminalia* bellirica *and Terminalia* chebula

Carbon content in leaf under elevated CO_2 increases due to the positive accumulation of carbohydrates as a product of photosynthetic amplification (Tjoelker *et al.*, 1999). Due to elevated CO_2 organic carbon content was increased, the plants fix extra carbon under elevated CO_2, and it was partitioned to other growing sinks to help the meristematic activity of plants (Sharma and Sengupta, 1990). In some plants increased C and decreased N will increase C: N ratio and the high C: N ratio reported in elevated CO_2 condition (Gifford *et al.*, 2000, Farage *et al.*, 1998). In the present study organic carbon content was high in all parts (leaf, stem, and root)) of *Terminalia arjuna, Terminalia bellirica* and *Terminalia chebula* under elevated CO_2 than ambient except Terminalia bellirica leaf, it shows high organic carbon content in ambient CO_2 than elevated CO_2 (fig: 43). Under elevated CO_2 plant N was declined when the carbon content was increased (Leaky *et al.*, 2009). Due to the dilution effect of carbohydrates will decline the N of several plants (Rogers *et al.*, 1996) or due to the acceleration of plant growth, but not the higher use of nitrogen (Coleman *et al.*, 1993). In this present study, total N was higher in ambient CO_2 in *Terminalia arjuna and Terminalia chebula*, and in *Terminalia bellirica* shows higher total N in elevated CO_2 condition (fig: 42). Phosphorous content was increased with elevated CO_2 (Rogers *et al.*, 1996). The present study shows higher phosphorous in elevated CO_2 (*Terminalia arjuna and Terminalia bellirica*) and *Terminalia chebula* shows higher phosphorous in ambient CO_2 (fig: 41). Potassium was higher in elevated CO_2 (*Terminalia arjuna and Terminalia chebula*), and in *Terminalia bellirica* potassium was higher in ambient CO_2 than elevated CO_2 (fig: 40).

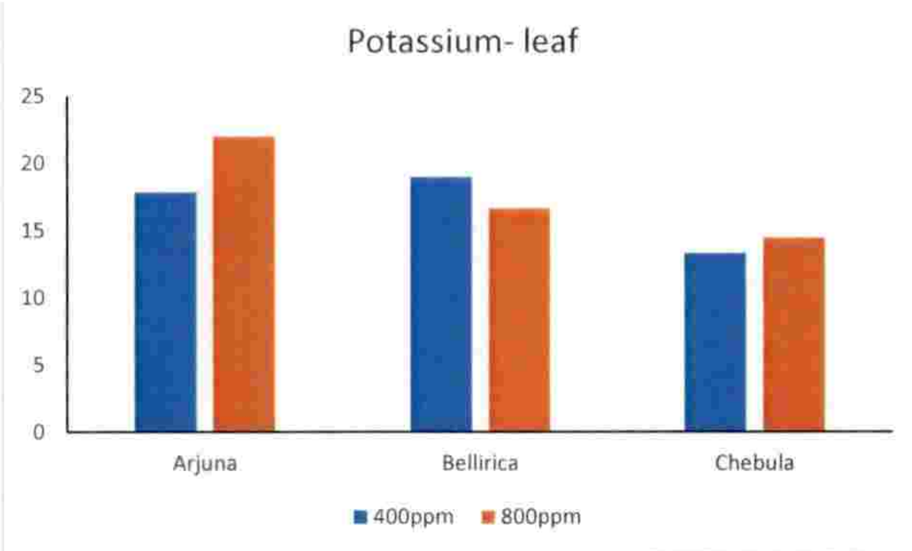

Figure 40: Impact of elevated CO_2 on leaf potassium at ambient (400ppm) and elevated (800ppm) of *Terminalia* arjuna*, Terminalia* bellirica *and Terminalia chebula*

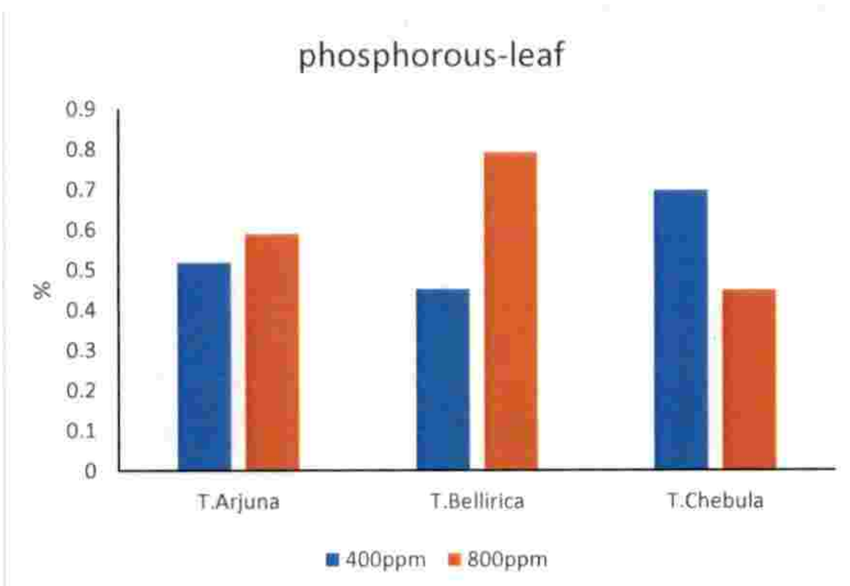

Figure 41: Impact of elevated CO_2 on leaf phosphorous at ambient (400ppm) and elevated (800ppm) of *Terminalia* arjuna*, Terminalia* bellirica *and Terminalia chebula*

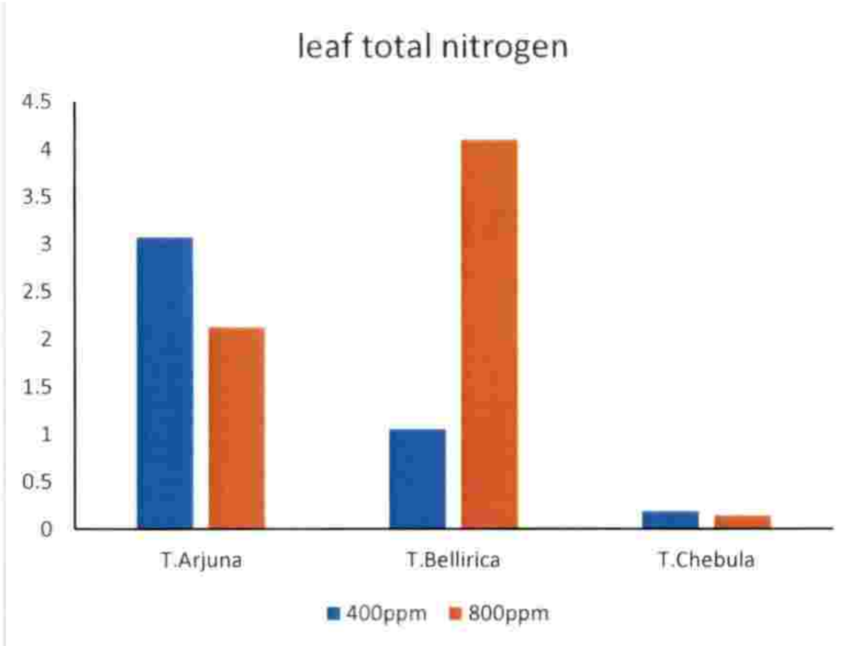

Figure 42: Impact of elevated CO_2 on leaf total nitrogen at ambient (400ppm) and elevated (800ppm) of *Terminalia arjuna, Terminalia bellirica and Terminalia chebula*

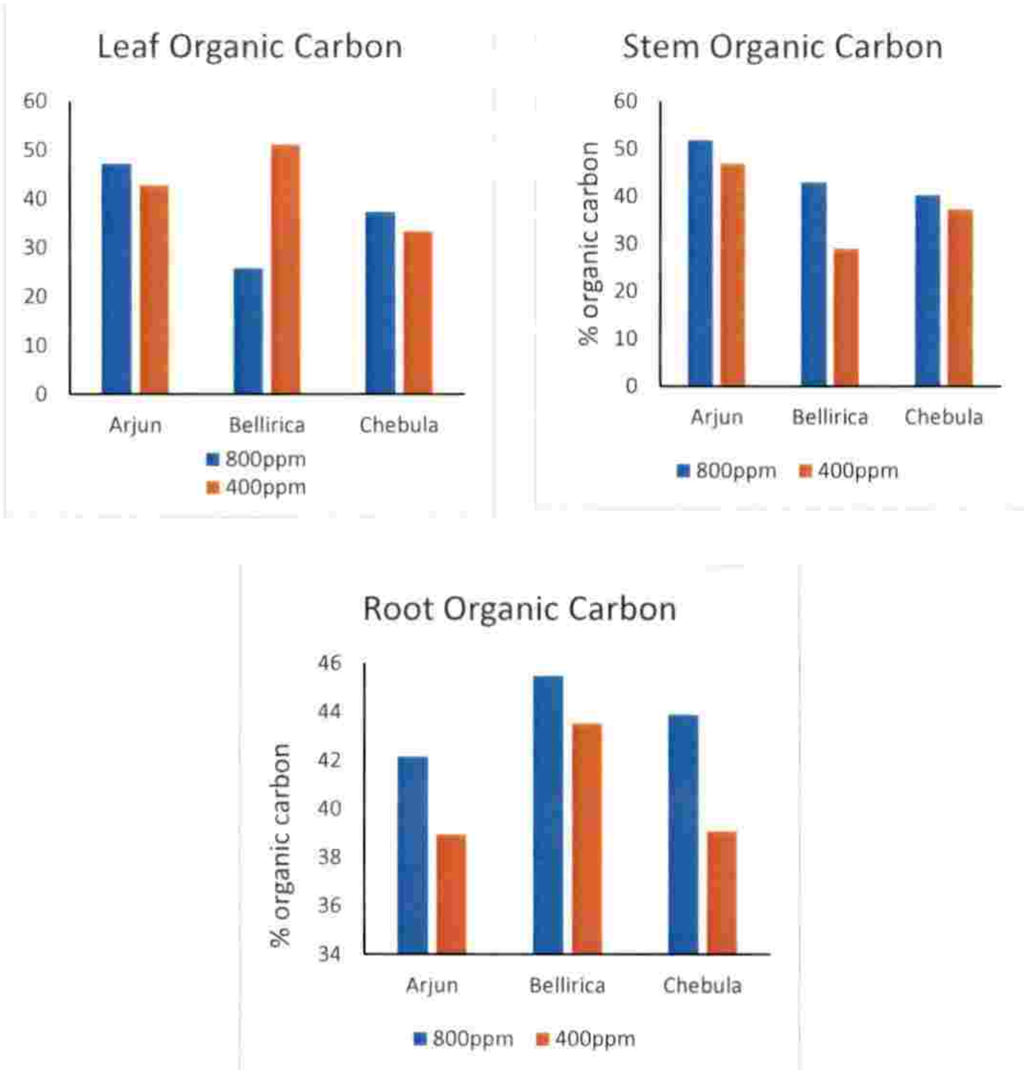

Figure 43: Impact of elevated CO_2 on organic carbon of various parts (Leaf, Stem, and Root) of *Terminalia arjuna, Terminalia bellirica,* and *Terminalia chebula* at ambient (400ppm) and elevated (800ppm)

Terminalia arjuna shows a positive impact on its morphological biochemical and physiological characteristics towards the elevated CO_2 (800ppm) than ambient 400ppm. *Terminalia bellirica* shows the good adaptive, biochemical response to elevated CO_2 (800ppm). *Terminalia chebula* shows the good adaptive, biochemical response to elevated CO_2 (800ppm). These plants are showing good adaptation and mitigation towards elevated CO_2 condition.

CONCLUSIONS

148

CHAPTER 6

CONCLUSION

This study is entitled as "Growth dynamics and physiological response of selected forestry species to CO_2 enriched atmosphere" and the species chosen for *T.arjuna, T.bellirica and T.chebula*. They show good adaptation, mitigation, and biochemical properties. The plants have increased in plant height, collar diameter, leaf length and width, number of leaves and branches, fresh and dry weight, moisture content, leaf area, leaf area index, SLA, AGR, RGR, LAR, LWR, NAR are higher in 800ppm compared to 400ppm. The biochemical properties like Total chlorophyll and carotenoids, protein, total sugar, proline, ascorbic acid are shown good response in 800ppm than 400ppm. But in between the 800ppm stress factor proline is very less in *T.arjuna* and it is higher in *T.bellirica*. Carbon sequestration, Carbon mitigation is higher in 800ppm than 400 ppm and the carbon partitioning more carbon allocated in stem parts compared 400ppm. Organic Carbon content also high in 800ppm than 400ppm. In phenolic response plants shows good photosynthetic response in all seasons (winter, spring, summer), in summer the stomatal conductance less than 400ppm, Ci is less in all seasons in 800ppm but in T.chebula shows higher than 400ppm in summer season, transpiration is less in 400ppm plants except *T.chebula*, Pn/E is higher in 800ppm at summer season than 400ppm, Pn/gs is higher in summer season at 800ppm, and it was higher in all seasons, Pn/Ci also higher in 800ppm at all seasons compared to 400ppm. Ci/gs also higher in all species of 800ppm at summer season, Night leaf respiration is higher in two species at 800ppm than 400ppm, but *T.arjuna* shows a decline in night respiration at 800ppm. Total nitrogen was higher in elevated condition growing *T.bellirica* than ambient. *T.arjuna* and *T. chebula* show a drastic reduction in total nitrogen under elevated CO_2. The total phosphorus is high in elevated condition growing *T.bellirica* and *T.arjuna* over ambient 400ppm, but *T.chebula* showed an increase in ambient condition than elevated CO_2. Total Potassium was higher in *T.chebula* and *T.arjuna* at elevated CO_2 than ambient, and the *T. bellirica* shows the higher response at ambient CO_2. *T.arjuna* is more adaptive and mitigative to elevated CO_2. These plants are useful for future especially as medicinal properties, fuel, fodder, shade, timber. This study also has limitations, and it needs a long term study about the responses and other properties of these slow-growing plants.

REFERENCES

151

REFERENCES

2017 UK GREENHOUSE GAS EMISSIONS, PROVISIONAL FIGURES, 29 March 2018

Acock, B. and Allen, L. H., Jr 1985. Crop responses to elevated carbon dioxide concentrations. In: *Direct Effect of Increasing Carbon Dioxide on Vegetation* (eds B. R. Strain & J. D. Cure). U. S. Department of Energy, DOC/ER-0238, Washington, D, C. pp: 53-98.

Amthor, J. S. 1995. Terrestrial higher-plant response to increasing atmospheric [CO_2] in relation to the global carbon cycle. Glob. Change Biol. Vol. 1. Issue, 4. Pg: 243-274.

Arp, W. J. 1991. Effect of source-sink relations on photosynthetic acclimation to elevated CO_2. *Plant Cell Environ.* 14:869-638.

Assman, S. M. 1999. The cellular basis of guard cell sensing of rising CO_2. *Plant Cell Environ.* 14:869-875.

Barnola, J. M., Raynaud, D., korotkevich, Y.S., and Lorius, C. 1987. Vostok ice core provides 160,000-year record of atmospheric CO_2. *Nature* 329:408-414

Bazzaz, F. A., Jasienski. M., Thomas. S. C., and Wayne. P.M. 1995. Micro-evolutionary responses in experimental populations of plants to CO2-enriched environments. PNAS. 92(18):8161-8165 ·

Becker, C and klaring, H. P. 2015. CO_2 enrichment can produce high red leaf lettuce yield while increasing most flavonoid glycoside and some caffeic acid derivatives concentrations. food chem. 199:736-745

Booker, F. L. and Mayer, C. A. 2001. Atmospheric carbon dioxide, irrigation, and fertilization effects on phenolic and nitrogen concentrations in loblolly pine (Pinus taeda) needles. *Tree Physiol*. 21: 609-616.

Bowes, G. 1991. Growth at elevated CO_2: photosynthetic responses mediated through Rubisco. *Plant cell environ*. 14(8): 795-806.

Carter, D. R. and Peterson, K. M. 1983. Effects of CO_2 enriched atmosphere on the growth and competitive interaction of a C_3 and C_4 grass. *Oecologia*. 58:188-193.

Cha, S., Chae, H-M., Lee, S-H., Shim, J-K. (2017). Effect of elevated atmospheric CO2 concentration on growth and leaf litter decomposition of Quercus acutissima and Fraxinus rhynchophylla. PLoS One 12(2): e0171197. doi:10.1371/journal.pone.017119.

Coleman, J. S., McConnaughag, K.D. M., and Bazzaz, F. A. 1993. Elevated CO_2 and plant nitrogen use: is redused tissue nitrogen concentration size dependent. *Oecologia*. 93:195-200.

Curtis, P. S., and Wang, X. 1998. A meta-analysis of elevated CO_2 effects on woody plant mass, form, and physiology. *Oecologia*. 113(3):299–313.

Curtis, P. S., Snow, A. A. & Miller, A. S. 1994. Genotype-specific effect of elevated CO_2 on fecundity in wild radish (*Raphanus raphanistrum*). *Oecologia*. 97:100-105.

Deb, A., Barua, S., Das, B. 2016. Pharmacological activities of Baheda (Terminalia bellerica): A review. *IJPPR*. 5(1): 194-197.

Dlugokencky, E. and Tans, P. 2017. Trends in Atmospheric Carbon Dioxide. National Oceanic & Atmospheric Administration, Earth System Research Laboratory (NOAA/ESRL).

Esashi, Y., Abe, Y., and Ashino, H. 1989. Germination of cocklebur seed and growth of their axial and cotyledonary tissues in response to ethylene, carbon dioxide and/or oxygen under water stress. *Plant Cell Environ*. 12: 183-190.

Estiarte, M., penuelas, J., Kimball, B. A., Hendrix, D. L., Pinter, P. J., Wall, G. W., LaMorte, R. L. and Hunsaker, D. J. 1999. Free-air CO2 Enrichment of Wheat: leaf flavonoid concentration throughout the growth cycle. *Physiol. plant.* 105: 1148-1154.

Estiartea, M., Penuelas, P., Kimballb, B. A., Hendrixc, D. L., Jr, P. J. P., Wallb, G. W., LaMorteb, R. L., and Hunsakerb, D. J. 1999. Free-air CO_2 enrichment of wheat: leaf flavonoid concentration throughout the growth cycle. *Physiologia plantarum*. 105:423–433.

Fact Sheet: Climate Change Science – The Status of Climate Change Science Today, UNFCC, 2011, 7 (pg.).

Farage, P. K., Mckee, I. F., and Long, S. P. 1998. Does a low nitrogen supply necessarily lead to acclimation of photosynthesis to elevated CO_2. *Plant Physiol.* 118:573-580.

Gao, J., Han, X., seneweera, S., Li, P., Zong, Y. Z., Dong, Q. 2015. Leaf photosynthesis and yield components of mung bean under fully open-air elevated CO_2. *Integr.Agric.* 14(5): 977-983.

Garbutt, K. and Bazzaz, F. A. 1984. The effects of elevated CO_2 on plants. III. Flower, fruit and seed production and abortion. *New Phytol.* 98:433-446.

Ghannoum, O., von Caemmerer, S., Ziska, L. H., and Conroy, J. P. 2000. The growth response of C_4 plants to rising atmospheric CO_2 partial pressure: a reassessment. *Plant Cell Environ.* 23: 931-942.

Ghasemzadeh, A. and Jaafar, H. Z. E. 2011. Effect of CO2 Enrichment on Synthesis of Some Primary and Secondary Metabolites in Ginger (Zingiber officinale Roscoe). ***Int.** J. **Mol.*** 12: 1101-1114.

Ghasemzadeh, A., Jaafar, H. Z. E and Rahmat, A. 2010. Elevated CO_2 Increases Contents of Flavonoids and Phenolic Compounds, and Antioxidant Activities in

Malaysian Young Ginger (Zingiber officinale Roscoe.) Varieties. *Molecules*. 15:7907-7922.

Gifford, R. M., and Barrett, D. J., and Lutze, J. L. 2000. The effect of elevated CO_2 on C:N ratio and C:P mass ratio of plant tissues. Plant soil. 224:1-14.

Graaff, M. D., Groenigen, K. V., Six, J., Hungatez, B., and Kessel, C. R. V. 2006. Interactions between plant growth and soil nutrient cycling under elevated CO_2: a meta-analysis. *Rev. Glob. Change Biol.* 12:2077–2091, doi: 10.1111/j.1365-2486.2006.01240.x.

Hardy, R. W. F. and Havelka, U. D. K. 1975. Symbiotic N_2 fixation: multi-fold enhancement by CO_2 enrichment of field-ground soybeans. *Plant. Physiol.* 48:35.

Hendry, G. A., and Grime, J. P. 1993. Methods in comparative plant ecology-a laboratory manual. Landon: Chapman and Hall.

http://vikaspedia.in/agriculture/crop-production/package-of-practices/medicinal-and-aromatic-plants/terminalia-arjuna

http://vikaspedia.in/agriculture/crop-production/package-of-practices/medicinal-and-aromatic-plants/terminalia-chebula

http://www.flowersofindia.net/catalog/slides/Arjun%20Tree.html

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/695930/2017_Provisional_Emissions_statistics_2.

https://en.wikipedia.org/wiki/Terminalia_arjuna

https://pfaf.org/user/Plant.aspx?LatinName=Terminalia+arjuna

https://www.planetayurveda.com/library/haritaki-terminalia-chebula

Ibrahim, M. H and Jaafa, H. Z. E. 2011. Increased Carbon Dioxide Concentration Improves the Antioxidative Properties of the Malaysian Herb Kacip Fatimah (*Labisia pumila Blume*). *Molecules*. 16:6068-6081.

Ibrahim, M. H., Jaafar, H. Z. E., Karimi, E., and Ghasemzadeh, A.2014. Allocation of Secondary Metabolites, Photosynthetic Capacity, and Antioxidant Activity of Kacip Fatimah (Labisia pumila Benth) in Response to CO_2 and Light Intensity. *Sci. World J.* 13. Article ID 360290

Idso, S. B. 1988. Three Phases of Plant Response to Atmospheric CO_2 Enrichment. *Plant Physiol.* 87:5-7.

IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y . Xia, V . Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY , USA.

IPCC [Inter Governmental Panel on Climate Change]. 2007. Summary Report of the Working Group of IPCC, Paris.

IPCC. 2014. Climate Change 2014 Synthesis Report.

Jaafar, H. Z. E., Ibrahim, M. H., and Karimi, E. 2012. Phenolics and Flavonoids Compounds, Phenylanine Ammonia Lyase and Antioxidant Activity Responses to Elevated CO_2 in *Labisia pumila (Myrisinaceae). Molecules*. 17:6331-6347.

Jach, M. E. and Ceulemans, R. 1999. Effects of elevated atmospheric CO_2 on phenology, growth and crown structure of Scots pine (*Pinus sylvestris*) seedlings after two years of exposure in the field. *Tree Physiol.* 19:289-300.

Janani, s., Priyadharshini, p., Jayaraj, R. S. C., Buvaneswaran, C., Warrier, R. R. 2016. Growth, physiological and biochemical responses of Meliaceae species - *Azadirachta indica* and *Melia dubia* to elevated CO_2 concentrations. *J. appl. biol.* 4(03):052-060. DOI: 10.7324/JABB.2016.40309.

Jeong, H.M., Kim, H.R., Hong, S., and You, Y.H. 2018. Effect of elevated CO_2 concentration and increased temperature on leaf quality responses of rare and endangered plants. *Journal of ecology and environment,* springer. 42:1.

156

Jin, J., Tang, C., and Sale, P. (2015). The impact of elevated carbon dioxide on the phosphorus nutrition of plants: a review. *Rev. Ann. Bot.* 116: 987–999.

Jones, H. G. 1998. Stomatal control of photosynthesis and transpiration. *J. Exp. Bot.* 49:387-398.

Katul, G., Manzoni, S., Palmroth, S., and Oren, R. (2010). A stomatal optimization theory to describe the effects of atmospheric CO_2 on leaf photosynthesis and transpiration. *Ann. Bot.* 105(3):431-442.

Kimball, B. A. 1993. Effects of increasing atmospheric CO_2 on vegetation. *Vegetatio,* 104/105, 65-83.

Kuo, C., Lindberg, C., and Thompson. D. J. 1990. Coherence established between atmospheric carbon dioxide and temperature. *Nature* 343:709-714.

Kvet, J. and Marshall, J.K. 1971. Assessment of leaf area and other assimilating plant surface. *In:* Plant photosynthetic production. Manuals of methods. (Eds., Sestak, Z., Catsky, J., Jarvis, P. G..). pp. 517-546. Dr. Junk Publ., The Hague.

Kvet, J.P., Necas, J., and Jarvis, P.G. 1971. Methods of growth analysis, *In:* Plant photosynthetic production. Manuals of methods. (Eds., Sestak, Z., Catsky, J., Jarvis, P. G..). pp. 343-391. Dr. Junk Publ., The Hague.

Leakey, A. D. B., Xua, F., Gillespie, K. M., Mcgrath, J. M., Ainswortha, E. A., and Ort, D. R. 2009. Genomic basis for stimulated respiration by plants growing under elevated carbon dioxide. *PNAS*. 106(9). 3597–3602.

Leaky, A. D. B., Ainsworth, E. A., Bernacchi, C. J., Rogers, A., Long, S. P., and Ort, D.R. 2009. Elevated CO_2 effects on plant carbon, nitrogen and water relations: six important lessons from FACE. *J Exp Bot*. 60:371-379.

Lin, W., and Wang, D. 1998. Effect of elevated CO_2 on growth and carbon partitioning in rice. *Chin Sci Bull*. 43:1982-1986.

Luna, R.K. 1996. Plantation trees. International book distributers. Dehradun, pp 975.

158

Mafakheri, A., Siosemardeh, A., Bahramnejad, B., Struik, P. C., Sohrabi, E. 2010. Effect of drought stress on yield, Proline and chlorophyll content in three chickpea cultivars. *Aust. J. Crop Sci.* 4(8):580-585.

Makino, A., and Mae, T. 1999. Photosynthesis and plant growth at elevated levels of CO_2. *Plant cell physiol*. 40:999-1006.

Medlyn, B. E., Badeck, F. W., Pury, D. G. G. D., Barton, C.V. M., Broadmeadow, M., Ceulemans, R., Angelis, P. D., Forstreuter, M., Jach, M. E., Kellomäki, S., Laitat, E., Marek, M., Philippot, S., A. Rey, A., Strassemeyer, J., Laitinen, K., Liozon, R., Portier, B., Roberntz, P., Wang, K., and Jarvis, P. G. 1999. Effects of elevated [CO_2] on photosynthesis in European forest species: a meta-analysis of model parameters. *Plant, Cell and Environ*. 22: 1475–1495.

Medrano, H., Magdalena, T., Martorell, S., Flexas, J., Hernandenz, E., Rossello, J., Pou, A., Mariano J-E., and Bota, J. 2015. From leaf to whole-plant water use efficiency (WUE) as a selection target. *Crop J*. 3: 220-228.

Morison, J. I. L., and Gifford, R. A. 1984. Plant growth and water use with limited water supply in high CO_2 concentrations: leaf area, water use and transpiration. *Plant physiol*. 11:361-374.

Mustafa, G., Arif, R., Atta, A., Sharif, S., and Jamil, A. 2017. Bioactive Compounds from Medicinal Plants and Their Importance in Drug Discovery in Pakistan. *Matrix Sci Pharma. Vol.1:17-26*

Natesh, S. Arjun .REMARKABLE TREES ON NII CAMPUS.

Palta, J. A. and Nobel, P. S. 1989. Influence of soil O_2 and CO_2 on root respiration for *Agave deserti. Plant Physiol.* 76:187-192.

Pandey, S.K., and Singh, H. 2011. A simple, cost-effective method for leaf area estimation. *J. Bot.*, 11:6.

Parmesan, C. 2006. Ecological and Evolutionary Responses to Recent Climate Change. *Annu. Rev. Ecol. Evol. Syst.*, 42: 181-203.

Pinelli, P. and Loreto, F. 2003. CO_2 emission from different metabolic pathways measured in illuminated and darkened C_3 & C_4 leaves at low, atmospheric and elevated CO_2 concentrations. *J. Exp. Bot.* 54:1761-1769.

Poorter, H.1993. Interspecific variation in the growth response of plants to an elevated ambient CO_2 concentration. In: Rozema J., Lambers H., Van de Geijn S.C., Cambridge M.L. (eds) CO_2 and biosphere. *Appl. Veg. Sci.. Springer,* Dordrecht. 14:77-98.

Pritchard, S. G., Rogers, H. H., Prior, S. A., and Peterson, C. M. (1999). Elevated CO_2 and plant structure: a review. *Rev. Glob. Change Biol. 5:807-837.*

Qu, M., Bunce, J. A., Sicher, R. C., Zhu, X., Gao, B., and Chen, G. 2017. An attempt to interpret a biochemical mechanism of C4 photosynthetic thermotolerance under sudden heat shock on detached leaf in elevated CO_2 grown maize. PLoS One. 12(12):e0187437. https://doi.org/10.1371/ journal.pone.0187437.

Rae, A. M., Tricker, P. J., Bunn, S. M., and Taylor, G. 2007. Adaptation of tree growth to elevated CO_2, quantitative trait loci for biomass in populous. *New physiol.* 175:59-69.

Ramawat, K. G., and Goyal, S. (2008). The Indian Herbal Drugs Scenario in Global Perspectives. Springer. Merillon, J. M (eds.). DOI: 10.1007 / 978-3-540-74600-3_18. Pg.323-345.

Reddy, A. R., Rasineni, G. K., and Raghavendra, A. S. 2010. The impact of global elevated CO_2 concentration on photosynthesis and plant productivity. Rev: *Curr. Sci*, 99(1):46-57.

Reekie, E. G. and Bazzaz, F. A. 1991. Phenology and growth in four annual species grown in ambient and elevated CO_2. *Can. J. Bot.* 69:2475-2481.

Reekie, J. Y. C., Hicklenton, P. R. & Reekie, E. G. 1997. The interactive effects of carbon dioxide enrichment and day length on growth and development in *Petunia hybrid. Ann. Bot.* 80:57-66.

Rogers, H. H., Peterson, C. M., McCrimmon, J. N. and Cure, J. D. 1992. Response of plant roots to elevated atmospheric CO_2. *Plant Cell Environ.* 15: 749-752.

Rozema, J. 1993. Plant responses to atmospheric carbon dioxide enrichment: interactions with some soil and atmospheric conditions. *Springer*. 104(1):173–190..

Sage, R. F., Sharkey, T. D., and Seemann, J. R. 1989. Acclimation of Photosynthesis to Elevated CO_2 in Five C3 Species. *Plant Physiol.* 89: 590-596.

Salick, J., Ghimire, S. K., Fang, Z., Dema, S., and Konchar, K. M. (2014). Himalayan Alpine Vegetation, Climate Change and Mitigation. J. Ethnobiol. 34(3): 276–293.

Saravanan, S and Karthi, S. *2014.* Effect of Elevated CO_2 on Growth and Biochemical Changes in *Catharanthus Roseus* - A Valuable Medicinal Herb. *WJPPS.* Vol: 3(11): 411-422.

Saravanan, S., and Karthi, S. 2017. Distinction In Morphological and Biochemical Changes In Valuable Medicinal Herb *Adhatoda Vasica* under Elevated CO_2. *WJPPS*. 6(10):888-899.

Sharma, A., and Sengupta, U. K. 1990. Carbon dioxide enrichment effect on photosynthesis and related enzymes in Vigna radiate wilezek. *Indian J. Plant Physiol*. 33:340-346.

Sharma, R., Singh, H., Kaushik, M., Nautiyal, R., and Singh, O. 2018. Adaptive physiological response, carbon partitioning, and biomass production of *Withania somnifera* (L.) Dunal grown under elevated CO_2 regimes. *3 Biotech.* 8:1-10.

Sharma, R., Singh, H., Kaushik, M., Nautiyal, R., and Singh, O., 2018. Adaptive physiological response, carbon partitioning, and biomass production of Withania somnifera (L.) Dunal grown under elevated CO_2 regimes. *3 Biotech*. 8(6): 267.

Sicher, R. C. 1998. Yellowing and photosynthetic decline of barley primary leaves in response to atmospheric CO_2 enrichment. *Physiol. Plant.* 108:193-199.

Sims, D. A., Cheng, W., Luo, Y. & Seemann, 1999. Photosynthetic acclimation to elevated CO_2 in a sunflower canopy. *J. Exp. Bot.* 50:645-653.

160

Singh, H., Sharma, R., Savita. Singh, M. P., Kumar, K., Verma. A., Ansari, M. W., Negi, M., and Sharma, S. K. 2018. Adaptive Physiological Response of Parthenium Hysterophorus to Elevated Atmospheric CO_2 Concentration. *Indian For.*. 144(1): 6-19.

Singh, R.V. 1982. Fodder trees of India. Oxford and IBH Publ. Co., New Delhi, pp 663.

St. Omer, L. and Horvath, S. M. 1983. Elevated CO_2 concentrations and whole plant senescence. *Ecology*. 64:1311-1314.

Stephen H. Schneider. The Greenhouse Effect: Science and Policy. Science. Vol. 243, Issue. 4892, pp. 771-781, doi: 10.1126/science.243.4892.771.

Teng, N., Jin, B., Wang, Q., Hao, H.,Ceulemans, R., Kuang, T., and Lin, J. 2009. No detectable maternal effects of elevated CO_2 on Arabidopsis thaliana over 15 generations. PLoS One. 25:4(6).

Teng, N., Wang, J., Chen, T., Wu, X., Wang, Y and Lin, J. 2006. Elevated CO_2 induces physiological, biochemical and structural changes in leaves of *Arabidopsis thaliana*. *New Phytol.* 172: 92–103.

Thomas, R. B and Strain, B. R. 1991. Root restriction as a factor in photosynthetic acclimation of seedlings grown in elevated CO_2. *Plant Physiol.* 96:627-634.

Tiwari, D. N.1995. Agroforestry for increased productivity sustainability and poverty alleviation. International book distributers. Dehradun, pp 799.

Tjoelker, M.g., Reich, P.B., and Oleksyn, J. 1999. Changes in leaf nitrogen, carbohydrates underlie temperature and CO_2 acclimation of dark respiration in five boreal tree species. *Plant cell environ.* 22:267-278.

Tropical Plants Database, Ken Fern. Tropical.theferns.info. 2018-10-24. - <tropical.theferns.info/viewtropical.php?id=Terminalia+bellirica>

Tropical Plants Database, Ken Fern. Tropical.theferns.info. 2018-10-24. <tropical.theferns.info/viewtropical.php? Id=Terminalia+chebula>

161

United Nations Framework Convention on Climate Change, United Nations, 1992

Walkley, A. and I. A. Black. 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 37: 29-37.

Ward, J. K., and Strain, B. R. 1997. Effects of low and elevated CO_2 partial pressure on growth and reproduction of *Arabidopsis thaliana* from different elevations. *Plant Cell Environ.* 20:254-260.

Warrier, A., Jayaraj, R.S.C. and Balu, A. 2013. Variation in Gas Exchange Characteristics in Clones of Eucalyptus camaldulensis Under Varying Conditions of CO_2. *J. stress physiol. biochem.* 9(3): 333-344.

Watling, J.R., Press, M. C., and Quick, W. P. 2000. Elevated CO_2 Induces Biochemical and Ultrastructural Changes in Leaves of the C4 Cereal Sorghum. *Plant Physiol.* Vol. 123, pp. 1143–1152.

Weerakoon, W. M., Olszyk, D. M. & Moss. D. N. 1999. Effects of Nitrogen nutrition on response of rice seedlings to carbon dioxide. *Agric. Ecosyst. Environ.* 72:1-8.

Weitere, M., Vohmann, A., Schulz, N., Linn, C., Dietrich, D., and Arndt, H. 2009. Linking environmental warming to the fitness of the invasive clam Corbicula fluminea. *Glob. Change Biol,* 15: 2838-2851.

Williams, R.F. 1946. The physiology of plant growth with special reference to the concept 836 of net assimilation rate. *Ann. Bot.* 10: 41-72.

Wong, S. C. 1979. Elevated Atmospheric Partial Pressure of CO_2 and Plant Growth I. Interactions of Nitrogen Nutrition and Photosynthetic Capacity in C3 and C4 Plants. *Oecologia.* 44(1):68-74.

World Health Report 2002 - Reducing Risks, Promoting Healthy Life.

Wu, J., Hong, J., Wang, X., Sun, J., Lu, X., Fan, J., and Cai. Y. 2013. Biomass Partitioning and Its Relationship with the Environmental factors at the Alpine

162

Steppe in Northern Tibet. *PLoS ONE.* 8(12): e81986. Doi: 10. 1371/journal.pone.0-12-460370-X, pg.215, 233.

Xu, Z., Jiang, Y., and Zhou, G. 2015. Response and adaptation of photosynthesis, respiration, and antioxidant systems to elevated CO_2 with environmental stress in plants. *Front. Plant Sci.* Plant Nutrition. 6:701

Zak, D. R., Pregitzer, K. S., Curtis,P. S., Teeri, J. A., Fogel R., and Randlett, D. L. 1993. Elevated atmospheric CO z and feedback between carbon and nitrogen cycles. *Plant soil* 151, 105-117.

Zinta, G., AbdElgaward, H., Domagalska, M. A., Vergauwen, L., Knapen, D., and Nijs, I. 2014. Physiological, biochemical, and genome-wide transcriptional analysis reveals that elevated CO_2 mitigates the impact of combined heat wave and drought stress in Arabidopsis thaliana at multiple organizational levels. *Glob. Change Biol.* 20: 3670-3685.

Ziska, L. H. & Caulfield, F. A. 2000. Rising carbon dioxide and pollen production of common ragweed, a known allergy-inducing species: implications for public health. *Aust. J. Plant. Physiol.* 27:893-900.

Ziska, L. H., and Bunce, J. A. 1993. The influence of elevated carbon dioxide and temperature on seed germination and emergence from soil. *Field Crops Res.*, 34: 147-157.

Ziska, L. H., Weerakoon, W., Namuco, O. S. & Pamplona, R. 1996. The influence of nitrogen on the elevated CO_2 response in field-grown rice. *Aust. J. Plant Physiol.,* 23:45-52.

Ziska, L. R. 2001. Changes in competitive ability between a C_4 and a C_3 weed with elevated CO_2. *Weed. Sci.* 49:622-627.

Zobeyad, S., and Saxena, P. K. 2004. Production of St. John's wort plants under controlled environment for maximizing biomass and secondary metabolites. *In Vitro Cell. Dev. Biol. Plant.* 40: 108-114.

Growth dynamics and physiological response of selected forestry species to CO_2 enriched atmosphere

---

By

ANUSHA R M

2014-20-127

ABSTRACT

Submitted in partial fulfilment of the

Requirement for the degree of

B.Sc-M.Sc (Integrated) CLIMATE CHANGE ADAPTATION

Kerala Agricultural University

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR - 680 656

KERALA, INDIA

2019

Abstract

Terminalia arjuna, Terminalia bellirica and *Terminalia chebula* are important medicinal plants and part of *Triphala*, there is less study about the adaptation and mitigation of these species to elevated CO_2. This study is helpful to understand about the adaptive and mitigative and biochemical efficiency of these plants. Under elevated these three species are showed a better response in elevated CO_2 800ppm over ambient 400ppm. The plant height, leaf length and width, stem diameter, number leaves and branches, root length, are higher in elevated 800ppm CO_2 over ambient 400ppm as well as the biochemical properties like total chlorophyll and carotenoids, ascorbic acid, protein, proline, total sugar are increased dramatically at 800ppm over 400ppm. The photosynthetic rate was higher in elevated CO_2 in all seasons (winter, spring, and summer), stomatal conductance was higher in 800ppm spring and lower at summer. The intercellular CO_2 concentration was higher in plants grown in 800ppm *T.chebula* in winter in the summer season. Transpiration rate was higher in winter and reduced over ambient in summer. Night respiration is less in *T.arjuna* compared to ambient, and there is a fluctuation concerning seasonality and species. Carbon sequestration, carbon partitioning, carbon mitigation and carbon stocks are high in elevated CO_2 growing plants except for *T.bellirica.* Organic carbon was higher in elevated CO_2 than ambient. Potassium, phosphorous and total nitrogen they with species and change in concentration according to elevated CO_2.

The plants grown in elevated CO_2 are healthier than ambient condition and increases the health-promoting characters. These species are more adaptive and show mitigation efficiency and good biochemical efficiency. In future more studies needed to know about the response of plants towards elevated CO_2.