STUDY THE IMPACT OF ABIOTIC STRESS ON PHOTOSYNTHETIC POTENTIAL OF TROPICAL TUBER CROPS UNDER ELEVATED CO_2

ANCY P.
(2014-20-117)

THESIS
Submitted in partial fulfilment of the
requirements for the degree of

BSc-MSc (Integrated) CLIMATE CHANGE ADAPTATION
Faculty of Agriculture
Kerala Agricultural University

ACADEMY OF CLIMATE CHANGE EDUCATION AND RESEARCH
VELLANIKKARA, THRISSUR-680 656
KERALA, INDIA
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2019

DECLARATION

I, hereby declare that this thesis entitled **"Study the impact of abiotic stress on photosynthetic potential of tropical tuber crops under elevated CO_2"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associate ship, fellowship or other similar title, of any other university or society.

Place : Vellanikkara **ANCY P.**
Date : **(2014-20-117)**

CERTIFICATE

Certified that this thesis entitled **"STUDY THE IMPACT OF ABIOTIC STRESS ON PHOTOSYNTHETIC POTENTIAL OF TROPICAL TUBER CROPS UNDER ELEVATED CO_2"** is a record of research work done independently by Ms. ANCY P. (2014-20-117) 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.

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LIST OF SYMBOLS AND ABBREVIATIONS USED

%	:Percentage
^{o}C	:Degree Celsius
MAP	:Months After Planting
MT	:Million Tonnes
FAO	:Food and Agriculture Organization
ha	:Hectare
mm:	:Milli Metre
eCO_2	:Elevated Carbon Dioxide
ppm	:Parts Per Million
IPCC	:Intergovernmental panel on climate change
RuBP	:Rubilose Bisphosphate
Pr	:Photo Respiration
CO_2	:Carbon Dioxide
µmol	:Micromol
m	:Metre
s	:Second
PPFD	:Photosynthetic Photon Flux Density *Pn*
cm	:Centi Metre
viz.	:Videlicet/ Which is
ml	:Milli Litre
nm	:Nano Metre
µg	:Micro Gram
g	:Gram
fw	:Fresh Weight
V	:Volume
W	:Weight
SAS	:Statistical Analysis System

CD	:Critical Difference
mmol	:Millimol
g_s	:Stomatal Conductance
Tr	:Transpiration
Ci	:Sub-Stomatal Intercellular CO_2 concentration
ICAR	:Indian Council of Agricultural research
RBD	:Randomized Block Design
WDS	:Water Deficit Stress
Cm	:Centi Metre
CTCRI	:Central Tuber Crops Research Institute
P_2O_5	:Phosphorous Pentoxide
K_2O	:Potassium Oxide
N	:Nitrogen
AM	:Ante Meridiem
PM	:Post Meridiem
Chl.	:Chlorophyll
Fl	:Fresh leaf

INTRODUCTION

CHAPTER 1
INTRODUCTION

Root and tuber crops cultivated in the tropical and sub-tropical regions of the world are called tropical root and tuber crops. After cereals (49%), tuber crops (with 5.4% energy) are the second most important crop plants providing food energy for humans. Among them, tropical root and tuber crops contribute to 3.9% of human energy (Nayar, 2014). They contribute significantly to food security as they can be produced with low inputs and are consumed by the poorest. In India cassava (*Manihot esculenta*), sweet potato (*Ipomoea batatas*), yams (*Dioscorea alata*) and aroids viz., taro (*Colocasia esculenta*), tannia (*Xanthosoma sajittifolium*), elephant foot yam (*Amorphophallus paeoniifolius*) and arrow root (*Maranta arundinacea*) are the major tropical tuber crops cultivated in different States. Among these Cassava, Sweet potato and Yams include in the list of top 15 crop plants of the world in cultivated area.

Cassava is a tropical root crop (*Manihot esculenta* Crantz), belongs to the family Euphorbiaceae and genus *Manihot*. Cassava is a woody perennial shrub, that grows from 1 m to 5 m in height and leaves are pale to dark green in colour and palmate (hand-shaped). Starch storing organs are cone shaped roots that are covered with a papery bark and a pink to white cortex. The flesh colour ranges from bright white to pale yellow. Cassava is primarily grown for its edible starchy storage roots. Its leaves are also consumed as a protein-rich leafy vegetable. Its root starch is used in several industries, such as textiles, food manufacturing, pharmaceuticals, paper and adhesives, plywood and as feedstock in the production of ethanol bio fuel.

Each variety of cassava has its own distinctive qualities and is adapted to specific environmental conditions. It is adapted well between 25 to 35^{o}C and grows better in areas with well distributed annual rainfall of 1000-1500 mm. Once established cassava is drought tolerant and able to tolerate dry spells for three to six months and can survive in low fertile and acidic soils. Cassava has no definite maturation point. The storage root starts bulking after about 3 month, and attains utmost size at 10 to 12 months. The harvested storage roots can be stored for about 1 to 2 months. Cassava can be harvested at 7 months after planting (MAP) in short duration varieties or at 8 month onwards in long duration varieties. These features have made cassava into a crop of primary importance for house hold food security when adverse climatic conditions and unstable social environments limit the production of other foods.

Cassava is the fourth provider of dietary energy in tropics and the ninth world-wide. Cassava has been cultivated for 9000 years, mainly for its starchy roots and is one of the oldest crops in agriculture. Farming of cassava expanded considerably in the 20th century, when it emerged as an important food crop across sub-Saharan Africa, India, Indonesia and in Philippines. Nigeria is the world's leading producer of cassava followed by Thailand, Indonesia, Brazil Ghana and Congo. Conventionally, cassava is produced on small-scale family farms. It serve as a staple food for an estimated 800 million people worldwide. Cassava held the status of one of the fastest expanding staple crop at global level with an uninterrupted growth above 3% per annum and reaching a production volume of 277 million tonnes in 2018 (FAO, 2018). Cassava is grown in India in an area of 190 x 10^3 ha with an annual total production of 3627 x 10^3MT. The major cassava growing states in India in terms of area and production are Kerala, Tamil Nadu, Andhra Pradesh and North Eastern states.

Sweet potato (*Ipomoea batatas*) is a tropical root crop, belongs to the morning glory family *(Convolvulaceae)*, mainly grown in tropics and have wide climatic adaptability. The optimum temperature condition for the best growth is between 21°C to 29°C, although they can tolerate temperatures as low as 18°C and as high as 35°C. Sweet potato is a herbaceous perennial vine, bearing simple and alternately arranged leaves and medium sized sympetalous flowers. Leaf colour can be green, green-yellowish or can have purple pigmentation in part or the entire leaf blade. The edible tuberous root is long and tapered, with a smooth skin whose colour ranges between yellow, orange, red, brown and purple. Its flesh colour ranges from light brown through white, yellow, pink, orange, red, purple and violet. Duration of sweet potato varies between 90 and 120 days.

Sweet potato is the sixth most important food crop in the world, and the reason is that it is a reliable crop in case of crop failure of other staple food. They are cultivated mainly for storage roots and are a good source of carbohydrates. While sweet potato tops contain additional nutritional components in much higher concentrations, young leaves and shoots are sometimes eaten as greens. Sweet potatoes contain iron, magnesium, potassium, complex carbohydrates, dietary fibre and β carotene including vitamin B5, vitamin B6 and manganese. It is a versatile plant offering various products and diverse uses ranging from a staple food, flour, noodles, natural colorant, candy, alcohol, animal feed, and raw material for industrial purposes.

Sweet potatoes were domesticated at least 5,000 years ago in Central America. From the Americas, the Spanish brought the sweet potato to Europe, where it spread to Africa, India, China and Japan (Katayama *et al.*, 2017). Sweet potato is cultivated in India in an area of 131 x 10^3 ha with an annual production of 1465 x 10^3 MT. Major states producing sweet potato in India are Odisha (36%), Uttar Pradesh (26%) and West Bengal (21%).

Climate affects all components of crop production. Every crop is adapted to a particular climatic condition in which they show maximum growth and yield. A changing climate could have both positive and negative effects on crops. Climate change scenarios include higher temperatures, changes in precipitation, and higher atmospheric CO_2 concentrations. The atmospheric CO_2 concentration is continuously rising due to human activities and is expected to increase to 700-900 ppm by the end of the 21st century (IPCC 2001, Teng *et al.*, 2006). The rise in atmospheric CO_2 concentration can positively influence the photosynthetic efficiency and productivity of crop species with C_3 photosynthetic pathway. This is because, first, the carboxylation of Rubisco will react to rising CO_2 as the photosynthetic enzyme Ribulose biphosphate carboxylase (Rubisco) has a low likeness for CO_2 on carboxylation and this reaction is not saturated at the present CO_2 concentration. Second, rising CO_2 50% reduces the photorespiration as CO_2 competes with O_2 and thus net efficiency of photosynthesis increases (Lawlor and Mitchell, 2000). This is mainly important in the context of climate change and food security of ever growing population amidst shortage of natural resources.

Tropical root and tuber crops being C_3 plants have many advantages from this elevated CO_2. However, the beneficial effect of eCO_2 will be influenced by other players of climate change such as drought and temperature stress under tropical conditions. The search of photosynthetically efficient climate smart crops/ varieties, this project aims to study the adverse effects of climate change such as water deficit stress and high temperature stress on photosynthetic potential of four varieties of cassava and four varieties of sweet potato under elevated $CO_{2.}$ This will help in identifying crops/varieties suitable for future environment with changing climate.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

Climate change is currently a recognized fact and reality. The evidence gathered by various national and international agencies across the world is unquestionable. Recent and predicted patterns of global climate change are becoming a major concern for various areas of socio economic activities such as agriculture, livestock production, fisheries, forestry and biodiversity. Human activities like rapid industrialization, increasing fossil fuel use, deforestation, intensive agriculture and excessive use of fertilizers are the major causes for global climate change. The atmospheric CO_2 has been estimated to remain at ~280 ppm before 1750 and then steadily increased to ~400 ppm at present and is expected to increase to 700-900 ppm by the end of the 21st century (IPCC 2001, Teng *et al*., 2006).

Climate change scenarios comprise higher temperatures, changes in precipitation, and higher atmospheric CO_2 concentrations. Climate change is likely to directly impact agriculture and there by food production across the globe. So agriculture sector is the most sensitive sector to the climate change. Climate change represents one of the greatest research challenges currently faced by agronomists, plant biologists and conservation biologists. With global greenhouse gas emissions set to continue to rise for the foreseeable future, the impact of elevated atmospheric CO_2 (eCO_2), and related shifts in temperature and precipitation are all likely to impact plant ecophysiology, distribution and interactions with other organisms (IPCC, 2014).

2.1 Concentration of CO_2 in atmosphere

Atmospheric carbon dioxide (CO_2) is regarded as the prime donor to the global warming and force climate change. Starting from the industrial revolution atmospheric CO_2 concentrations have increased from 278 parts per million (ppm) to 401 ppm. That is ∼40% increase compared to pre industrial era (Hungershoefer *et al*., 2010). The major source of CO_2 is fossil fuels combustion. Other important sources include land use changes and ocean and animal respiration, while it is removed by plants through photosynthesis, dissolution in the ocean and by carbon deposition (Peters *et al*., 2007). It is predicted that the CO_2 concentration will lift up two-fold, that is, up to 800 ppm at the end of this century (Prentice *et al*., 2001; Bolin and Kheshgi, 2001; IPCC 2007; Canadell *et al.*, 2007; Sun *et al.*, 2009). Atmospheric CO_2 concentrations have been calculated directly with high precision since 1957 by Keeling and his group at the Mauna Loa observatory (Keeling *et al*., 1996), which continues to show a remarkable increasing pattern of atmospheric CO_2.

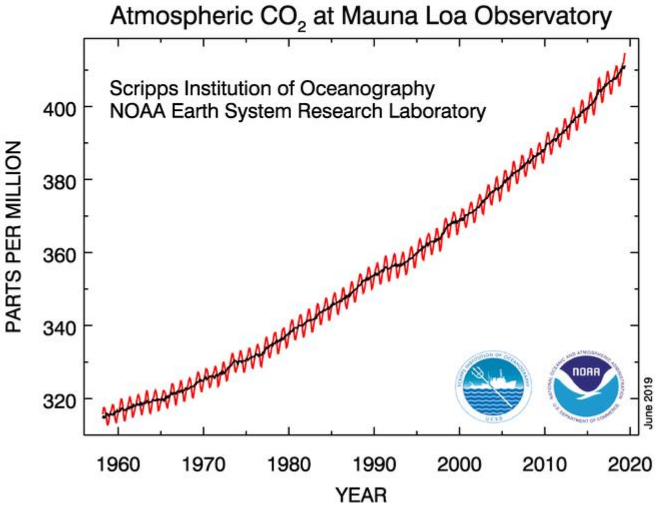

Fig. 2.1. Changes in CO_2 concentrations at Mauna Loa Observatory since 1960.

Analysis of proxy records, such as gas bubbles trapped in glacial ice, at a range of places all over the world suggests that the atmospheric concentration of CO_2 has varied noticeably over geologic time. But the atmospheric carbon dioxide concentration remained in the range of 280 ±10 ppm for several thousand years earlier to the Industrial Era (1750). It has risen gradually at first and then progressively faster to reach a value of 400 ppm in 2014 (Tans and Keeling, 2016). Most important reason for this rapid change is anthropogenic CO_2 emissions (IPCC, 2014). Predictions warn that the global CO_2 concentration will go on to rise as human carbon emissions continue. (Meehl *et al.*, 2007). Increase in CO_2 concentration will accelerate air temperature. Higher temperatures and increased CO_2 both will cause serious problems to the environment and in particular to plants. This is because plants cannot withstand this rapid increase in CO_2 by means of adaptation alone, as most plants are adapted to an atmospheric CO_2 of below 300 ppm.

2.2 Response of plants to elevated CO_2 (eCO_2)

The working group II of IPCC concluded with high confidence that anthropogenic climate change will continue to have a strong effect on plant life cycle and species interactions. Climate change can affect crop production mainly in three ways. First, increased atmospheric CO_2 concentrations can have a direct effect on the growth rate of crop plants and weeds. Secondly, CO_2-induced changes of climate may alter levels of temperature, rainfall and sunshine that can influence plant and animal productivity. Finally, rises in sea level may lead to loss of farmland by inundation and increasing salinity of groundwater in coastal areas. Climate change scenarios include higher temperatures, changes in precipitation, and higher atmospheric CO_2 concentrations. All these factors have great impact on plants by affecting photosynthesis and transpiration rates, growth rates, quality and quantity of yield, moisture availability, and through changes of water use and agricultural inputs such as herbicides, insecticides, fertilizers etc.

The rise in atmospheric CO_2 concentration is an important change which can positively influence the productivity of crop plants. Crops directly respond to rising CO_2 concentrations through photosynthesis and stomatal physiology. However, these responses are greatly dependent on many environmental (temperature, light intensity) and plant factors (e.g. age, hormones) (Polley, 2002; Ziska and Bunce, 1997). Therefore, predicting the effect of elevated CO_2 on the reaction of stomata is still very difficult (Rosenzweig and Hillel 1995). For example, rice yields will increase by 0.5 t/ha with every 75 ppm increase in CO_2

concentration, but yield will decrease by 0.6 t/ha for every 1°C increase in temperature (Sheehy *et al.*, 2007).

Response of plants to eCO_2 differs from species to species. Plants with C_3 photosynthetic pathway exhibit a better response to high CO_2. Photosynthetic rate of C_3 plants increases with increase in atmospheric CO_2 concentrations (Drake *et al.*, 1997; Ainsworth and Long, 2005; Wang *et al.*, 2012). In C_3 plants, which accounts great majority of plant species, all the carbon is assimilated through the Calvin cycle. CO_2 reacts with ribulose-1, 5-bisphosphate (RuBP) to yield two molecules of 3-phosphoglycerate. This reaction is catalyzed by the RuBP carboxylase/ oxygenase generally known as Rubisco. In addition to the function as a carboxylase Rubisco can also perform as an oxygenase. The latter function results in photorespiration associated with O_2 uptake and CO_2 evolution (Makino and Mae, 1999). Photorespiration *(Pr)* decreases net efficiency of photosynthesis by 20-50% depending on temperature (Lawlor and Mitchell, 2000). Rubisco has a low affinity for CO_2 on carboxylation and this reaction is not saturated at the present CO_2 concentration. Higher atmospheric CO_2 levels increases the CO_2 surrounding Rubisco, shifting the ratio of CO_2:O_2 and thereby increasing the rate of carboxylation at the same time decreasing the rate of oxygenation (Makino and Mae, 1999). As the CO_2% increases CO_2 competes with O_2 and reduces the oxygenase (photorespiration) reaction of Ribulose Therefore, increased photosynthesis under eCO_2 occurs due to increase in Rubisco carboxylation activity (Drake *et al.*, 1997). Ainsworth and Long (2005) reported that the photosynthetic rates of C_3 plants were approximately doubled when they were exposed to 700 ppm compared to 380 ppm. Elevated CO_2 enhances net photosynthetic CO_2 uptake and consequently increases biomass production and yield of C_3 crops (Rosenthal *et al.,* 2012; Cruz *et al.,* 2014).

Since the C_4 plants have a mechanism to increase the CO_2 concentration in their leaves, carboxylation reaction of photosynthesis in C_4 plants is saturated at current ambient CO_2 concentrations. Due to this in contrast to the C_3 plants, plants with C_4 photosynthetic pathway show little response to rising atmospheric CO_2.

However C_4 plants can exhibit growth simulation because eCO_2 can increase water use efficiency. The C_3 plants generally benefits from both increased photosynthesis and water use efficiency.

CO_2 from the atmosphere disperse towards chloroplasts and photosynthesis take place. Both CO_2 and water vapour travels in the leaf through stomatal pore but in opposite directions. Hence an increase in stomatal conductance result in higher CO_2 uptake, and increasing transpiration rates (Taiz and Zeiger, 2006). Increasing CO_2 causes partial closure of stomata. Stomatal conductance for water vapour decreases about 40% for a doubling of CO_2. Transpiration of leaves decreases as stomatal conductance decreases but it is not in direct proportion to the decrease of stomatal conductance. Because with doubled CO_2, leaf temperature increases 1 to 2^oC due to decreased evaporational cooling. In turn, a greater leaf-to air vapour pressure difference is created as vapour pressure of water inside leaves increases and it is the driving force for transpiration. This effect partially offsets decreased stomatal conductance, and thus transpiration is maintained merely a little lower (10%) than would exist at ambient CO_2 (Allen *et al.* 2003). Even though crop transpiration decreases under eCO_2, water use will increase if temperatures rise. At the mean temperature of 23^oC the decline in water use by doubled CO_2 was about 9% in soybean (Allen and Prasad, 2004). Over the average daily temperature range of $20–40^oC$ crop water use may increase about four-fold. Therefore, small increases in temperatures would have more impact over the water reduction effect of CO_2 through reduced stomatal conductance (Allen *et al.* 2003).

Regardless of the initial stimulation of photosynthesis seen at eCO_2, a down regulation or decrease in photosynthesis is reported in both FACE studies (Ainsworth and Long, 2005) and chamber experiments (Warren *et al.*, 2014) under long term exposure to eCO_2. This is known as acclimation. However it does not completely nullify the positive effects on photosynthesis by eCO_2. For example, in one study white clover grown under 600 ppm CO_2 concentration for 8 years showed a 37% increase in photosynthesis after acclimation was observed (Ainsworth *et al.*, 2003).

A significant increase in yield with eCO_2 is reported in many crops such as rice, maize, wheat, soybean, castor bean, cotton and vegetable crops (Prasad *et al.*, 2005, Chowdhury *et al.*, Reddy and Hodges, 2000, 2005, De Souza *et al.*, 2008, Vanaja *et al.*, 2008, Razzaque *et al*., 2009, Singh and Jasrai, 2012, O'Leary *et al*., 2015, Zhang *et al*., 2015). In limited studies, crop productivity has been reported to rise up to 1,000 ppm CO_2 concentrations and above, but a significant missing link is that it is not known, what be the threshold CO_2 concentration above which the development and productivity of a crop will affect. Crop species also differed in their sensitivity to atmospheric concentration and some plants including potato exhibit leaf injury (chlorosis, necrosis, senescence) and dying of plants at CO_2 concentrations above 700 ppm (Kauder *et al*., 2000).

2.3 Global warming

Earth receives its energy in the form of short wave radiations from the Sun. Earth radiates back this energy as long wave radiation to the space. Green House Gases in the atmosphere such as water vapour, carbon dioxide, methane, nitrous oxide and ozone play an important role in trapping this long wave radiation and retaining heat, thereby maintaining the earth's temperature at a level that can support life. This phenomenon is called the greenhouse effect and is natural and necessary to support life on earth. The earth would be approximately 33°C cooler than today if there was no greenhouse effect, (IPCC, 2001).

Since the Industrial Revolution global atmospheric carbon dioxide concentration has increased from 270 to 401ppm and is expected to rise further more due to anthropogenic CO_2 emissions. As a result, average global temperatures have risen by 0.85°C in past 200 years (IPCC, 2014). By the end of this century, atmospheric CO_2 is expected to reach at least 700 ppm, and global temperatures are projected to rise by 4°C or more based on greenhouse gas scenarios (IPCC, 2014). Even if countries reduce their greenhouse gas emissions, the earth will continue to warm. All climate models indicate a rising trend in temperature.

According to 5th assessment report of IPCC, by the mid of 21st century the average annual temperature will rise by more than 2°C in most of the South Asia and temperature increases will exceed 3°C and as much as 6°C in high altitudes compared to the 20th century under a high-emission scenario. Similarly, under a low-emission scenario, the average temperature will rise by less than 2°C whereas in higher altitudes the temperature will rise by as much as 3°C in the 21st century. The projected rate of warming is unprecedented during last 10,000 years. It is anticipated that the increasing rate of the average temperature in the Himalaya will be greater than the global average. The increasing temperatures may affect the timing and quantity of precipitation, which would consequently change the water availability (Mishra *et al.*, 2014)

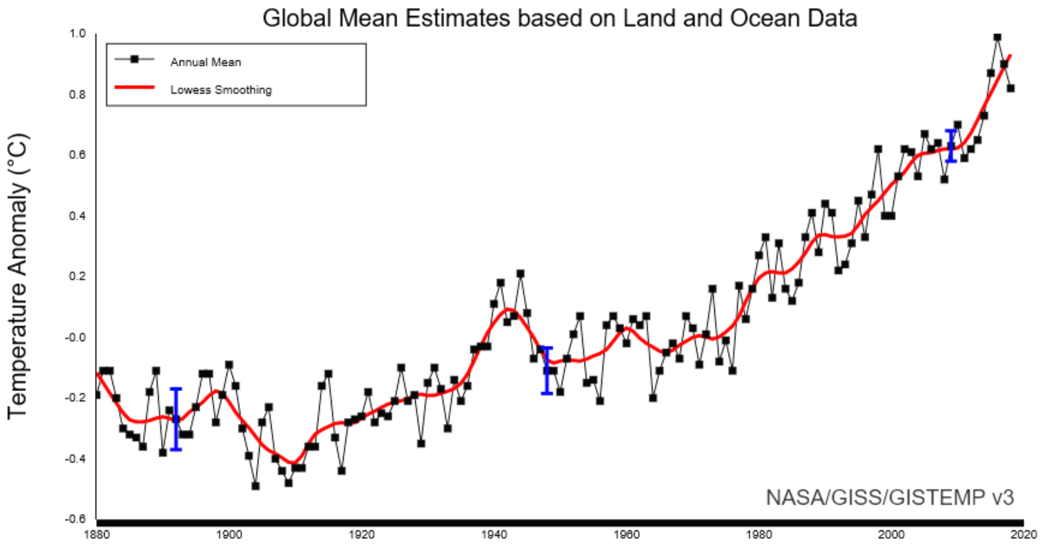

Fig. 2.2 Instrumental temperature data 1880-2018. Source: NASA Goddard Institute for Space Studies (GISS).

Global warming and climate change refer to the increase in average global temperatures due to the increase in greenhouse effect resulted from the rise in the greenhouse gas concentration in the atmosphere. As a result of global warming, the type, frequency and intensity of extreme events, such as tropical cyclones, floods, droughts and heavy precipitation are expected to rise even with relatively small average temperature increases. Changes in some types of extreme events have already been observed, for example, increases in the frequency and intensity of heat waves and heavy precipitation events (Meehl *et al.*, 2007). Heat wave occurred during June 2015 in India killed more than 2500 people. It also severely affected cattle and crop production (Sivaraman, 2015).

2.4 Response of crops to increasing air temperature

The surface air temperature is one of the important variables, which influences all stages of crop throughout its growth, development and reproduction. Most of the crops have upper and lower limits of temperature below or above which growth and development ceases and an optimum temperature in which crops have maximum growth. These are known as cardinal temperatures and different crops have different temperatures. These values were summarized by Hatfield *et al.* (2008, 2011) for a number of different species typical of grain and fruit production. Air temperature affects leaf production, expansion and flowering. At high temperature and high humidity, most of the crop plants are affected by pests and diseases. The diffusion rates of gases and liquids changes with temperature. Temperature not only affects the physical and physiological processes but also influence different chemical and enzymatic reactions in plants. Solubility of different substances, Equilibrium of various systems and compounds, stability of enzymatic systems etc. depend on temperature. Most of the higher plants grow between 0°C to 60°C and crop plants are further restricted from 10°C to 40°C. However, maximum dry matter is produced between 20°C and 30°C.

Agriculture is considered to be one of the most vulnerable sectors to climate change. Most plants are not able to adapt with rapid changes in its environment caused by global warming. Increase in the mean seasonal temperature can reduce the duration of many crops and hence reduce final yield. In areas where temperatures are already close to the physiological maxima for crops, further warming will impact yields more immediately (IPCC, 2007). Increasing temperature is reducing global production of major crops with increasing food demand which seriously affect food security. Also climate change affects the number of days per year suitable for crop growth.

Responses to temperature differ among crop species and are mainly phenological responses. Temperatures affecting plant development is dependent on the species, because each species has different cardinal temperatures. Elevated temperatures may either increase or decrease the vegetative biomass production of crops. Warm-climate species or cultivars like sugarcane, soybean, and peanut shows slight increase in vegetative biomass with increase in temperature, whereas vegetative biomass of cool-climate cultivars tends to decrease with increasing temperature (Allen and Prasad, 2004). Higher temperatures exceeding the maximum temperature limit for a plant during reproductive phase will affect pollen viability, fertilization and fruit or grain formation (Hatfield *et al.*, 2008, 2011).Seed yield generally shows negative response to rise in temperature. Quantity of the reduction in seed yield varies among species and crop cultivars, but follows a similar pattern. Seed yield decline about 10% per 1^{o}C and reaches zero at about 10^{o}C above optimum temperature (Allen and Prasad, 2004).

2.5 Drought in the context of climate change

The duration between the 19th and the 21st centuries is considered to be the period which experienced the most warming (Pachauri *et al.*, 2014). Based on greenhouse gas scenarios, by the end of this century, atmospheric CO_2 concentration is expected to reach at least 700 ppm, and global temperatures are projected to rise by 4°C or more. Such an exponential climb in CO_2 concentration in the atmosphere causes global warming resulting in an increase in atmospheric temperature in addition to drought. Changes in the distribution and intensity of precipitation are more unpredictable. As the hydrologic cycle intensifies, precipitation regimes are likely to move on a regional scale resulting in larger extremes in dry versus wet conditions (Medvigy and Beaulieu, 2012). Extreme precipitation events may cause destructions due to floods in some parts while the shortage or lack of rainfall for a longer period leads to drought stresses in another part (Khan *et al*., 2016). Precipitation pattern has changed with decreased rainfall over south and south-east Asia. More intense and longer droughts have occurred since 1970s. Climate projections predict more intensified droughts and longer dry period in many regions (Dai, 2013). According to IPCC working group II (2014) longer or more frequent meteorological droughts and agricultural droughts will experience in some regions and in some seasons, particularly under the RCP 8.5, because of reduced rainfall and increased evaporation. More severe droughts will put added pressure on water supply systems mainly in dry areas, but could be controllable in wetter areas, if adaption measures are implemented. Renewable water supply is also expected to decline in certain areas whereas expand in others. However, short-term deficits of water resources are still possible in regions where gains are expected, because of increased fluctuations of stream flow and of seasonal cutbacks. Agriculture is the largest consumer of fresh water in the world. Such overall decline in water supply will exaggerate competition for water among settlements, agriculture, industry, ecosystems and energy production, affecting regional food, water and energy, security. Since 2015 India has experienced widespread drought every year except 2017. According to data up to March 2019 from Drought Early Warning System (DEWS) about 42 per cent of India’s land area is facing drought in which 6 per cent face unusual dry conditions.

Drought is expected to have the highest influence on decrease in crop productivity in the context of increasing temperature. Boyer (1982) points out lack of water is responsible for the enormous crop losses compared to various stresses such as high temperatures. According to Burke *et al*. (2006) by the end of twentieth century 30% of land will be exposed to extreme drought. As a result, in future demand for irrigation will significantly increase. Due to reducing availability of irrigation water careful and scientific management and use of water resources is required to obtain crop production for food and feed. All of this, together with the higher evapotranspiration resulting from warmer conditions, can subject agricultural crops to a larger risk of more harsh and prolonged water deficiency. Studies revealed that impact of drought on food grain production is more severe than that of flood (Singh *et al.*, 2011).

2.6 Effect of Water Deficit Stress (WDS) on crops

Drought is a period of unusually dry weather, results in soil water deficit and subsequently plant water deficit. Generally drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause constant loss of water by transpiration or evaporation. The ability of crops to yield in periodically dry environments can depend on their ability to tolerate water deficits or to develop mechanisms that avoid water deficit. Drought stress tolerance is seen in almost all plants but its degree varies from species to species and even within species. Mainly plants respond to the drought in three ways, which are drought escape, drought avoidance, and drought tolerance (Levitt, 1972). Some species, such as desert ephemerals, escape drought by completing their life cycle when water is abundant and it is different from drought resistance. Others avoid water deficit by maintaining a water status through enhancement off water balance through developing a large root system that extracts water from deep soil profile and/or reducing water loss by increasing leaf waxiness. Biochemical mechanisms involves in drought tolerance that trigger after stress to facilitate plant to maintain functional growth under low available water. Usually, plants combine different drought responses, and their adaptation and productivity depend on balance between all three strategies.

Hot, dry conditions maximize the water potential gradient between soil and atmosphere. Under such conditions plants can transpire many times their own water content every day. Transpiration cools the leaf and as a result supra optimal leaf temperature reduces. It may limit photosynthesis and cause injury, since sufficient regulation of leaf water loss is essential to avoid leaf water deficits and injury.

Water deficit and salt stresses are global issues to ensure survival of agricultural crops and sustainable food production (Jaleel *et al.*, 2007a-b). Drought stress is considered to be a moderate loss of water, which leads to stomatal closure and limitation of gas exchange. Desiccation is much more extensive loss of water, which can potentially lead to gross disruption of metabolism and cell structure and ultimately to the cessation of enzyme catalyzed reactions (Smirnoff, 1993; Jaleel *et al.*, 2007c). Drought stress is characterized by reduction of water content, diminished leaf water potential and turgor loss, closure of stomata and decrease in cell enlargement and growth. Severe water stress may result in the arrest of photosynthesis, disorder of metabolism and finally the death of plant (Jaleel *et al.*, 2008b). Water Deficit stress inhibits cell enlargement and there by reduces plant growth by affecting various physiological and biochemical processes, such as photosynthesis, translocation, respiration, ion uptake, nutrient metabolism, carbohydrates and growth promoters (Jaleel *et al.*, 2008a-d; Farooq *et al.,* 2008).

Photosynthetic pigments are important to plants for capturing light energy and producing carbohydrates. Both chlorophyll a and chlorophyll b are prone to water deficit stress (Farooq *et al.*, 2009). But carotenoids help the plants to tolerate adverse impacts of drought. Water deficit stress produces changes in the ratio of chlorophyll 'a' and 'b' and carotenoids (Anjum *et al.*, 2003; Farooq *et al.,* 2009). A reduction in chlorophyll content was reported under drought stress conditions in plants like cotton, *Catharanthus roseus*, sunflower, *Vaccinium myrtillus* ((Massacci *et al.*, 2008; Jaleel *et al.,* 2008a-c; Kiani *et al.*, 2008; Tahkokorpi *et al.*, 2007). Photosynthetic rate decreases as the relative water content and leaf water potential decreases (Lawlor and Cornic, 2002). However it is not sure whether drought limits photosynthesis through stomatal closure or through metabolic impairment (Lawson *et al.*, 2003; Anjum *et al.*, 2003). Both stomatal and non-stomatal limitation was generally accepted to be the main determinant of reduced photosynthesis under drought stress (Farooq *et al.,* 2009).

Drought and high temperature stress together causes more damage to plants compared to the impact of individual stress (Wang and Huang, 2004). Under combined stress condition function of photo system II decreased in *Leymus chinensis* (Xu and Zhou 2006). Water deficit and temperature extremes influence the productive phase of plant growth. Drought and high temperatures are major stress factors with high impact on cereal yields (Barnabas *et al.*, 2008). Most of the studies concluded that water deficit stress has negative effect on overall crop production. But the severities of these effects depend on the phonological stage of the crop in which the water deficit stress (WDS) occurs. It was reported that the water deficit stress badly affect flower initiation and inflorescence in cereals (Winkel *et al.,* 1997). Drought stress has greatly reduced the yield of wheat from 1% to 30% under mild drought stress at post-anthesis while this reduction increased up to 92% in case of long-lasting mild drought stress at flowering and grain formation (Araus *et al.,* 2002; De Oliveira *et al*., 2013). Drought stress occur at grain filling stage of soybean causes 42% reduction of yield (Maleki *et al*., 2013). Baroowa and Gogoi (2014) reported 31% to 57% yield reduction in Mash bean (*Vigna mungo L.*) during the flowering stage while a 26% reduction during the reproductive phase.

2.7 Response of tuber crops to elevated CO_2 and different abiotic stresses

Environmental factors that influence plants and decrease growth and yield below optimum levels are known as abiotic stress. Abiotic stress factors for plants include extremes in temperature, water, gasses, radiation, nutrients, wind and other environmental conditions. CO_2 and methane emissions are likely to increase which may cause impact in terms of more demand for water, increased temperature and increased biotic and abiotic stresses. Many researchers around the world are giving evidences about the positive responds of many crops, mainly

C_3 crops to growing atmospheric CO_2 concentrations under stress free conditions (Long *et al.*, 2004). But this direct advantageous effect of eCO_2 can be hindered by other players of climate change such as elevated temperature, changes in the patterns of precipitation and higher tropospheric ozone concentrations (Easterling *et al.,* 2007).

Being a C_3 plant Tuber crops have advantages from elevated atmospheric CO_2. Tuber crops are tolerant to mid season drought and high temperature. Under rain fed conditions its spread is limited by the length of rainy season as being long duration crop. Increase in temperature due to global warming may shorten the duration of tuber crops. Hence it may be grown in short rainy season areas also. Further being tropical crop, increase of temperature and CO_2 will enhance its productivity when water is not limited (Jata *et al.*, 2010). Elevated CO_2 generally increases biomass, length of roots and volume as well as increasing biomass allocation to roots (increased root-shoot ratio). Root and tuber crops tend to have a greater yield (Allen and Prasad, 2004).

Photosynthetic rate of sweet potato increases with an increase in CO_2 concentration from 250 to 560 ppm under controlled conditions and it is due to the increase in inter cellular CO_2 concentration and the response is highly temperature dependent (Cen and Sage, 2005). An increase in storage root yield of sweet potato is observed up to a CO_2 concentration of 750ppm (Mortley *et al.*, 1996). Both above ground and below ground biomass of sweet potato is increased at a higher CO_2 concentration of 1520 ppm (Czek *et al.*, 2012). Increase in above ground dry biomass was 43% for organic source of nutrients, whereas the increase was 31% for inorganic source of nutrients at eCO_2. The below ground biomass increased by 61% in organic treatment and 101% increase in inorganic treatment. The increase in below ground biomass is considerably higher than increase in above ground biomass for both organic and inorganic treatments under higher CO_2 concentrations (Czek *et al.,* 2012). It attributes importance of root and tuber crops under high CO_2 environment.

Previous studies indicated that the net photosynthetic rate (*Pn*) of field grown six sweet potato genotypes varied between 21.4 and 23.7 µmol $CO_2/m^2/s$ (Ravi and Saravanan, 2001) and the rates saturated at 600 µmol/m^2/s photon flux density (PPFD) at ambient CO_2 concentration (~330 ppm) (Mortley *et al.,* 1996, Ravi and Saravanan, 2001). The *Pn* increased at the rate of 0.056 µmol CO_2/m2/s per 1 ppm rise in CO_2 at 34°C and at the rate of 0.048 µmol $CO_2/m^2/s$ per 1 ppm rise in CO_2 at 38°C. Sweet potato tuber yield per plant increased significantly (41.3 g/plant) due to rise in CO_2 concentration from 363 ppm to 514ppm but further rise in CO_2 did not significantly increase tuber yield. Under high photon flux density (PPFD), leaf carboxylation rate is linked with the availability of CO_2 and increasing CO_2 concentration positively influences the *Pn* and yield. Sweet potato responds positively to increase in atmospheric CO_2 concentration. Ravi et al. (2017) reported an average *Pn* of 26.30, 33.41, 38.02 and 40.32 µmol/m^2/s at 400, 600, 800 and 1000 ppm CO_2 respectively. The per cent of increment in *Pn* at eCO_2 significantly reduces (average 5.98%) at CO_2 concentrations above 800 ppm. However the beneficial effects are still persisting.

Cassava plants grown under higher CO_2 concentration of 750 ppm produced more dry mass than plants grown under CO_2 concentration of 390 ppm (Imai *et al.* 1984; Fernandez *et al.,* 2002; Rosenthal *et al.,* 2012). Elevated CO_2 concentration delays occurrence of water deficit stress in cassava by reducing stomatal conductance and minimizing transpiration rates. Cruz *et al*., (2016) reported that even under water deficit stress under elevated CO_2 conditions biomass production is greater in cassava due to increase in photosynthetic rate and instantaneous transpiration efficiency (ITE). Cassava cultivation usually does not require any chemical input (Asher *et al*., 1980). Under drought conditions cassava maintains nearly 50% of photosynthetic rate (Ravi and Saravanan, 2001). Cassava also shows significant growth under high temperature and CO_2 conditions (Ravi *et al*., 2011). These features make cassava a future food security crop. Although cassava genotypes show tolerance (survival) under drought conditions, genotypes shows significant reduction in tuber yield and a wide variability was reported in tuber yield under drought conditions (Ramanujam 1990; Ravi and James, 2003).

Tuber yield increased in potato up to 1000 ppm (Wheeler *et al.,* 1994). Chinese yam grown under elevated CO_2 concentrations exhibit increase in the vine length, leaf area, leaf dry weight (DW), number of leaves, vine DW, and root DW and total plant dry weight than that are grown under ambient CO_2 levels under both low and high temperature regimes (Thinh *et al*., 2017).

In studies conducted at CTCRI, Thiruvananthapuram, Kerala, photosynthetic rate of elephant foot yam steadily increased with increase in CO_2 concentration. 56.71 to 82.51% hike in *Pn* at eCO_2 (1000 ppm) compared to ambient CO_2 (400 ppm) was reported by Ravi *et al*. (2018). Elephant foot yam respond well to increase in photosynthetic photon flux density. *Pn* steadily increases with increase in PPFD and reach maximum at 1500 $\mu mol/m^2/s$ PPFD (Ravi *et al.,* 2018). However increase in *Pn* at PPFDs above 1000 $\mu mol/m^2/s$ is reported as insignificant (Ravi *et al.*, 2017). Elephant foot yam, tannia and arrow root are tolerant to shade conditions. Recent studies reveal that taro exhibit 61.80 to 113.30% increase in photosynthetic rate at eCO_2 (1000 ppm) compared to ambient atmospheric concentration of CO_2, 400 ppm (Ravi *et al.*, 2018). Taro ca benefited from increasing PPFD. *Pn* steadily increases with increase in PPFD and reach maximum at 1500 $\mu mol/m^2/s$ PPFD. Increase in *Pn* up to 600 $\mu mol/m^2/s$ PPFD is reported as statistically significant (Ravi *et al*., 2018).

Roots and tubers are highly important food resources in developing countries. Increasing demand for food under climate change scenarios points out the importance of tropical root and tuber crops as a staple food commodity in the diet, especially at lower income groups in developing nations. They are also used for animal feed and various industrial applications. Important advantage of tropical root and tuber crops is that tuber and shoots which are economically important grows simultaneously under normal as well as unfavourable conditions. They cease tuber development and vegetative growth and become dormant during stress conditions such as drought, flood and heat stress and resume growth when conditions become favourable. So instance of crop failure is very less for tropical tuber crops (Lal *et al*, 2014), whereas other staple food crops such as cereals are highly sensitive to environmental stress conditions. Tuber crops need less input and maintenance but provide high yields and they provide food security for poor and marginal farmers.

Tropical root and tuber crops can provide food security for future environment under climate change. Because, being C_3 plants they have a positive effect from the eCO_2 concentrations. They can also adapt to higher temperatures and water deficit conditions. However, studies regarding to the response of tropical root and tuber crops under future changing climate scenarios is very less compared to other crops such as rice, wheat, cotton and soybean. The major objective of this study is to determine the interactive effect of elevated CO_2, higher temperature and drought stress on various photosynthetic parameters of cassava and sweet potato varieties.

MATERIALS AND METHOD

CHAPTER 3

MATERIALS AND METHODS

The study titled “Study the impact of abiotic stress on photosynthetic potential of tropical tuber crops under elevated CO_2. “ was conducted at ICAR-Central Tuber Crops Research Institute (CTCRI), Thiruvananthapuram during the period of October 2018 to July 2019 on four contrasting sweet potato and four contrasting cassava varieties. In this work, cassava and sweet potato varieties considered contrasting for leaf shape, branching nature, drought tolerance and yield. Details regarding the experimental materials used and methodology adopted for this experiment are presented in this chapter.

3.1 Cultivation of cassava

Four varieties of cassava *viz*. Sree Athulya, H-226, Sree Pavithra and Sree Vijaya were planted in RBD on 20 October 2018 in the farm of ICAR-CTCRI. Crops were planted under field conditions with three replications and each replication had 25 plants. Cassava varieties were planted at a spacing of 90 x 90 cm and the plot size was 4.5x 4.5 m. Control plants were irrigated regularly to grow the plants under WDS free conditions. WDS was imposed by withholding irrigation during 3-6 months after planting (MAP). During WDS, the water content in the soil was 7 to 10%.

As per the package of practices recommended by ICAR-CTCRI, N: P_2O_5 and K_2O were applied at the rate of 100:50:100 kg/ha. Plants were grown under open sunlight conditions with ≈12 hour’s sun light per day under ≈1700 μ mol m^2/h at 32°C ± 2°C during day time and 23°C ± 1°C during night time. During day time the atmospheric CO_2 concentration changed from ~470 ppm at 6.00 AM to ~380 ppm at 12.00 AM and ~400 ppm at 4.0 PM.

3.2 Design and layout

The experiment was laid out in randomized block design (RBD) with three replications (Fig.3.1a) and (Fig.3.1b). The details of the layout are given below.

Design : Randomized block design (RBD)
Replication : 3
Plot size : 4.5 m × 4.5 m
Spacing : 90 cm × 90 cm
Crop : Cassava

3.2.1 Treatments

I Variety (V): 4

V_1: Sree Athulya
V_2: H-226
V_3: Sree Pavithra
V_4: Sree Vijaya

II Growing conditions (P): 2

P_1: Water Deficit Stress Free Condition (Irrigated condition)
P_2: Water Deficit Stress Condition

III CO_2 Concentrations (C): 4

C_1: 400 ppm CO_2 using portable photosynthesis system with short term exposure
C_2: 600 ppm CO_2 using portable photosynthesis system with short term exposure
C_3: 800 ppm CO_2 using portable photosynthesis system with short term exposure
C_4: 1000 ppm CO_2 using portable photosynthesis system with short term exposure

IV Temperature (T): 10

T_1: 28°C using portable photosynthesis system with short term exposure
T_2: 30°C using portable photosynthesis system with short term exposure
T_3: 32°C using portable photosynthesis system with short term exposure
T_4: 34°C using portable photosynthesis system with short term exposure
T_5: 36°C using portable photosynthesis system with short term exposure
T_6: 38°C using portable photosynthesis system with short term exposure
T_7: 40°C using portable photosynthesis system with short term exposure
T_8: 42°C using portable photosynthesis system with short term exposure
T_9: 44°C using portable photosynthesis system with short term exposure
T_{10}: 45°C using portable photosynthesis system with short term exposure

3.3 Cultivation of sweet potato

Four sweet potato varieties *viz*., Sree Arun, Bhu Krishna, Kanhangad and Sree Kanaka were planted in RBD-Factorial design on 19 November 2018 in the farm of ICAR-CTCRI. Crops were planted under field conditions with three replications and each replication had 25 plants. Spacing for sweet potato varieties was 60 x 20 cm and the plot size was 3 x 1 m. Control plants were irrigated regularly to grow the plants under WDS free conditions. WDS was imposed by withholding irrigation during 2-4 MAP. During WDS, the water content in the soil was 7 to 10%.

N: P_2O_5 and K_2O were applied at the rate of 75:25:75 kg/ha. Plants were grown under open sunlight conditions with ≈12 hour's sun light per day under ≈1700 μ mol m^2/h at temperature ranging from 32°C ± 2°C during day to 23°C ± 2°C during night. Atmospheric CO_2 concentration in the field indicated a dip from ~470 ppm at 6.00 AM to ~380 ppm at 12.00 AM and ~400 ppm at 4.0 PM.

3.4 Design and layout

The experiment was laid out in randomized block design (RBD) with three replications (Fig.3.2a) and (Fig.3.2b). The details of the layout are given below.

Design	: Randomized block design (RBD)
Replication	: 3
Plot size	: 3 m × 1 m
Spacing	: 60 cm × 20 cm
Crop	: Sweet potato

3.4.1 Treatments

I Variety (V): 4

V_1: Sree Arun
V_2: Bhu Krishna
V_3: Kanhangad
V_4: Sree Kanaka

II Growing conditions (P): 2

P_1: Water Deficit Stress Free Condition (Irrigated condition)

P_2: Water Deficit Stress Condition

III CO_2 Concentrations (C): 4

C_1: 400 ppm CO_2 using portable photosynthesis system with short term exposure

C_2: 600 ppm CO_2 using portable photosynthesis system with short term exposure

C_3: 800 ppm CO_2 using portable photosynthesis system with short term exposure

C_4: 1000 ppm CO_2 using portable photosynthesis system with short term exposure

IV Temperature (T): 10

T_1: 28^oC using portable photosynthesis system with short term exposure

T_2: 30^oC using portable photosynthesis system with short term exposure

T_3: 32^oC using portable photosynthesis system with short term exposure

T_4: 34^oC using portable photosynthesis system with short term exposure

T_5: 36^oC using portable photosynthesis system with short term exposure

T_6: 38^oC using portable photosynthesis system with short term exposure

T_7: 40^oC using portable photosynthesis system with short term exposure

T_8: 42^oC using portable photosynthesis system with short term exposure

T_9: 44^oC using portable photosynthesis system with short term exposure

T_{10}: 45^oC using portable photosynthesis system with short term exposure

V_1R_1	V_2R_2	V_3R_2	V_4R_3
V_2R_1	V_1R_2	V_4R_2	V_3R_3
V_3R_1	V_4R_1	V_1R_3	V_2R_3

Fig.3.1a Layout of experiment for WDS Free condition in cassava

V_1R_1	V_2R_2	V_3R_2	V_4R_3
V_2R_1	V_1R_2	V_4R_2	V_3R_3
V_3R_1	V_4R_1	V_1R_3	V_2R_3

Fig.3.1b Layout of experiment for WDS condition in cassava

V_1R_1	V_2R_2	V_3R_2	V_4R_3
V_2R_1	V_1R_2	V_4R_2	V_3R_3
V_3R_1	V_4R_1	V_1R_3	V_2R_3

Fig.3.2a Layout of experiment for WDS Free condition in sweet potato

V_1R_1	V_2R_2	V_3R_2	V_4R_3
V_2R_1	V_1R_2	V_4R_2	V_3R_3
V_3R_1	V_4R_1	V_1R_3	V_2R_3

Fig.3.2b Layout of experiment for WDS condition in sweet potato

Sree Athulya

H-226

Sree Pavithra

Sree Vijaya

Plate 3.1: Cassava varieties

Sree Arun

Bhu Krishna

Kanhangad **Sree Kanaka**

Plate 3.2: Sweet potato varieties

Plate 3.3: Recording photosynthetic parameters using LI6400 portable photosynthesis system in the field.

3.5 Observations on photosynthetic parameters

Observations on photosynthetic parameters *viz.* the net photosynthetic rate (*Pn*), stomatal conductance (g_s), transpiration (*Tr)* and sub-stomatal/intercellular CO_2 concentration (*Ci*) were recorded using a LI6400 portable photosynthesis system, LI-COR Inc, Lincoln, USA. Desired CO_2 concentrations, Photon Flux Density (PPFD) and temperature can be set at the climate controlled cuvette system of this instrument by an inbuilt programme. Recently, Ravi *et al.* (2017, 2018, 2019) have reported reliability of LI6400 portable photosynthesis system to set the desired CO_2 concentrations and PPFDs in sweet potato, elephant foot yam and taro.

3.5.1 Observations on photosynthetic parameters of cassava

The net photosynthetic rate (P_n), stomatal conductance (g_s), intercellular CO_2 concentration (C_i) and transpiration (*Tr*) were measured in the fully mature, healthy, individual leaves in each plant (6th to 15th leaf) tested with the range of concentrations of CO_2 during 3rd, 5th and 6th month after planting (MAP). To study the interactive effect of WDS and eCO_2 on photosynthetic potential of cassava varieties, photosynthetic parameters were measured in fully expanded 6th to 15th leaf during short term (10 minutes) exposure to CO_2 concentrations *viz.* 400, 600, 800 and 1000 ppm at 30°C and 1500 µmol/m^2/s Photosynthetic Photon Flux Density (PPFD) inside controlled climate cuvette using a portable photosynthesis system. To study the interactive effect of temperature and eCO_2 on photosynthetic potential of cassava varieties, photosynthetic parameters were measured in fully expanded 6th to 15th leaf during short term (10 minutes) exposure to CO_2 concentrations *viz.* 400, 600, 800 and 1000 ppm at 28, 30, 32, 34, 36, 38, 40, 42, 44, 45°C and 1500 µmol/m^2/s PPFD during 3rd, 5th and 6th MAP. Observations were taken from the leaves of 10 plants from each replication. Leaves in each plant were tested repeatedly with the range of CO_2 concentrations and temperature. To avoid error due to time of measurement, measurements were repeated at 3 different times in the same plant between 10-12 AM. Average of 24 values was taken for the analysis of interactive effect of eCO_2 and WDS Free and

WDS conditions. Average of 12 values was taken for the analysis of interactive effect of eCO_2 and temperature.

3.5.2 Observations on photosynthetic parameters of sweet potato

The net photosynthetic rate (P_n), stomatal conductance (g_s), sub-stomatal/intercellular CO_2 concentration (C_i) and transpiration (Tr) were measured in the fully mature, healthy, individual leaves in each plant (5th to 10h leaf) tested with the range of CO_2concentrations during 3rd, 5th and 6th MAP. To study the interactive effect of WDS and eCO_2 on photosynthetic potential of sweet potato varieties, photosynthetic parameters were measured in fully expanded 5th to 10th leaf during short term (10 minutes) exposure to CO_2 concentrations *viz.* 400, 600, 800 and 1000 ppm at 30°C and 1500 µmol/m^2/s PPFD inside controlled climate cuvette using a portable photosynthesis system during 2nd, 3rd and 4th MAP. To study the interactive effect of temperature and eCO_2 on photosynthetic potential of sweet potato varieties, photosynthetic parameters were measured in fully expanded 5th to 10th leaves during short term (10 minutes) exposure to CO_2 concentrations *viz.* 400, 600, 800 and 1000 ppm at 28, 30, 32, 34, 36, 38, 40, 42, 44, 45°C and 1500 µmol/m^2/s PPFD during 2nd, 3rd and 4th MAP. Observations were taken from the leaves of 10 plants from each replication. Leaves in each plant were tested repeatedly with the range of CO_2 concentrations and temperature. To avoid error due to time of measurement, measurements were repeated at 3 different times in the same plant between 10-12 AM. Average of 24 values was taken for the analysis of interactive effect of eCO_2 and WDS Free and WDS conditions. Average of 12 values was taken for the analysis of interactive effect of eCO_2 and temperature.

3.6 Leaf Chlorophyll estimation

Total chlorophyll content of leaves was estimated according to Lichtenthaller (1987). Fully mature and disease free leaf samples of cassava (6th to 15th) and sweet potato (5th to 10th) were collected from the field during early hours in the morning. Collected leaf samples were cleaned to remove dust and water content from the surface of leaf. The main veins of the leaves were removed and lamina cut into small pieces. 0.15g sample was weighed out immediately with three replications. Weighed samples transferred into a pre chilled mortar and ground using ice cold 80% acetone to get a homogenous suspension. The homogenate was filtered using filter paper. After the filtration the volume was made up to 50 ml using 80% acetone. Absorbance of this was measured at 663.2nm, 646.8nm and 470nm using a spectrophotometer. The chlorophyll content was estimated using formula.

Chlorophyll a (µg/g fw) = $(12.21A_{663.2} - 2.79A_{646.8}) \times 1 \times V / W$

Chlorophyll b (µg/g fw) = $(20.13A_{646.8} - 5.03A_{663.2}) \times 1 \times V / W$

Total Chlorophyll (µg/g fw) = Chlorophyll a (µg/g) + Chlorophyll b (µg/g)

Carotenoids (µg/ g fw) = (Carotenoids (µg/ml) x 1 x V) /W

Where, V = final volume of chlorophyll extracted in 80% acetone, W = fresh weight of the leaf sample used

3.7 Meteorological Parameters

Weather parameters including maximum temperature, minimum temperature, relative humidity, photo synthetically active radiation, soil temperature, soil moisture and rain fall for the cropping period is given in Appendix 1.

3.8 Statistical analysis of data

The data were statistically analyzed using SAS/Software Version 9.3, SAS Institute Inc., Cary, NC, USA2010. The level of statistical significance was set at $P<0.05$. Data of the experiments were analyzed separately and in combination (pooled analysis).

RESULTS

CHAPTER 4

RESULTS

4.1. Measurement of photosynthetic parameters

Photosynthetic parameters were recorded in fully mature, healthy, physiologically active leaves of four cassava varieties *viz.* Sree Athulya, H-226, Sree Pavithra and Sree Vijaya during 3rd, 5th and 6thmonths after planting (MAP) and four sweet potato varieties *viz.*, Sree Arun, Bhu Krishna, Kanhangad and Sree Kanaka during 2nd, 3rd and 4th MAP. The differences in photosynthetic parameters across time were not found to be statistically significant. Hence the data were pooled for convenient presentation.

4.1.1 Changes in photosynthetic rate of cassava varieties as affected by WDS under eCO$_2$

The *Pn* was recorded in 6th to 15th leaf of four cassava varieties during short term (10 minutes) exposure to CO$_2$ concentrations *viz.* 400, 600, 800 and 1000 ppm at 30°C and 1500 µmol/m^2/s Photosynthetic Photon Flux Density (PPFD) inside controlled climate cuvette using a portable photosynthesis system (LICOR 6400,USA) under water deficit stress (WDS) free and WDS conditions. The *Pn* of all varieties steadily increased with increase in CO$_2$ under WDS free conditions as well as under WDS (Fig. 4.1).

Under WDS free conditions, at 400 ppm CO$_2$, *Pn* varied from 23.95µmol CO$_2$/m^2/s in the variety Sree Vijaya to 29.13µmolCO2/m^2/s in the variety Sree Athulya. At 600 ppm CO$_2$, *Pn* varied from 31.54µmol CO$_2$/m^2/s in the variety Sree Pavithra to 34.83µmol CO$_2$/m^2/s in the variety H22. At 800 ppm CO$_2$, *Pn* varied from 33.89 µmol CO$_2$/m^2/s in the variety Sree Pavithra to 37.69µmol CO$_2$/m^2/s in the variety H22. At 1000 ppm CO$_2$, *Pn* varied from 34.93 µmol CO$_2$/m^2/s in the variety Sree Pavithra to 38.51µmol CO$_2$/m^2/s in the variety Sree Athulya. Cassava varieties exhibited an increase of 32.21to 60.56% in *Pn* rate in plants under WDS free conditions at eCO$_2$ (1000 ppm) compared to ambient CO$_2$ (400 ppm). However the per cent increase in *Pn* for every 200ppm between 400 to 1000 ppm declined by 36.24% to 1.14%. The differences in *Pn* across varieties were not statistically significant.

Under WDS conditions, at 400 ppm CO_2, under WDS conditions *Pn* varied from 12.08 µmol $CO_2/m^2/s$ in the variety Sree Pavithra to 16.02µmol $CO_2/m^2/s$ in the variety Sree Vijaya. At 600 ppm CO_2, *Pn* varied from 17.27µmol $CO_2/m^2/s$ in the variety Sree Athulya to 21.95µmol $CO_2/m^2/s$ in the variety Sree Pavithra. At 800 ppm CO_2, *Pn* varied from 20.60 µmol $CO_2/m^2/s$ in the variety Sree Vijaya to 22.45µmol $CO_2/m^2/s$ in the variety Sree Pavithra. At 1000 ppm CO_2, *Pn* varied from 21.34 µmol $CO_2/m^2/s$ in the variety Sree Athulya to 25.64 µmol $CO_2/m^2/s$ in the variety Sree Pavithra. Cassava varieties exhibited an increase of 56.44 to 112.22% in plants under WDS conditions at eCO_2 (1000 ppm) compared to ambient CO_2 (400 ppm). Under WDS conditions, varieties Sree Athulya and H226 showed a decrease in per cent increase in *Pn* rate from 400 to 1000 ppm CO_2. But a hike in per cent increase in *Pn* rate was observed in the varieties Sree Pavithra (14.20%) and Sree Vijaya (21.68%) at 1000 ppm CO_2.

Under WDS conditions of plants *Pn* rate decreased compared to plants under irrigated WDS free conditions. The difference in *Pn* rate between WDS free conditions and WDS conditions was statistically significant (CD=0.974). At 400 ppm CO_2, per cent decrease in *Pn* rate under WDS varied from 33.08% in the variety Sree Vijaya to 53.75% in the variety Sree Athulya. At 600 ppm CO_2, per cent decrease in *Pn* rate under WDS varied from 30.40% in the variety Sree pavithra to 49.58% in the variety Sree Athulya. At 800 ppm CO_2, per cent decrease in *Pn* rate under WDS varied from 33.76% in the variety Sree pavithra to 41.07% in the variety Sree Athulya. At 1000 ppm CO_2, per cent decrease in *Pn* rate under WDS varied from 26.60% in the variety Sree pavithra to 44.58% in the variety Sree Athulya. Overall, as the CO_2 concentration increased, the per cent decrease in *Pn* rate at WDS decreased. This evinces that eCO_2 benefits *Pn* under WDS conditions.

Maximum *Pn* rate in WDS free plants and plants under WDS conditions was recorded at 1000 ppm CO_2. *Pn* increased with eCO_2 at WDS free as well as WDS conditions and the changes across CO_2 concentration was statistically significant (CD=1.378). *Pn* significantly changed across varieties relative to WDS and WDS free conditions (CD=1.948). *Pn* also significantly changed under WDS conditions relative to WDS free conditions (CD=0.974). The interactive effect of CO_2 concentration and the variety as well as CO_2 concentration and WDS free/WDS conditions on *Pn* was not significant.

Table 4.1. Photosynthetic rate (CO_2 µmol/m^2/s) of cassava varieties as affected by WDS under eCO_2

Variety x CO_2 (ppm)	**Irrigation Condition**	
	WDS Free	**WDS**
Sree Athulya 400	29.19	13.18
Sree Athulya 600	34.20	16.25
Sree Athulya 800	35.61	20.65
Sree Athulya 1000	38.48	21.36
H226 400	26.78	12.73
H226 600	35.87	16.89
H226 800	38.28	22.89
H226 1000	38.44	23.96
Sree Pavithra 400	25.23	12.54
Sree Pavithra 600	31.96	22.14
Sree Pavithra 800	33.91	22.37
Sree Pavithra 1000	35.21	25.86
Sree Vijaya 400	23.84	16.20
Sree Vijaya 600	32.05	18.23
Sree Vijaya 800	36.36	21.31
Sree Vijaya 1000	38.40	25.07
Variety: NS	CO_2 : CD=1.378	Irrigation: CD=0.974
Variety x CO_2: NS	CO_2 x Irrigation: NS	Variety x Irrigation: CD=1.948
CO_2 x Variety x Irrigation: NS		

4.1.2. Changes in stomatal conductance of cassava varieties as affected by WDS under eCO_2

Changes in stomatal conductance of cassava varieties under WDS free and WDS conditions are depicted in Fig. 4.2. Under WDS free conditions, maximum g_s were exhibited at 600 ppm CO_2 by the variety Sree Pavithra and at 800 ppm CO_2 by other varieties, which then decreased at 1000 ppm CO_2. At 400 ppm CO_2 g_s varied from 0.36 mol $H_2O/m^2/s$ in the variety Sree Athulya to 0.81 mol $H_2O/m^2/s$ in the variety Sree Pavithra. At 600 ppm CO_2 g_s varied from 0.42 mol $H_2O/m^2/s$ in the variety Sree Athulya to 0.92 mol $H_2O/m^2/s$ in the variety Sree Pavithra. At 800 ppm CO_2 g_s varied from 0.42 mol $H_2O/m^2/s$ in the variety Sree Athulya to 0.84 mol $H_2O/m^2/s$ in the variety Sree Vijaya. At 1000 ppm CO_2 g_s varied from 0.38 mol $H_2O/m^2/s$ in the variety Sree Athulya to 0.80 mol $H_2O/m^2/s$ in the variety Sree Vijaya.

Under WDS conditions, g_s varied from 0.19 mol $H_2O/m^2/s$ in the variety Sree Pavithra to 0.25 mol $H_2O/m^2/s$ in the variety Sree Vijaya at 400 ppm CO_2. At 600 ppm CO_2, g_s varied from 0.08 mol $H_2O/m^2/s$ in the variety Sree Vijaya to 0.17 mol $H_2O/m^2/s$ in the variety Sree Pavithra. At 800 ppm CO_2, g_s varied from 0.03 mol $H_2O/m^2/s$ in the variety H226 to 0.18 mol $H_2O/m^2/s$ in the variety Sree Pavithra. At 1000 ppm CO_2, g_s varied from 0.03 mol $H_2O/m^2/s$ in the variety H226 to 0.22 mol $H_2O/m^2/s$ in the variety Sree Athulya.

At each CO_2 concentrations, g_s decreased under WDS conditions than g_s under WDS free conditions. At 400 ppm CO_2, g_s decreased by 39.77% in the variety Sree Athulya to 76.13% in the variety Sree Pavithra under WDS conditions. At 600 ppm CO_2, under WDS conditions g_s decreased by 49.57% in the variety Sree Athulya to 88.14% in the variety Sree Vijaya. At 800 ppm CO_2, g_s decreased by 76.83% in the variety Sree Pavithra to 93.53% in the variety H226 under WDS conditions. At 1000 ppm CO_2, g_s decreased by 39.99% in the variety Sree Athulya to 93.65% in the variety H226 under WDS conditions.

Differences in g_s across CO_2 were not statistically significant. However differences in g_s across varieties (CD= 0.042) and WDS free conditions relative to WDS (CD=0.030) conditions was statistically significant. The g_s in all varieties decreased considerably between 400 ppm and 1000 ppm CO_2, under WDS condition and was statistically significant (CD=0.060). g_s also depend on the interaction between the variety and WDS free/WDS conditions (CD=0.060). However the interactive effect of CO_2 concentrations and the variety was not statistically significant.

Table 4.2. Stomatal conductance (mol H_2O/m^2 /s) of cassava varieties as affected by WDS under eCO_2

Variety x CO_2 (ppm)	**Irrigation Condition**	
	WDS Free	**WDS**
Sree Athulya 400	0.37	0.22
Sree Athulya 600	0.42	0.05
Sree Athulya 800	0.42	0.05
Sree Athulya 1000	0.38	0.55
H226 400	0.58	0.25
H226 600	0.58	0.10
H226 800	0.65	0.04
H226 1000	0.63	0.04
Sree Pavithra 400	0.81	0.19
Sree Pavithra 600	0.92	0.18
Sree Pavithra 800	0.80	0.18
Sree Pavithra 1000	0.61	0.05
Sree Vijaya 400	0.68	0.26
Sree Vijaya 600	0.77	0.08
Sree Vijaya 800	0.85	0.05
Sree Vijaya 1000	0.80	0.06
Variety: CD= 0.042	CO_2 : NS	Irrigation: CD=0.030
Variety x CO_2: NS	CO_2 x Irrigation: CD=0.060	Variety x Irrigation: CD=0.060
CO_2 x Variety x Irrigation: CD= 0.119		

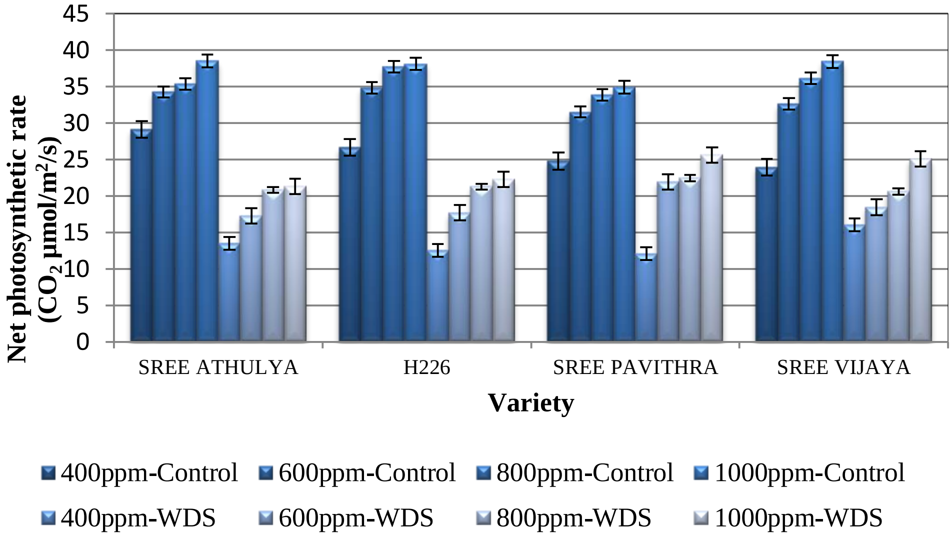

Fig. 4.1. Changes in photosynthetic rate at different CO_2 concentrations under WDS free conditions and WDS conditions in cassava varieties. The error bars indicates St. Dev.

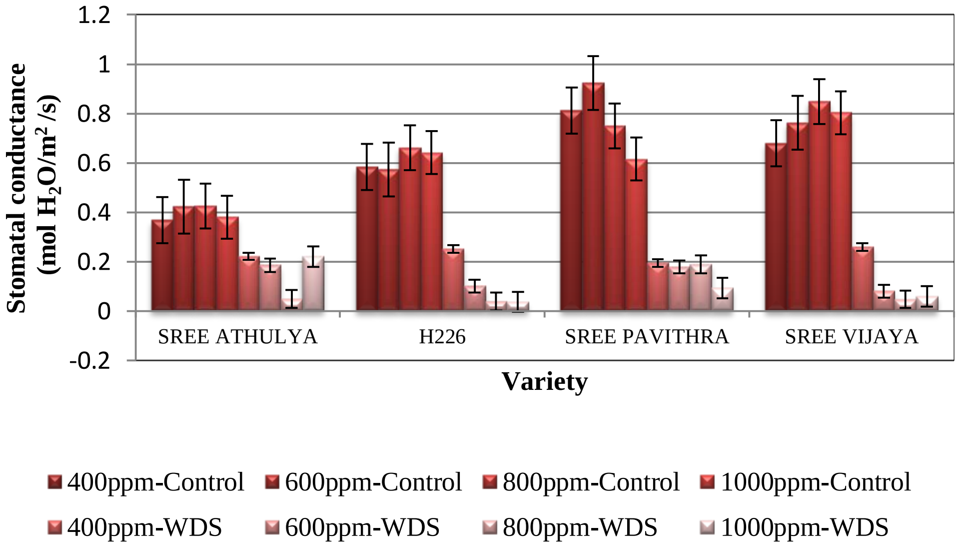

Fig. 4.2 Changes in *s*tomatal conductance at different CO_2 concentrations under WDS free conditions and WDS conditions in cassava varieties. The error bars indicates St. Dev.

4.1.3. Changes in intercellular CO_2 concentration of cassava varieties as affected by WDS under eCO_2

The *Ci* of all varieties steadily increased with increase in CO_2 under WDS free conditions as well as under WDS (Fig. 4.3). Under WDS free conditions, at 400 ppm CO_2, *Ci* varied from 236.17 ppm in the variety Sree Vijaya to 318.89 ppm in the variety H226. At 600 ppm CO_2, *Ci* varied from 410.07ppm in the variety Sree Vijaya to 489.01 ppm in the variety Sree Pavithra. At 800 ppm CO_2, *Ci* varied from 563.47 ppm in the variety Sree Athulya to 663.89 ppm in the variety Sree Pavithra. At 1000 ppm CO_2, *Ci* varied from 792.12 ppm in the variety H226 to 863.46 ppm in the variety Sree Vijaya. Cassava varieties exhibited an increase of 148.39% to 265.59% in *Ci* in plants under WDS free conditions at eCO_2 (1000 ppm) compared to ambient CO_2 (400 ppm).

Under WDS conditions *Ci* varied from 201.38ppm in the variety Sree Athulya to 362.06ppm in the variety H226 at 400 ppm CO_2. At 600 ppm CO_2, *Ci* varied from 3335.00ppm in the variety H226 to 438.03ppm in the variety Sree Pavithra. At 800 ppm CO_2, *Ci* varied from 344.50 ppm in the variety Sree Vijaya to 590.67 in the variety Sree Athulya. At 1000 ppm CO_2, *Ci* varied from 528.72 ppm in the variety Sree Vijaya to 767.99 ppm in the variety Sree Pavithra. Cassava varieties exhibited 88.01 to 257.16% increase in *Ci* of plants under WDS conditions at eCO_2 (1000 ppm) compared to ambient CO_2 (400 ppm).

Under WDS conditions *Ci* of plants significantly decreased than that of plants under WDS free conditions. At 400 ppm CO_2, per cent decrease in *Ci* under WDS compared to WDS free conditions varied from 10.86% in the variety Sree Pavithra to 27.43% in the variety Sree Athulya. At 600 ppm CO_2, per cent decrease in *Ci* under WDS varied from 5.05% in the variety H226 to 76.84% in the variety Sree Vijaya. At 800 ppm CO_2, per cent decrease in *Ci* under WDS varied from 45.86% in the variety Sree Vijaya to 112.84% in the variety Sree Athulya. At 1000 ppm CO_2, per cent decrease in *Ci* under WDS varied from 123.86% in the variety Sree Vijaya to 159.81% in the variety Sree Athulya.

Ci varied significantly across CO_2 concentrations (CD=18.939), varities (CD=13.392) as well as between WDS free and WDS conditions (CD=18.939). Maximum *Ci* was recorded at 1000 ppm CO_2 in WDS free plants as well as plants under WDS conditions. The interaction of CO_2 with varieties (CD=37.878) and irrigation (CD=26.784) as well as the variety and WDS free/WDS conditions (CD=26.784) was significant. For cassava varieties *Ci* depends on eCO_2 concentration, the variety and WDS free/WDS conditions (CD=26.784). The lower percent increase in *Ci* under WDS relative to plants under WDS free conditions is due to decrease in stomatal conductance and in *Pn* in plants under WDS conditions.

Table 4.3. Intercellular CO_2 concentration (ppm) of cassava varieties as affected by WDS under eCO_2

Variety x **CO_2 (ppm)**	**Irrigation Condition**	
	WDS Free	**WDS**
Sree Athulya 400	279.93	263.01
Sree Athulya 600	427.30	389.30
Sree Athulya 800	565.08	590.11
Sree Athulya 1000	796.97	720.63
H226 400	311.02	282.41
H226 600	420.94	340.87
H226 800	615.80	579.34
H226 1000	791.50	751.33
Sree Pavithra 400	306.89	272.54
Sree Pavithra 600	480.47	391.34
Sree Pavithra 800	677.06	537.76
Sree Pavithra 1000	842.56	755.45
Sree Vijaya 400	266.53	280.49
Sree Vijaya 600	420.80	417.79
Sree Vijaya 800	583.03	354.79
Sree Vijaya 1000	875.40	527.24
Variety: CD=18.939	CO_2 : CD=18.939	Irrigation: CD=13.392
Variety x CO_2: CD=37.878	CO_2 x Irrigation: CD=26.784	Variety x Irrigation: CD=26.784
CO_2 x Variety x Irrigation: CD=53.567		

4.1.4. Changes in transpiration rate of cassava varieties as affected by WDS under eCO_2

Plants under WDS free conditions exhibited higher *Tr* rate than that of plants under WDS conditions and the differences were statistically significant (CD=0.144) (Fig. 4.4). At 400 ppm CO_2, *Tr* varied from 5.99 mmol in the variety Sree Vijaya to 8.87 mmol in the variety Sree Pavithra under WDS free conditions. At 600 ppm CO_2, *Tr* varied from 5.83 mmol in the variety Sree Vijaya to 8.87 mmol in the variety Sree Pavithra. At 800 ppm CO_2, *Tr* varied from 5.53 mmol in the variety Sree Vijaya to 7.86 mmol in the variety Sree Pavithra. At 1000 ppm CO_2, *Tr* varied from 6.12 mmol in the variety Sree Vijaya to 8.44 in the variety Sree Pavithra.

Under WDS conditions, *Tr* varied from 4.95 mmol in the variety Sree Pavithra to 6.67 mmol in the variety Sree Vijaya at 400 ppm CO_2. At 600 ppm CO_2, *Tr* varied from 5.30 mmol in the variety Sree Pavithra to 6.52 mmol in the variety H226. At 800 ppm CO_2, *Tr* varied from 4.29 mmol in the variety H226 to 6.40 mmol in the variety Sree Vijaya. At 1000 ppm CO_2, *Tr* varied from 4.99mmol in the variety Sree Pavithra to 6.62 in the variety Sree Athulya.

Plants under WDS free conditions exhibited higher *Tr* rate than that of plants under WDS conditions. At 400 ppm CO_2, per cent decrease in *Tr* rate under WDS varied from 0.55% in the variety Sree Athulya to 44.11% in the variety Sree Pavithra. At 600 ppm CO_2, per cent decrease in *Tr* rate under WDS varied from 0.15% in the variety Sree Athulya to 40.20% in the variety Sree Pavithra. At 800 ppm CO_2, per cent decrease in *Tr* rate under WDS varied from 3.76% in the variety Sree Athulya to 41.30% in the variety H226. At 1000 ppm CO_2, per cent decrease in *Tr* rate under WDS varied from 8.44% in the variety Sree Athulya to 43.66% in the variety Sree Pavithra.

The differences in *Tr* among varieties (CD=0.204) as well as across CO_2 concentrations (CD=0.204) was significant. The interactive effect of CO_2 concentration and the variety (CD=0.408) as well as the variety and WDS free/WDS conditions (CD=0.288) was also significant. However interactive effect of CO_2 concentration and WDS free/WDS conditions was not significant. *Tr* depends on CO_2 concentration, the variety and WDS free/WDS conditions (CD=0.576). *Tr* rate decreased under WDS than under WDS free conditions due to the partial closure of stomata to reduce water loss.

Table 4.4. Transpiration rate (mmol) of cassava varieties as affected by WDS under eCO_2

Variety x **CO_2 (ppm)**	**Irrigation Condition**	
	WDS Free	**WDS**
Sree Athulya 400	6.18	6.00
Sree Athulya 600	6.33	6.04
Sree Athulya 800	5.88	6.45
Sree Athulya 1000	6.16	6.48
H226 400	7.47	6.14
H226 600	7.65	6.41
H226 800	7.78	4.32
H226 1000	7.51	5.35
Sree Pavithra 400	9.78	5.00
Sree Pavithra 600	8.74	5.40
Sree Pavithra 800	8.69	5.30
Sree Pavithra 1000	8.23	5.05
Sree Vijaya 400	6.79	6.69
Sree Vijaya 600	6.33	5.98
Sree Vijaya 800	6.09	6.43
Sree Vijaya 1000	5.99	6.45
Variety: CD=0.204	CO_2 : CD=0.204	Irrigation: CD=0.144
Variety x CO_2: CD=0.408	CO_2 x Irrigation: NS	Variety x Irrigation: CD=0.288
CO_2 x Variety x Irrigation: CD=0.576		

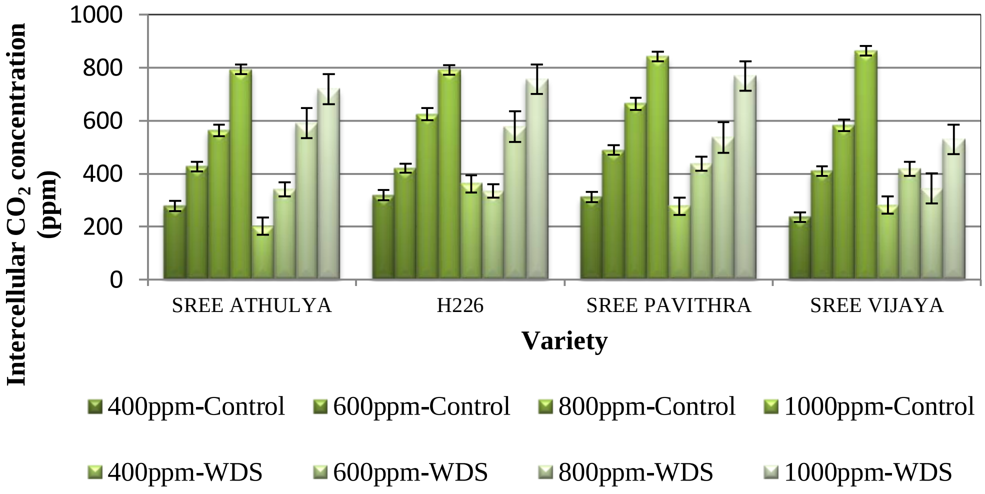

Fig. 4.3 Changes in intercellular CO_2 concentration at different CO_2 concentrations under WDS free conditions and WDS conditions in cassava varieties. The error bars indicates St. Dev.

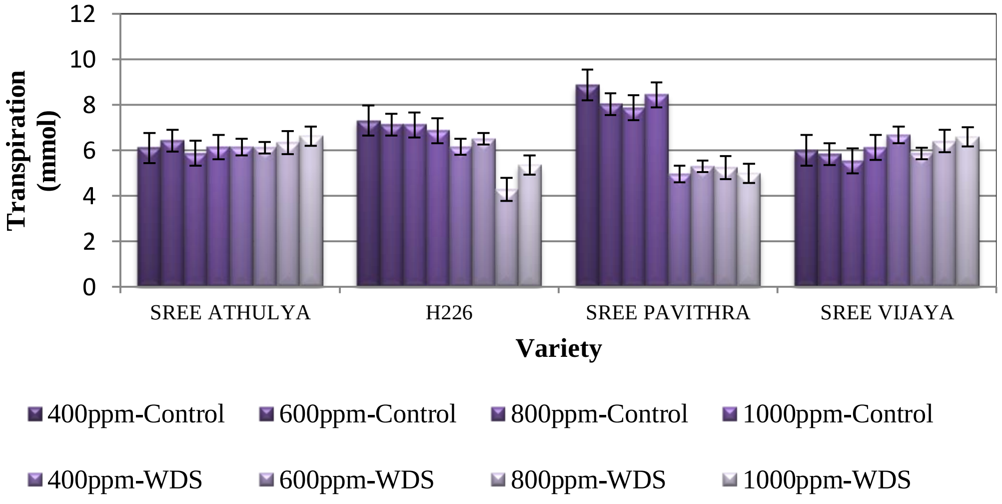

Fig. 4.4 Changes in transpiration rate at different CO_2 concentrations under WDS free conditions and WDS conditions in cassava varieties. The error bars indicates St. Dev.

4.1.5. Changes in photosynthetic rate of cassava varieties as affected by temperature under eCO_2

The *Pn* was recorded in 6th to 15th leaf of four cassava varieties during short term (10 minutes) exposure to CO_2 concentrations *viz*. 400, 600, 800 and 1000 ppm at 28, 30, 32, 34, 36, 38, 40, 42, 44 and 45°C and 1500 µmol/m^2/s PPFD inside controlled climate cuvette in a portable photosynthesis system. All the varieties exhibited maximum *Pn* rate at a temperature range of 36 to 40°C at 400, 600, and 800 ppm CO_2 concentrations. At 1000 ppm CO_2 three varieties except the variety Sree Vijaya had maximum *Pn* rate at 42-44°C.

At 400 ppm CO_2, *Pn* increased from 30.86 µmol CO_2/m^2/s to 31.28 µmol CO_2/m^2/s in the variety Sree Athulya, but decreased from 25.87 µmol CO_2/m^2/s to 24.71 µmol CO_2/m^2/s in the variety H226, from 20.59 µmol CO_2/m^2/s to 19.67 µmol CO_2/m^2/s in the variety Sree Pavithra and from 20.38 µmol CO_2/m^2/s to 20.17 µmol CO_2/m^2/s in the variety Sree Vijaya (Fig. 4.5). The *Pn* increased from 28 to 45°C, by 1.34% in the variety Sree Athulya. Whereas, the per cent decrease was from 1.01 to 4.49% between 28 and 45°C in other varieties.

At 600 ppm CO_2, *Pn* rate changed from 34.02 µmol CO_2/m^2/s to 33.15 µmol CO_2/m^2/s in the variety Sree Athulya, 28.29 µmol CO_2/m^2/s to 28.26 µmol CO_2/m^2/s in the variety H226, 25.16 µmol CO_2/m^2/s to 24.17 µmol CO_2/m^2/s in the variety Sree Pavithra and 28.40 µmol CO_2/m^2/s to 26.42 µmol CO_2/m^2/s in the variety Sree Vijaya (Fig. 4.6). *Pn* rate decreased in all varieties across temperatures and the per cent decrease was from 0.09% to 6.96% between 28 and 45°C.

At 800 ppm CO_2, *Pn* rate increased from 37.44 µmol CO_2/m^2/s to 39.51 µmol CO_2/m^2/s in the variety Sree Athulya, from 34.91 µmol CO_2/m^2/s to 35.05 µmol CO_2/m^2/s in the variety H226, but decreased from 29.93 µmol CO_2/m^2/s to 28.27 µmol CO_2/m^2/s in the variety Sree Pavithra and from 35.04 µmol CO_2/m^2/s to 30.21 µmol CO_2/m^2/s in the variety Sree Vijaya (Fig. 4.7). The variety Sree Athulya (5.53%) and H226 (0.39%) had an increment in *Pn* rate at temperatures between 28 and 45°C while Sree Pavithra (5.55%) and Sree Vijaya (13.78%) showed a decrease.

At 1000 ppm CO_2 *Pn* increased from 47.38 µmol $CO_2/m^2/s$ to 49.55 µmol CO_2 $/m^2/s$ in the variety Sree Athulya, 35.52 µmol $CO_2/m^2/s$ to 40.10 µmol $CO_2/m^2/s$ in the variety H226, 36.01 µmol $CO_2/m^2/s$ to 39.28 µmol $CO_2/m^2/s$ in the variety Sree Pavithra and 38.99 µmol $CO_2/m^2/s$ to 39.47 µmol $CO_2/m^2/s$ in the variety Sree Vijaya (Fig. 4.8). *Pn* increased across temperatures in all varieties and the per cent increase was 1.22% to 12.88% at 45°C compared to 28°C.

At each CO_2 concentration differences in the *Pn* rate across 28 to 45°C temperatures were statistically significant (CD=1.208). However differences in *Pn* across temperature were not statistically significant. The differences in *Pn* across CO_2 concentrations (CD=0.382) as well as varieties (CD=0.382) was also statistically significant. Interactive effect of temperature and the variety was not significant.

Table 4.5. Changes in photosynthetic rate (CO_2 µmol/m^2/s) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Athulya

Temperature (°C)	**photosynthetic rate (CO_2 µmol/m^2/s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	30.87	34.03	37.44	47.39
30	30.98	35.82	37.65	47.34
32	31.58	35.50	38.64	47.55
34	31.02	35.18	40.12	47.76
36	31.78	35.48	41.69	48.85
38	31.69	35.09	41.48	49.13
40	31.88	34.40	40.89	49.85
42	31.22	34.17	40.47	50.42
44	31.65	34.00	40.27	50.13
45	31.28	33.15	39.52	49.56

Variety: CD=0.382	CO_2 : CD=0.382	Temperature: NS
Variety x CO_2: CD=0.764	CO_2 x Temperature: CD=1.208	Variety x Temperature: NS
CO_2 x Variety x Temperature: NS		

Table 4.6. Changes in photosynthetic rate (CO_2 µmol/m^2/s) of cassava varieties as affected by temperature under eCO_2 in the variety H-226

Temperature (^oC)	**photosynthetic rate (CO_2 µmol/m^2/s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	25.88	28.29	34.91	35.53
30	26.05	27.62	34.82	36.45
32	25.66	27.74	34.68	36.86
34	25.40	27.39	35.49	37.91
36	25.52	28.49	35.74	39.03
38	25.54	28.90	36.13	39.21
40	25.44	28.09	36.15	39.69
42	25.29	28.26	35.89	39.69
44	24.78	28.20	35.33	40.24
45	24.71	28.27	35.05	40.10

Variety: CD=0.382	CO_2 : CD=0.382	Temperature: NS
Variety x CO_2: CD=0.764	CO_2 x Temperature: CD=1.208	Variety x Temperature: NS
CO_2 x Variety x Temperature: NS		

Table 4.7. Changes in photosynthetic rate (CO_2 µmol/m^2/s) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Pavithra

Temperature (^oC)	**photosynthetic rate (CO_2 µmol/m^2/s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	20.60	25.17	29.94	36.01
30	20.02	24.96	29.93	35.83
32	20.37	24.31	29.84	36.08
34	20.50	24.43	29.70	35.60
36	20.37	24.71	29.83	36.62
38	20.62	24.76	28.63	37.05
40	20.46	24.95	28.17	37.25
42	20.03	24.82	28.56	38.03
44	19.69	24.64	28.37	38.74
45	19.68	24.17	28.27	39.28

Variety: CD=0.382	CO_2 : CD=0.382	Temperature: NS
Variety x CO_2: CD=0.764	CO_2 x Temperature: CD=1.208	Variety x Temperature: NS
CO_2 x Variety x Temperature: NS		

Table 4.8. Changes in photosynthetic rate (CO_2 µmol/m^2/s) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Vijaya

Temperature (°C)	**photosynthetic rate (CO_2 µmol/m^2/s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	20.38	28.40	35.04	38.99
30	20.48	28.00	34.55	40.45
32	20.33	28.01	34.12	41.48
34	20.84	27.69	33.48	41.38
36	20.93	27.55	33.02	41.91
38	20.77	27.49	32.35	42.51
40	20.62	27.38	31.49	42.02
42	20.49	27.21	30.73	41.38
44	20.51	26.90	30.44	40.00
45	20.18	26.42	30.21	39.47

Variety: CD=0.382	CO_2 : CD=0.382	Temperature: NS
Variety x CO_2: CD=0.764	CO_2 x Temperature: CD=1.208	Variety x Temperature: NS
CO_2 x Variety x Temperature: NS		

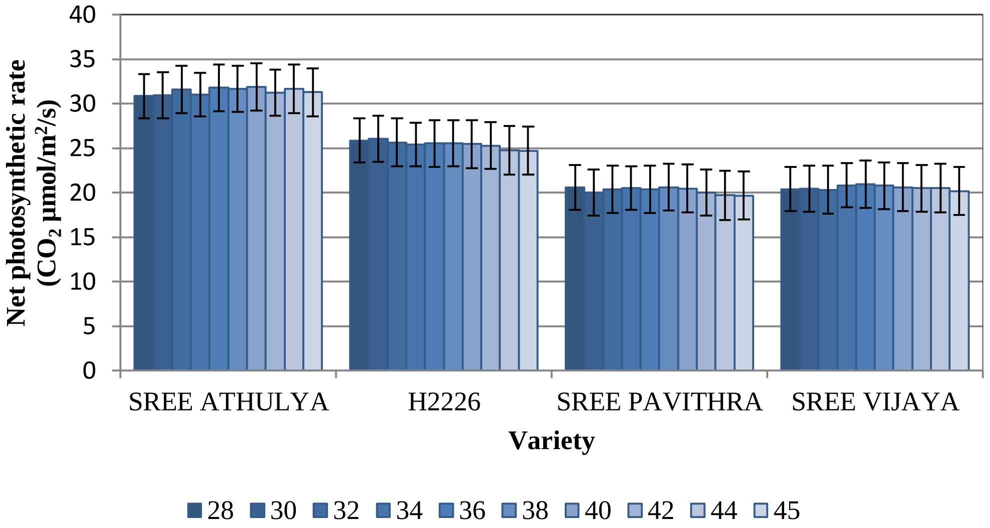

Fig. 4.5 Changes in photosynthetic rate at different temperatures at 400 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

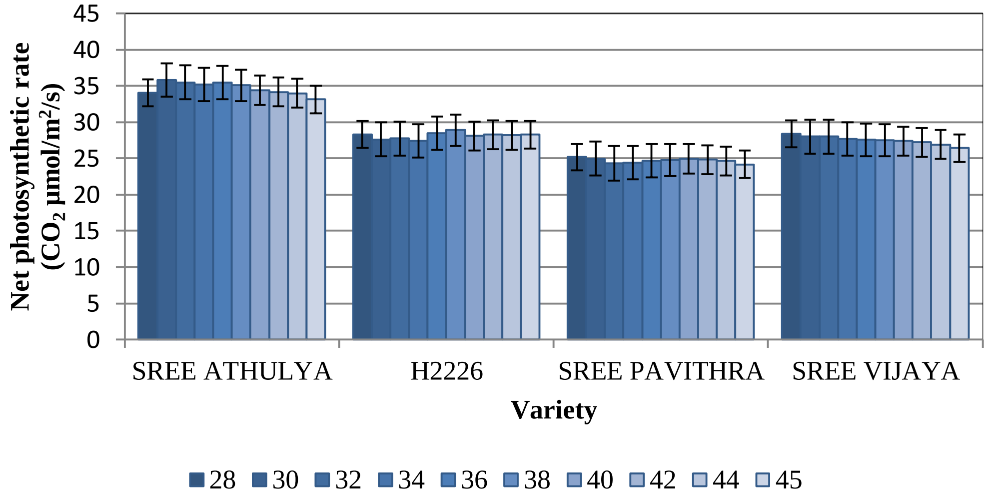

Fig. 4.6 Changes in photosynthetic rate photosynthetic rate at different temperatures at 600 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

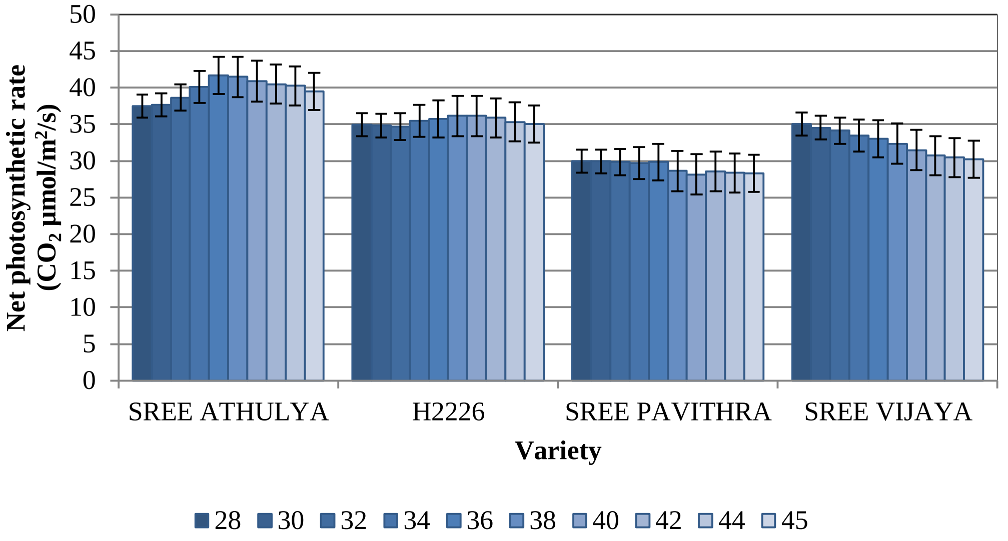

Fig. 4.7 Changes in photosynthetic rate at different temperatures at 800 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

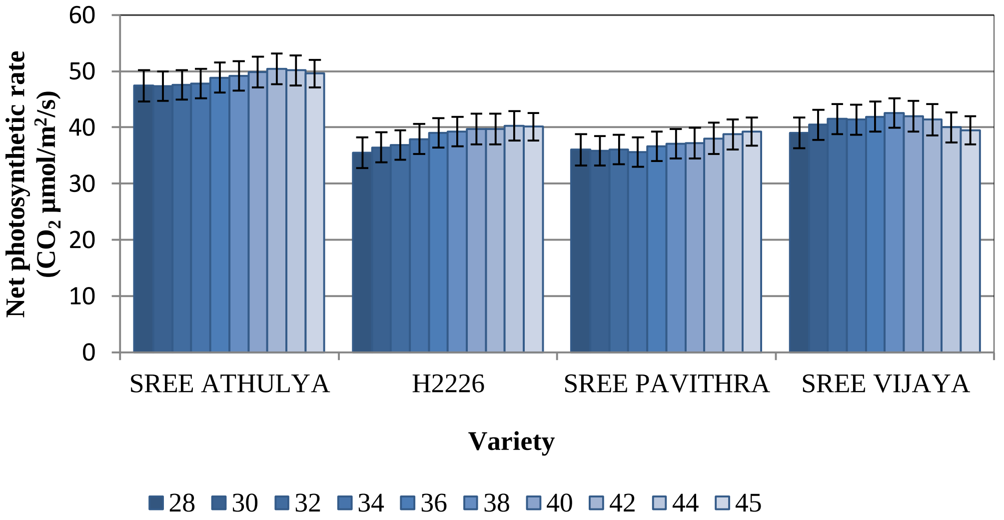

Fig. 4.8 Changes in photosynthetic rate at different temperatures at 1000 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

4.1.6. Changes in stomatal conductance of cassava varieties as affected by temperature under eCO_2

The g_s decreased with increase in temperature at all CO_2 concentrations and the decrease was statically significant (CD=0.005). All the varieties exhibited maximum g_s at a temperature range of 28 to 30°C in each CO_2 concentrations.

At 400 ppm CO_2, g_s decreased from 0.56 mol $H_2O/m^2/s$ at 28°C to 0.48 mol $H_2O/m^2/s$ at 45°C in the variety Sree Athulya, from 0.63 mol $H_2O/m^2/s$ to 0.39 mol $H_2O/m^2/s$ in the variety H226, from 0.57 mol $H_2O/m^2/s$ to 0.28 mol $H_2O/m^2/s$ in the variety Sree Pavithra and from 0.22 mol $H_2O/m^2/s$ to 0.20 mol $H_2O/m^2/s$ in the variety Sree Vijaya (Fig. 4.9). The per cent decrease in g_s at 45°C relative to 28°C was minimum in the variety Sree Vijaya (5.89%) and maximum in the variety Sree Pavithra (50.40%).

At 600 ppm CO_2, g_s decreased from 0.33 mol $H_2O/m^2/s$ to 0.20 mol $H_2O/m^2/s$ in the variety Sree Athulya, 0.31 mol $H_2O/m^2/s$ to 0.25 mol $H_2O/m^2/s$ in the variety H226, 0.44 mol $H_2O/m^2/s$ to 0.22 mol $H_2O/m^2/s$ in the variety Sree Pavithra and 0.15 mol $H_2O/m^2/s$ to 0.14 mol $H_2O/m^2/s$ in the variety Sree Vijaya (Fig. 4.10). The per cent decrease in g_s at 45°C relative to 28°C was minimum in the variety Sree Vijaya (9.35%) and maximum in the variety Sree Pavithra (49.66%).

At 800 ppm CO_2, g_s decreased from 0.24 mol $H_2O/m^2/s$ to 0.14 mol $H_2O/m^2/s$ in the variety Sree Athulya, from 0.39 mol $H_2O/m^2/s$ to 0.26 mol $H_2O/m^2/s$ in the variety H226, from 0.46 mol $H_2O/m^2/s$ to 0.31 mol $H_2O/m^2/s$ in the variety Sree Pavithra and from 0.21 mol $H_2O/m^2/s$ to 0.15 mol $H_2O/m^2/s$ in the variety Sree Vijaya (Fig. 4.11). The per cent decrease in g_s at 45°C relative to 28°C was minimum in the variety Sree Vijaya (26.78%) and maximum in the variety Sree Athulya (39.21%).

At 1000 ppm CO_2, g_s decreased from 1.93 mol $H_2O/m^2/s$ to 0.12 mol $H_2O/m^2/s$ in the variety Sree Athulya, from 0.22 mol $H_2O/m^2/s$ to 0.15 mol

$H_2O/m^2/s$ in the variety H226, from 0.99$H_2O/m^2/s$ to 0.44 mol $H_2O/m^2/s$ in the variety Sree Pavithra and from 0.22 mol $H_2O/m^2/s$ to 0.19 mol $H_2O/m^2/s$ in the variety Sree Vijaya (Fig. 4.12). The per cent decrease in g_s between temperatures 28 and 45°C relative to 28°C was minimum in the variety Sree Vijaya (14.79%) and maximum in the variety Sree Athulya (93.58%).

At each CO_2 concentration, differences in the *Pn* rate across 28 to 45°C temperatures were statistically insignificant (CD=0.010). The differences in g_s across CO_2 concentrations (CD=0.003) as well as varieties (CD=0.003) was also statistically significant. Interactive effect of temperature and the variety (CD=0.010) as well as CO_2 and the variety (CD=0.006) on g_s was significant. The interaction of temperature, the variety and CO_2 concentration was also statistically significant (CD=0.019).

Table 4.9. Changes in stomatal conductance (mol H_2O/m^2 /s) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Athulya

Temperature (°C)	**Stomatal conductance (mol H_2O/m^2 /s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	0.56	0.33	0.24	1.94
30	0.56	0.31	0.22	1.60
32	0.55	0.30	0.21	0.61
34	0.54	0.29	0.20	0.36
36	0.53	0.26	0.19	0.27
38	0.52	0.25	0.18	0.21
40	0.32	0.23	0.17	0.17
42	0.51	0.22	0.16	0.15
44	0.51	0.22	0.16	0.13
45	0.49	0.21	0.15	0.12

Variety: CD=0.003	CO_2 : CD=0.003	Temperature: CD=0.005
Variety x CO_2: CD=0.006	CO_2 x Temperature: CD=0.010	Variety x Temperature: CD=0.010
CO_2 x Variety x Temperature: CD=0.019		

Table 4.10. Changes in stomatal conductance (mol H_2O/m^2 /s) of cassava varieties as affected by temperature under eCO_2 in the variety H-226

Temperature (°C)	**Stomatal conductance (mol H_2O/m^2 /s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	0.63	0.31	0.39	0.22
30	0.61	0.29	0.36	0.22
32	0.59	0.27	0.33	0.20
34	0.56	0.25	0.31	0.19
36	0.53	0.24	0.29	0.18
38	0.50	0.23	0.28	0.17
40	0.46	0.23	0.27	0.17
42	0.43	0.23	0.26	0.17
44	0.41	0.24	0.26	0.16
45	0.40	0.25	0.26	0.16

Variety: CD=0.003 | CO_2 : CD=0.003 | Temperature: CD=0.005

Variety x CO_2: CD=0.006 | CO_2 x Temperature: CD=0.010 | Variety x Temperature: CD=0.010

CO_2 x Variety x Temperature: CD=0.019

Table 4.11. Changes in stomatal conductance (mol H_2O/m^2 /s) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Pavithra

Temperature (°C)	**Stomatal conductance (mol H_2O/m^2 /s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	0.57	0.45	0.46	0.99
30	0.52	0.44	0.44	0.88
32	0.47	0.34	0.41	0.77
34	0.43	0.34	0.45	0.66
36	0.40	0.33	0.39	0.66
38	0.38	0.33	0.37	0.56
40	0.35	0.33	0.36	0.55
42	0.32	0.23	0.34	0.45
44	0.29	0.23	0.33	0.44
45	0.28	0.23	0.31	0.44

Variety: CD=0.003 | CO_2 : CD=0.003 | Temperature: CD=0.005

Variety x CO_2: CD=0.006 | CO_2 x Temperature: CD=0.010 | Variety x Temperature: CD=0.010

CO_2 x Variety x Temperature: CD=0.019

Table 4.12. Changes in stomatal conductance (mol H_2O/m^2 /s) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Vijaya

Temperature (°C)	**Stomatal conductance (mol H_2O/m^2 /s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	0.22	0.16	0.21	0.22
30	0.24	0.16	0.21	0.22
32	0.24	0.16	0.20	0.22
34	0.24	0.16	0.18	0.22
36	0.23	0.15	0.18	0.22
38	0.22	0.15	0.16	0.19
40	0.22	0.15	0.17	0.20
42	0.22	0.15	0.16	0.20
44	0.22	0.15	0.16	0.19
45	0.21	0.14	0.16	0.19

Variety: CD=0.003	CO_2 : CD=0.003	Temperature: CD=0.005
Variety x CO_2: CD=0.006	CO_2 x Temperature: CD=0.010	Variety x Temperature: CD=0.010
CO_2 x Variety x Temperature: CD=0.019		

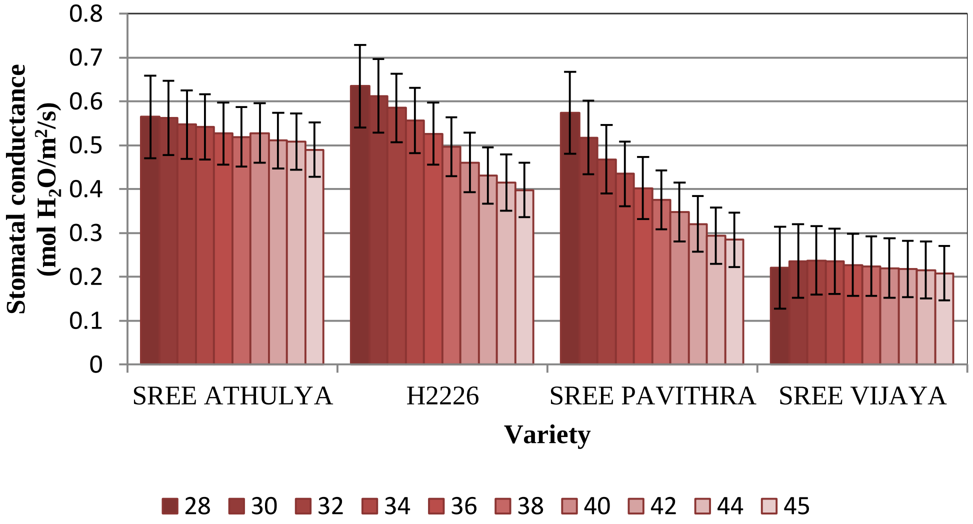

Fig. 4.9 Changes in *s*tomatal conductance at different temperatures at 400 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

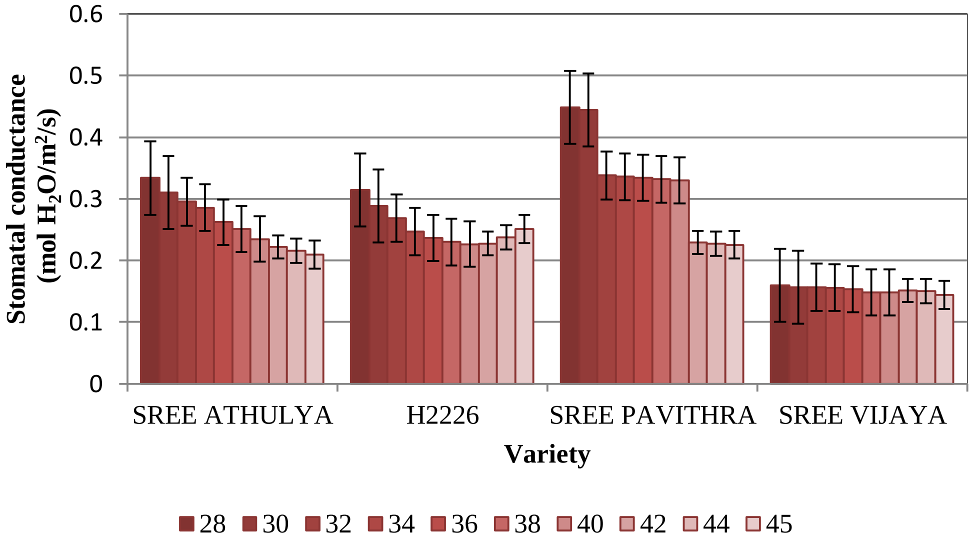

Fig. 4.10 Changes in *s*tomatal conductance at different temperatures at 600 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

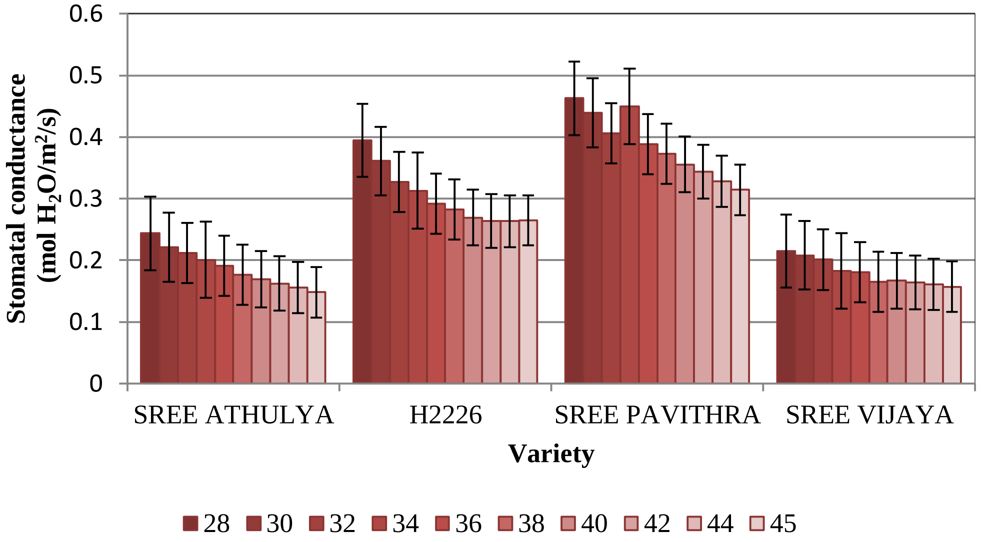

Fig. 4.11 Changes in stomatal conductance at different temperatures at 800 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

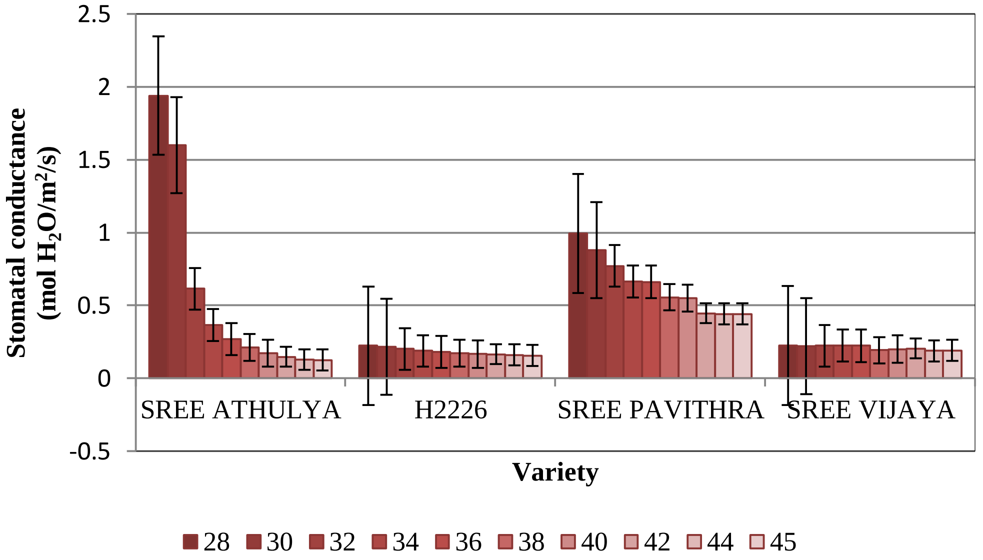

Fig. 4.12 Changes in stomatal conductance at different temperatures at 1000 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

4.1.7. Changes in intercellular CO_2 concentration of cassava varieties as affected by temperature under eCO_2

At each CO_2 concentration, differences in the *Ci* across 28 to 45°C temperatures were steadily decreased and was statistically significant (CD=3.369). All the varieties exhibited maximum *Ci* at a temperature range of 28 to 30°C in each CO_2 concentrations.

At 400 ppm CO_2, *Ci* decreased from 276.58 ppm at 28°C to 256.09 ppm at 45°C in the variety Sree Athulya, from 302.73 ppm to 265.79 ppm in the variety H226, from 302.67 ppm to 265.21 ppm in the variety Sree Pavithra and from 230.01 ppm to 214.94 ppm in the variety Sree Vijaya (Fig. 4.13). The per cent decrease varied from 3.90% to 12.37% between 28 and 45°C at 400 ppm CO_2.

At 600 ppm CO_2, *Ci* decreased in all varieties across temperatures between 28 and 45°C and the per cent decrease varied from 6.85% to 20.01%. *Ci* decreased from 393.312 ppm to 314.59 ppm in the variety Sree Athulya, from 394.66 ppm to 356.13 ppm in the variety H226, from 395.14 ppm to 354.36 ppm in the variety Sree Pavithra and from 347.41 ppm to 323.60 ppm in the variety Sree Vijaya (Fig. 4.14).

At 800 ppm CO_2, *Ci* decreased from 521.82 ppm to 372.42 ppm in the variety Sree Athulya, from 599.26 ppm to 493.35 ppm in the variety H226, from 642.25 ppm to 553.36 ppm in the variety Sree Pavithra and from 486.35 ppm to 433.51ppm in the variety Sree Vijaya (Fig. 4.15). In all varieties *Ci* decreased with increase in temperature and the per cent decrease varied from 10.86% to 28.63% between 28 and 45°C at 800 ppm CO_2.

At 1000 ppm CO_2, *Ci* increased by 1.14% between 28 and 45°C temperature in the variety Sree Vijaya. All other varieties had a decrease in *Ci* across temperatures between 28 and 45°C and the per cent decrease varied from 20.86% to 69.32%. *Ci* decreased from 946.67 ppm to 290 ppm in the variety Sree Athulya, from 668.32 ppm to 525.76 ppm in the variety H226 and from 668.47 ppm to 529 ppm in the variety Sree Pavithra but increased from 1296.69 ppm to 1311.54 ppm in the variety Sree Vijaya (Fig. 4.16).

The interactive effect among temperature and the variety (CD=3.369) as well as CO_2 and the variety (CD=2.131) was significant. The differences across CO_2 concentrations (CD=0,543), varieties (CD=0.543) as well as temperature (CD=3.369) was also statistically significant. *Ci* significantly depend on the interaction between CO2, the variety and temperature (CD=6.738).

Table 4.13. Changes in intercellular CO_2 concentration (ppm) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Athulya

Temperature (^oC)	**Intercellular CO_2 concentration (ppm)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	276.58	393.31	521.82	946.68
30	275.27	382.37	503.07	896.47
32	272.78	373.05	488.58	808.10
34	271.18	368.69	458.42	714.07
36	268.13	349.12	426.72	625.83
38	264.54	339.11	408.10	541.55
40	262.05	329.82	400.15	447.81
42	261.46	323.89	389.62	375.77
44	260.30	318.61	383.35	297.76
45	256.10	314.60	372.42	290.36

Variety: CD=1.065	CO_2 : CD=1.065	Temperature: CD=1.685
Variety x CO_2: CD=2.131	CO_2 x Temperature: CD=3.369	Variety x Temperature: CD=3.369
CO_2 x Variety x Temperature: CD=6.738		

Table 4.14. Changes in intercellular CO_2 concentration (ppm) of cassava varieties as affected by temperature under eCO_2 in the variety H-226

Temperature (^{o}C)	**Intercellular CO_2 concentration (ppm)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	302.74	394.67	599.27	668.33
30	300.03	383.87	585.02	658.07
32	296.80	373.69	563.86	632.67
34	293.05	362.04	548.15	599.45
36	288.19	354.68	526.46	585.26
38	282.84	348.03	513.84	564.83
40	275.81	347.25	501.76	550.17
42	271.65	345.81	495.19	549.01
44	270.49	349.17	493.15	541.67
45	265.79	356.14	493.36	525.76

Variety: CD=1.065	CO_2 : CD=1.065	Temperature: CD=1.685
Variety x CO_2: CD=2.131	CO_2 x Temperature: CD=3.369	Variety x Temperature: CD=3.369
CO_2 x Variety x Temperature: CD=6.738		

Table 4.15. Changes in intercellular CO_2 concentration (ppm) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Pavithra

Temperature (^{o}C)	**Intercellular CO_2 concentration (ppm)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	302.67	395.14	642.24	668.47
30	300.20	383.94	636.64	657.53
32	296.79	374.84	623.79	632.43
34	293.38	362.04	644.61	601.72
36	288.49	355.38	616.05	584.19
38	283.58	348.29	602.56	563.32
40	277.85	347.05	592.01	551.67
42	271.44	346.39	579.24	548.66
44	270.36	348.78	565.64	542.13
45	265.21	354.36	553.36	529.00

Variety: CD=1.065	CO_2 : CD=1.065	Temperature: CD=1.685
Variety x CO_2: CD=2.131	CO_2 x Temperature: CD=3.369	Variety x Temperature: CD=3.369
CO_2 x Variety x Temperature: CD=6.738		

Table 4.16. Changes in intercellular CO_2 concentration (ppm) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Vijaya

Temperature (°C)	**Intercellular CO_2 concentration (ppm)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	230.01	347.42	486.35	1296.69
30	237.61	349.47	489.64	1301.65
32	238.83	348.58	474.46	1299.77
34	231.51	344.55	467.69	1298.57
36	226.28	339.19	456.07	1302.35
38	222.82	329.38	448.58	1359.24
40	219.77	326.43	445.10	1337.26
42	219.02	332.02	443.38	1319.38
44	214.93	331.63	439.94	1319.53
45	214.95	323.60	433.52	1311.54

Variety: CD=1.065	CO_2 : CD=1.065	Temperature: CD=1.685
Variety x CO_2: CD=2.131	CO_2 x Temperature: CD=3.369	Variety x Temperature: CD=3.369
CO_2 x Variety x Temperature: CD=6.738		

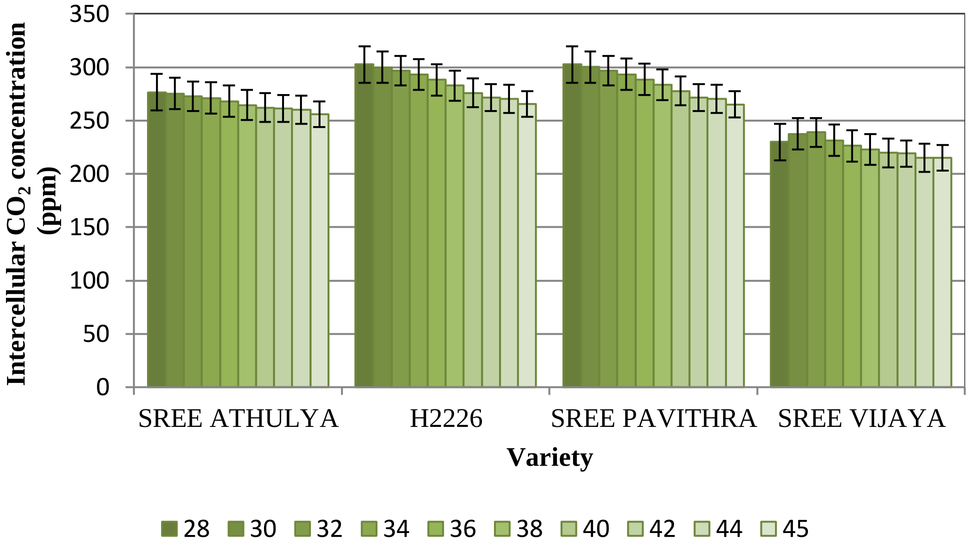

Fig. 4.13 Changes in intercellular CO_2 concentration at different temperatures at 400 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

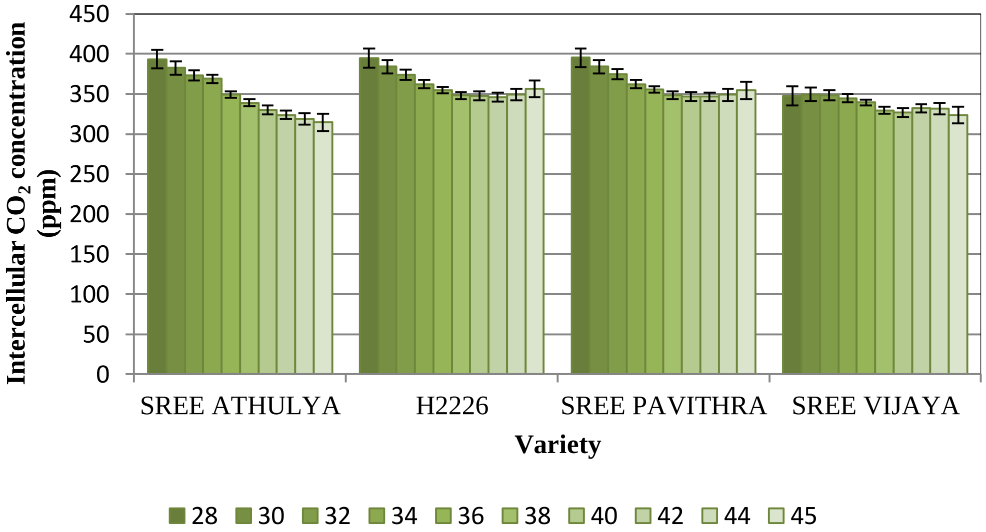

Fig. 4.14 Changes in intercellular CO_2 concentration at different temperatures at 600 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

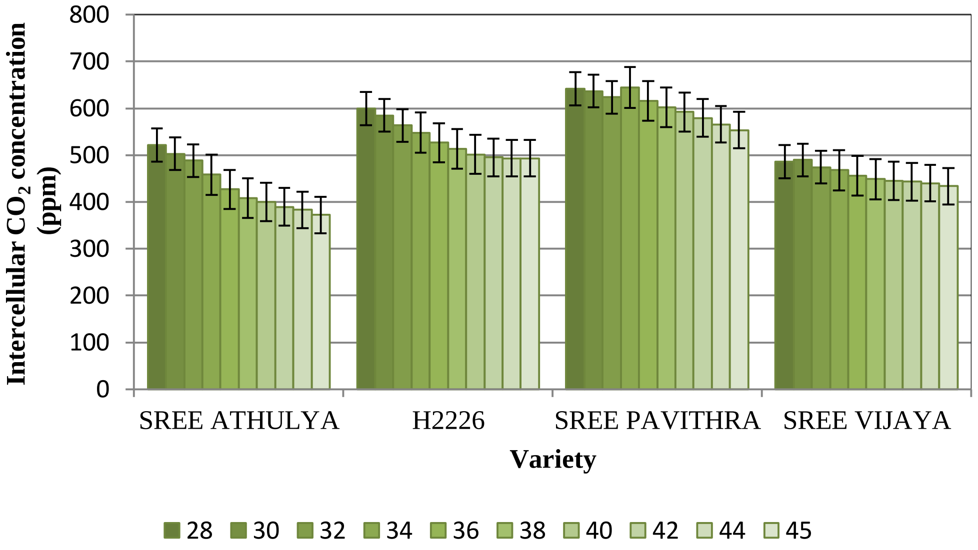

Fig. 4.15 Changes in intercellular CO_2 concentration at different temperatures at 800 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

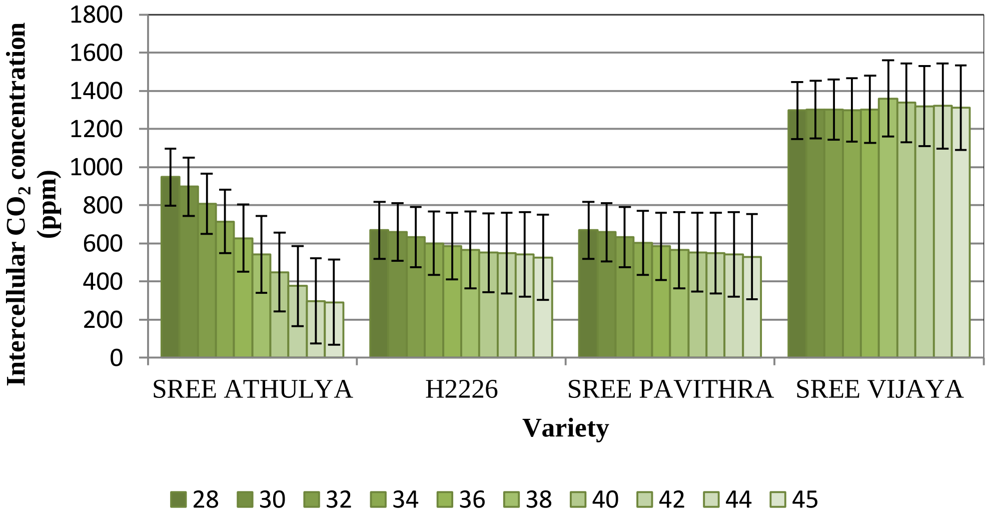

Fig. 4.16 Changes in intercellular CO_2 concentration at different temperatures at 1000 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

4.1.8. Changes in transpiration rate of cassava varieties as affected by temperature under eCO_2

The *Tr* rate increased with increase in temperature from 28 to 45°C in all varieties at every CO_2 concentrations. At each CO_2 concentration differences in the *Tr* rate across 28 to 45°C temperatures were statistically significant (CD=0.108). All the varieties exhibited maximum *Tr* rate at a temperature range of 42 to 45°C in every CO_2 concentrations.

At 400 ppm CO_2, *Tr* increased from 8.00mmol at 28°C to 12.13 mmol at 45°C in the variety Sree Athulya, from 9.98 mmol to 12.31 mmol in the variety H226, from 7.30 mmol to 11.04 mmol in the variety Sree Pavithra and from 8.04 mmol to 11.51 mmol in the variety Sree Vijaya (Fig. 4.17). The per cent increase varied from 23.38% to 51.61% between 28 and 45°C.

At 600 ppm CO_2, *Tr* rate increased in all varieties across temperatures and the per cent increase varied from 21.00% to 48.74% between 28 and 45°C. *Tr* rate increased from 7.22 mmol to 8.74 mmol in the variety Sree Athulya, from 7.16 mmol to 9.76 mmol in the variety H226, from 7.03 mmol to 10.46 mmol in the variety Sree Pavithra and from 7.18 mmol to 9.63 mmol in the variety Sree Vijaya (Fig. 4.18).

At 800 ppm CO_2, *Tr* rate increased from 5.70 mmol to 6.78 mmol in the variety Sree Athulya, from 8.08 mmol to 10.13 mmol in the variety H226, from 8.70 mmol to 10.56 mmol in the variety Sree Pavithra and from 5.24 mmol to 6.98 mmol in the variety Sree Vijaya (Fig. 4.19). The per cent increase varied from 18.92% to 33.10% at 45°C relative to 28°C.

At 1000 ppm CO_2, all varieties had an increase in *Tr* across temperature and the per cent increase varied from 23.07% to 30.98% at 45°C relative to 28°C. *Tr* increased from 5.71 mmol to 7.38 mmol in the variety Sree Athulya, from 5.73 mmol to 7.51 mmol in the variety H226, from 8.48 mmol to 10.94 mmol in the variety Sree Pavithra and from 6.48 mmol to 7.98 mmol in the variety Sree Vijaya (Fig. 4.20).

The interactive effect among temperature and the variety (CD=0.108) as well as CO_2 and the variety (CD=0.069) on *Tr* was significant. The differences across CO_2 concentrations (CD=0.034), varieties (CD=0.034) as well as temperature (CD=0.054) were statistically significant. *Tr* significantly depend on the interaction between CO_2, the variety and temperature (CD=0.217).

Table 4.17. Changes in transpiration rate (mmol) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Athulya

Temperature (°C)	**Transpiration rate (mmol)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	8.00	7.23	5.71	5.71
30	8.34	7.15	5.58	5.54
32	8.70	7.25	5.62	5.57
34	9.10	7.40	5.76	5.50
36	9.54	7.73	5.97	5.73
38	9.98	8.06	6.14	6.01
40	10.43	8.17	6.36	6.24
42	11.11	8.32	6.51	6.64
44	11.71	8.62	6.64	7.00
45	12.13	8.75	6.79	7.38

Variety: CD=0.034	CO_2 : CD=0.034	Temperature: CD=0.054
Variety x CO_2: CD=0.069	CO_2 x Temperature: CD=0.108	Variety x Temperature: CD=0.108
CO_2 x Variety x Temperature: CD=0.217		

Table 4.18. Changes in transpiration rate (mmol) of cassava varieties as affected by temperature under eCO$_2$ in the variety H-226

Temperature (^{o}C)	**Transpiration rate (mmol)**			
	400ppm CO$_2$	**600ppm** CO$_2$	**800ppm** CO$_2$	**1000ppm** CO$_2$
28	9.98	7.17	8.08	5.73
30	9.97	7.06	7.89	5.89
32	10.27	7.12	7.92	5.96
34	10.64	7.13	8.12	6.19
36	11.03	7.32	8.36	6.41
38	11.37	7.66	8.75	6.55
40	11.66	7.95	8.87	6.73
42	11.89	8.40	9.31	6.98
44	12.16	9.19	9.68	7.32
45	12.32	9.77	10.13	7.51

Variety: CD=0.034	CO$_2$: CD=0.034	Temperature: CD=0.054
Variety x CO$_2$: CD=0.069	CO$_2$ x Temperature: CD=0.108	Variety x Temperature: CD=0.108
CO$_2$ x Variety x Temperature: CD=0.217		

Table 4.19. Changes in transpiration rate (mmol) of cassava varieties as affected by temperature under eCO$_2$ in the variety Sree Pavithra

Temperature (^{o}C)	**Transpiration rate (mmol)**			
	400ppm CO$_2$	**600ppm** CO$_2$	**800ppm** CO$_2$	**1000ppm** CO$_2$
28	5.86	5.29	8.74	8.60
30	5.68	4.91	8.65	8.62
32	5.85	4.80	8.66	8.71
34	6.18	5.10	9.39	9.01
36	6.48	5.47	9.19	9.68
38	6.84	5.77	9.52	9.95
40	7.15	6.24	9.88	10.16
42	7.42	6.70	10.21	10.44
44	7.66	6.97	10.58	10.84
45	7.85	7.05	10.80	11.16

Variety: CD=0.034	CO$_2$: CD=0.034	Temperature: CD=0.054
Variety x CO$_2$: CD=0.069	CO$_2$ x Temperature: CD=0.108	Variety x Temperature: CD=0.108
CO$_2$ x Variety x Temperature: CD=0.217		

Table 4.20. Changes in transpiration rate (mmol) of cassava varieties as affected by temperature under eCO_2 in the variety Sree Vijaya

Temperature (^oC)	**Transpiration rate (mmol)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	5.49	4.09	5.26	7.27
30	5.98	4.14	5.11	7.15
32	5.85	4.36	5.23	7.12
34	5.98	4.63	4.96	7.08
36	7.02	4.89	5.33	6.97
38	6.91	5.18	5.17	6.39
40	7.62	5.44	5.74	6.60
42	8.05	5.83	5.97	6.64
44	8.08	6.26	6.22	6.32
45	8.72	6.39	6.36	6.33

Variety: CD=0.034	CO_2 : CD=0.034	Temperature: CD=0.054
Variety x CO_2: CD=0.069	CO_2 x Temperature: CD=0.108	Variety x Temperature: CD=0.108
CO_2 x Variety x Temperature: CD=0.217		

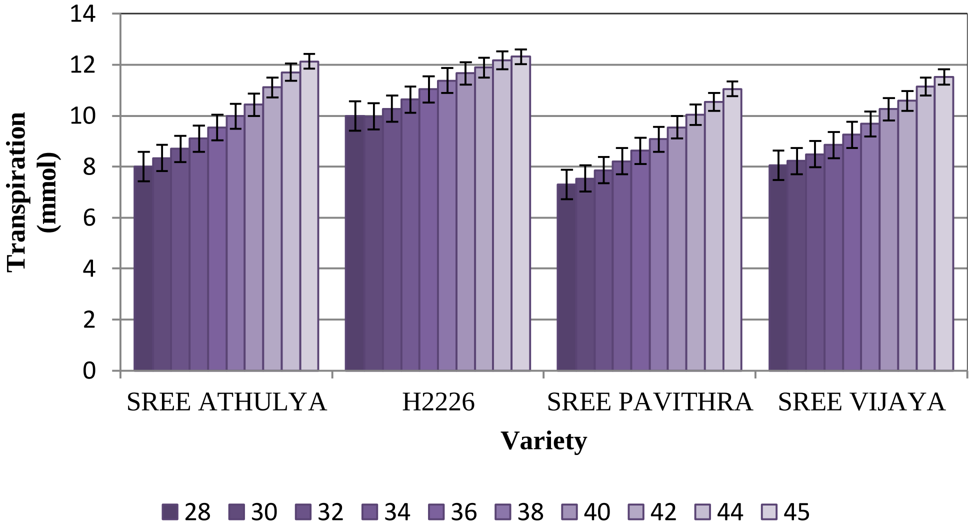

Fig. 4.17 Changes in transpiration at different temperatures at 400 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

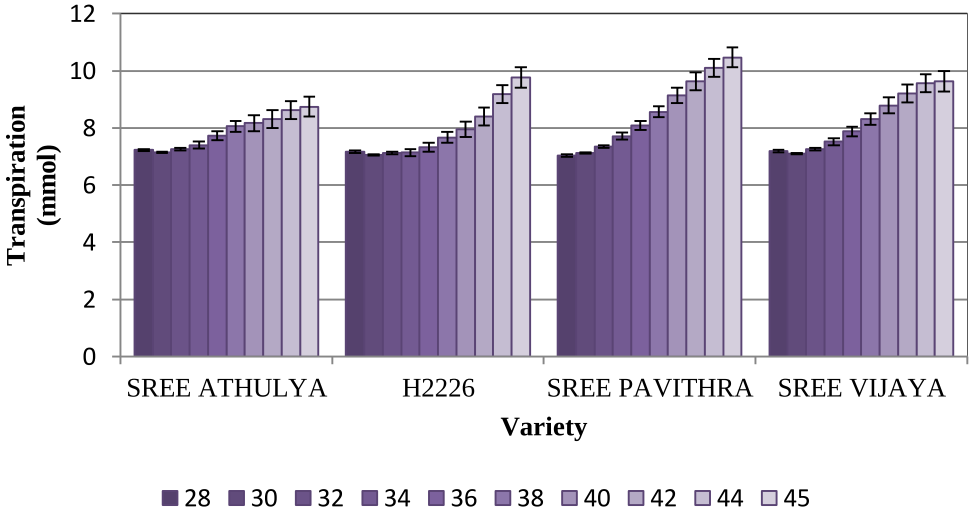

Fig. 4.18 Changes in transpiration at different temperatures at 600 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

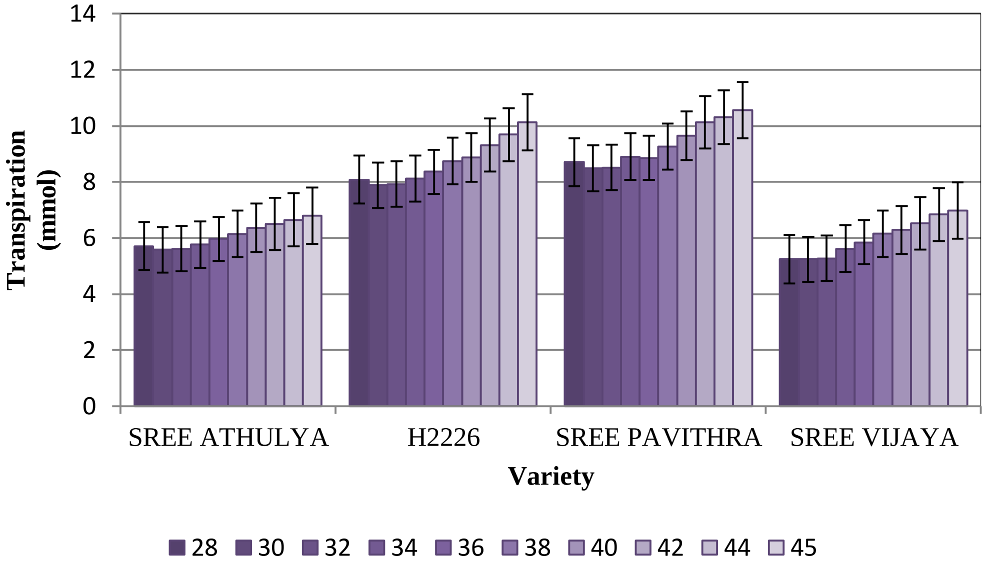

Fig. 4.19 Changes in transpiration at different temperatures at 800 ppm CO2, in cassava varieties. Error bars shows St. Dev.

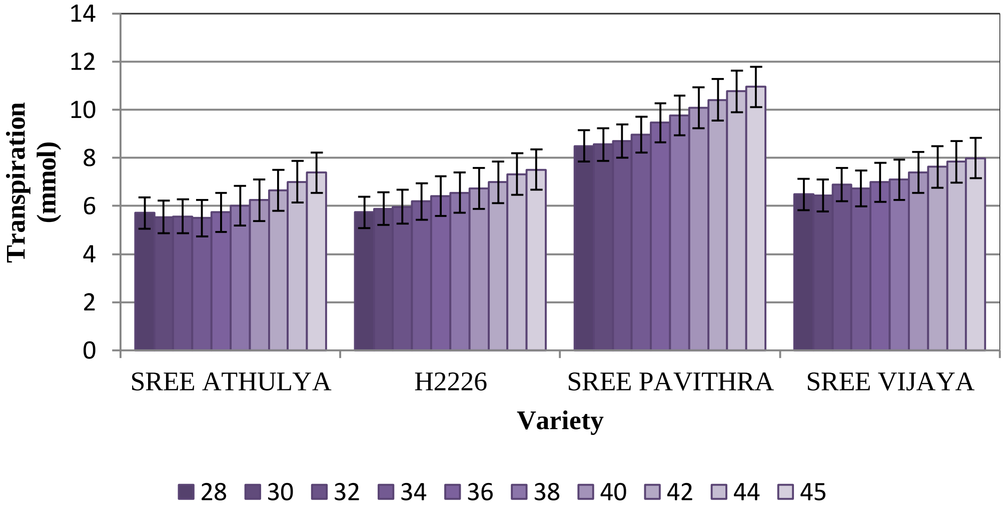

Fig. 4.20 Changes in transpiration at different temperatures at 1000 ppm CO_2 in cassava varieties. Error bars shows St. Dev.

4.1.9 Changes in photosynthetic rate of sweet potato varieties as affected by WDS under eCO_2

The *Pn* was recorded in 5th to 10th leaf of four sweet potato varieties during short term (10 minutes) exposure to CO_2 concentrations *viz.* 400, 600, 800 and 1000 ppm at 30°C and 1500 µmol/m^2/s PPFD inside controlled climate cuvette using a portable photosynthesis system under water deficit stress (WDS) and WDS free conditions. The *Pn* rate steadily increased with increase in CO_2 under WDS free conditions as well as under WDS (Fig. 4.21).

At 400 ppm CO_2, *Pn* varied from 23.31µmol CO_2/m^2/s in the variety Sree Kanaka to 29.83 µmol CO_2/m^2/s in the variety Sree Arun under WDS free conditions. At 600 ppm CO_2, *Pn* varied from 28.98 µmol CO_2/m^2/s in the variety Sree Kanaka to 31.58 µmol CO_2/m^2/s in the variety Sree Arun. At 800 ppm CO_2, *Pn* varied from 30.60 µmol CO_2/m^2/s in the variety Bhu Krishna to 33.19 µmol CO_2/m^2/s in the variety Sree Arun. At 1000 ppm CO_2, *Pn* varied from 29.45 µmol CO_2/m^2/s in the variety Bhu Krishna to 40.14 µmol CO_2/m^2/s in the variety Sree Kanaka. Sweet potato varieties exhibited an increase of 12.18 to 72.23% in *Pn* rate in plants under irrigated WDS free conditions at eCO_2 (1000 ppm) compared to ambient CO_2 (400 ppm). However the per cent increase in *Pn* at eCO_2 for every 200 ppm between 400 to 1000 ppm declined. But in varieties Sree Arun and Sree Kanaka increment rate was increased from 800 to 1000 ppm by 5.09% to 7.62% and 24.35% to 28.14% under WDS free conditions.

Under WDS conditions, *Pn* varied from 6.33 µmol CO_2/m^2/s in the variety Sree Arun to 17.04 µmol CO_2/m^2/s in the variety Bhu Krishna at 400 ppm CO_2. At 600 ppm CO_2, *Pn* varied from 5.87 µmol CO_2/m^2/s in the variety Sree Kanaka to 24.96 µmol CO_2/m^2/s in the variety Bhu Krishna. At 800 ppm CO_2, *Pn* varied from 11.21 µmol CO_2/m^2/s in the variety Sree Kanaka to 24.16 µmol CO_2/m^2/s in the variety Bhu Krishna. At 1000 ppm CO_2, *Pn* varied from 15.89 µmol CO_2/m^2/s in the variety Sree Kanaka to 28.39 µmol CO_2/m^2/s in the variety Bhu Krishna. Sweet potato varieties exhibited 66.58 to 171.58% increase in *Pn* rate under WDS conditions at eCO_2 (1000 ppm) compared to ambient CO_2 (400 ppm).Under WDS all varieties except Bhu Krishna exhibited an increase in *Pn* rate from 600 to 1000 ppm CO_2. The variety Bhu Krishna had a decrease in *Pn* at 1000 ppm (29.45 µmol $CO_2/m^2/s$) compared to *Pn* at 800 ppm (30.60 µmol $CO_2/m^2/s$).

Under WDS, *Pn* rate decreased significantly compared to WDS free conditions. At 400 ppm CO_2, per cent decrease in *Pn* rate under WDS varied from 35.07% in the variety Bhu Krishna to 63.03% in the variety Sree Kanaka. At 600 ppm CO_2, per cent decrease in *Pn* rate under WDS varied from 14.81% in the variety Bhu Krishna to 55.01% in the variety Sree Kanaka. At 800 ppm CO_2, per cent decrease in *Pn* rate under WDS varied from 21.06% in the variety Bhu Krishna to 64.19% in the variety Sree Kanaka. At 1000 ppm CO_2, per cent decrease in *Pn* rate under WDS varied from 3.59% in the variety Bhu Krishna to 60.40% in the variety Sree Kanaka.

Maximum *Pn* rate in plants under WDS free conditions and plants under WDS conditions was recorded at 1000 ppm CO_2. The changes in *Pn* across CO_2 concentrations (CD=0.727), varieties (CD=0.727) as well as WDS free/WDS conditions (CD=0.514) were statistically significant. The interaction between CO_2 concentrations and the variety (CD=1.453), CO_2 concentrations and WDS free/WDS conditions (CD=1.028) as well as the variety and WDS free/WDS conditions (CD=1.028) have significant effect on *Pn* of sweet potato. *Pn* significantly depend on the interaction between CO_2 concentrations, the variety and WDS free/WDS conditions (CD=2.055).

Table 4.21. Photosynthetic rate (CO_2 µmol/m^2/s) of sweet potato varieties as affected by WDS under eCO_2

Variety x **CO_2 (ppm)**	**Irrigation Condition**	
	WDS Free	**WDS**
Sree Arun 400	29.54	15.87
Sree Arun 600	31.65	20.84
Sree Arun 800	33.44	22.79
Sree Arun 1000	35.93	21.86
Bhu Krishna 400	26.73	17.17
Bhu Krishna 600	29.50	24.83
Bhu Krishna 800	30.45	24.19
Bhu Krishna 1000	29.54	27.96
Kanhangad 400	27.04	9.95
Kanhangad 600	31.68	14.25
Kanhangad 800	32.78	19.95
Kanhangad 1000	33.44	27.05
Sree Kanaka 400	23.35	6.39
Sree Kanaka 600	28.94	6.15
Sree Kanaka 800	31.43	11.07
Sree Kanaka 1000	40.12	15.90
Variety: CD=0.727	CO_2 : CD=0.727	Irrigation: CD=0.514
Variety x CO_2: CD=1.453	CO_2 x Irrigation: CD=1.028	Variety x Irrigation: CD=1.028
CO_2 x Variety x Irrigation: CD=2.055		

4.1.10. Changes in stomatal conductance of sweet potato varieties as affected by WDS under eCO_2

The g_s increased between 400 ppm and 1000 ppm in the variety Sree Kanaka. Whereas g_s decreased in all other varieties between 400 ppm and 1000 ppm CO_2 under WDS free conditions. Maximum stomatal conductance (gs) was exhibited at 400 ppm CO_2 by the variety Sree Arun, at 600 ppm CO_2 by the variety Bhu Krishna and Kanhangad and at 1000 ppm CO_2 by the variety Sree Kanaka (Fig. 4.22). At 400 ppm CO_2, g_s varied from 0.24 mol $H_2O/m^2/s$ in the variety Sree Kanaka to 0.64 mol $H_2O/m^2/s$ in the variety Sree Arun under WDS free conditions. At 600 ppm CO_2, g_s varied from 0.29 mol $H_2O/m^2/s$ in the variety Sree Kanaka to 0.76 mol $H_2O/m^2/s$ in the variety Bhu Krishna. At 800 ppm CO_2, g_s varied from 0.28 mol $H_2O/m^2/s$ in the variety Sree Kanaka to 0.69 mol $H_2O/m^2/s$ in the variety Bhu Krishna. At 1000 ppm CO_2, g_s varied from 0.35 mol $H_2O/m^2/s$ in the variety Sree Kanaka to 0.55 mol $H_2O/m^2/s$ in the variety Bhu Krishna.

Under WDS conditions, g_s increased between 400 ppm and 1000 ppm in the variety Kanhangad, whereas g_s decreased in all other varieties between 400 ppm and 1000 ppm CO_2. At 400 ppm CO_2, *gs* varied from 0.07 mol $H_2O/m^2/s$ in the variety Sree Kanaka to 0.19 mol $H_2O/m^2/s$ in the variety Sree Arun. At 600 ppm CO_2, g_s varied from 0.02 mol $H_2O/m^2/s$ in the variety Sree Kanaka to 0.18 mol $H_2O/m^2/s$ in the variety Sree Arun. At 800 ppm CO_2, g_s varied from 0.06 mol $H_2O/m^2/s$ in the variety Sree Kanaka to 0.50 mol $H_2O/m^2/s$ in the variety Kanhangad. At 1000 ppm CO_2, g_s changed from 0.05 mol $H_2O/m^2/s$ in the variety Sree Kanaka to 0.21 mol $H_2O/m^2/s$ in the variety Kanhangad.

Under WDS, g_s decreased significantly compared to WDS free conditions. Under WDS at 400 ppm g_s decreased from 68.38% in the variety Sree Kanaka to 82.03% in the variety Kanhangad. At 600 ppm CO_2, under WDS g_s decreased from 58.50% in the variety Kanhangad to 90.48% in the variety Sree Kanaka. At 800 ppm CO_2, g_s decreased from 16.40% in the variety Kanhangad to 79.34% in the variety Bhu Krishna under WDS. At 1000 ppm CO_2, g_s decreased from 65.01% in the variety Kanhangad to 82.15% in the variety Sree Arun.

The changes in g_s across CO_2 concentrations (CD=0.025), varieties (CD=0.025) as well as WDS free/WDS conditions (CD=0.018) were statistically significant. The interaction between CO_2 concentrations and the variety (CD=0.050), CO_2 concentrations and WDS free/WDS conditions (CD=0.036) as well as the variety and WDS free/WDS conditions (CD=0.036) have significant effect on *g_s* of sweet potato. *gs* significantly depend on the interaction between CO_2 concentrations, the variety and WDS free/WDS conditions (CD=0.071).

Table 4.22. Stomatal conductance (mol H_2O/m^2 /s) of sweet potato varieties as affected by WDS under eCO_2

Variety x **CO_2 (ppm)**	**Irrigation Condition**	
	WDS Free	**WDS**
Sree Arun 400	0.65	0.20
Sree Arun 600	0.58	0.18
Sree Arun 800	0.50	0.14
Sree Arun 1000	0.51	0.11
Bhu Krishna 400	0.54	0.12
Bhu Krishna 600	0.77	0.18
Bhu Krishna 800	0.72	0.11
Bhu Krishna 1000	0.56	0.10
Kanhangad 400	0.59	0.11
Kanhangad 600	0.65	0.25
Kanhangad 800	0.50	0.50
Kanhangad 1000	0.53	0.21
Sree Kanaka 400	0.24	0.08
Sree Kanaka 600	0.28	0.02
Sree Kanaka 800	0.28	0.07
Sree Kanaka 1000	0.36	0.05
Variety: CD=0.025	CO_2 : CD=0.025	Irrigation: CD=0.018
Variety x CO_2: CD=0.050	CO_2 x Irrigation: CD=0.018	Variety x Irrigation: CD=0.018
CO_2 x Variety x Irrigation: CD=0.036		

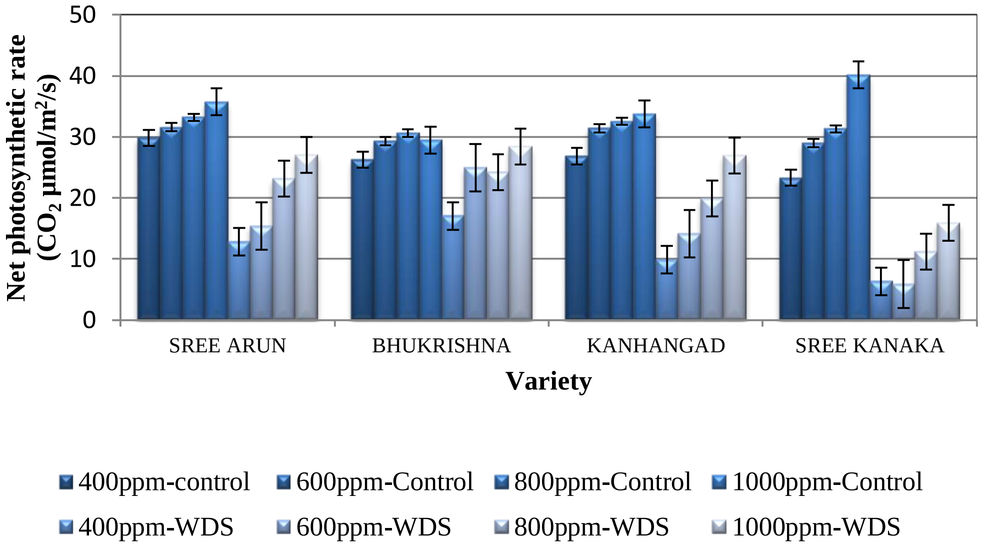

Fig. 4.21. Changes in photosynthetic rate at different CO_2 concentrations under WDS free conditions and WDS conditions in sweet potato varieties. The error bars indicates St. Dev.

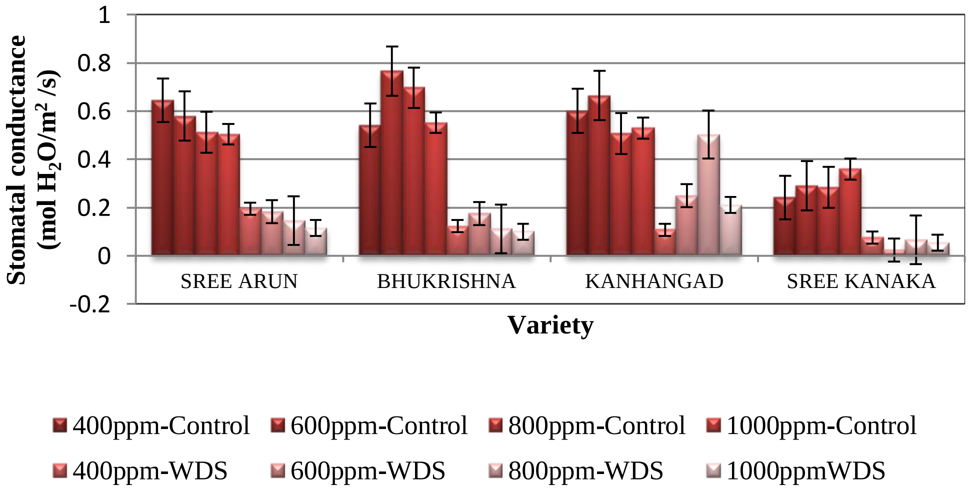

Fig. 4.22. Changes in stomatal conductance at different CO_2 concentrations under WDS free conditions and WDS conditions in sweet potato varieties. The error bars indicates St. Dev.

4.1.11. Changes in intercellular CO_2 concentration of sweet potato varieties as affected by WDS under eCO2.

The *Ci* of all varieties steadily increased with increase in CO_2 under WDS free conditions as well as WDS (Fig. 4.23). Maximum *Ci* was recorded at 1000 ppm CO_2 in WDS free plants as well as plants under WDS conditions. At 400 ppm CO_2, *Ci* varied from 192.67 ppm in the variety Sree Kanaka to 314.95 ppm in the variety Kanhangad under WDS free conditions. At 600 ppm CO_2, *Ci* varied from 334.04 ppm in the variety Sree Kanaka to 569.97 ppm in the variety Sree Arun. At 800 ppm CO_2, *Ci* varied from 355.98 ppm in the variety Sree Kanaka to 722.43 ppm in the variety Bhu Krishna. At 1000 ppm CO_2, *Ci* varied from 248.64 ppm in the variety Sree Kanaka to 867.69 ppm in the variety Bhu Krishna. Sweet potato varieties exhibited 29.05% to 208.03% per cent increase in *Ci* under WDS free conditions at eCO_2 (1000 ppm) compared to ambient CO_2 (400 ppm).But Sree Kanaka recorded a decrease in *Ci* from 800 to 1000 ppm CO_2 under WDS free conditions as well as WDS.

Under WDS at 400 ppm CO_2, *Ci* varied from 232.64 ppm in the variety Sree Kanaka to 318.20 ppm in the variety Kanhangad. At 600 ppm CO_2, *Ci* varied from 282.26 ppm in the variety Sree Kanaka to 511.57 ppm in the variety Kanhangad. At 800 ppm CO_2, *Ci* varied from 425.38 ppm in the variety Sree Arun to 670.48 ppm in the variety Bhu Krishna. At 1000 ppm CO_2, *Ci* varied from 493.52 ppm in the variety Bhu Krishna to 674.59 ppm in the variety Kanhangad. Sweet potato varieties exhibited 81.03% to 121.11% increase in *Ci* under WDS conditions at eCO_2 (1000 ppm) compared to ambient CO_2 (400 ppm).

Varieties Sree Arun and Bhu Krishna exhibited higher *Ci* under WDS free conditions compared to WDS conditions. But Kanhangad and Sree Kanaka exhibited higher *Ci* under WDS conditions than WDS free conditions. At 400 ppm CO_2, per cent decrease in *Ci* under WDS was 3.21% in the variety Bhu Krishna and 13.34% in the variety Sree Arun. Per cent increase in *Ci* under WDS was 1.03% in the variety Kanhangad and 20.74% in the variety Sree Kanaka. At

600 ppm CO_2, per cent decrease in *Ci* under WDS was 15.4% in the variety Bhu Krishna, 22.26% in the variety Sree Arun and 46.49% in the variety Sree Kanaka. Per cent increase in *Ci* under WDS was 62.42% in the variety Kanhangad. At 800 ppm CO_2, per cent decrease in *Ci* under WDS was 50.95% in the variety Sree Arun and 138.02% in the variety Bhu Krishna. Per cent increase in *Ci* under WDS was 98.89% in the variety Kanhangad and 197.19% in the variety Sree Kanaka. At 1000 ppm CO_2, per cent decrease in *Ci* under WDS was 86.81% in the variety Sree Arun and 75.20% in the variety Bhu Krishna. Per cent increase in *Ci* under WDS was 114.19% in the variety Kanhangad and 166.99% in the variety Sree Kanaka.

The changes in *Ci* across CO_2 concentrations (CD=21.705) as well as varieties (CD=21.705) were statistically significant. Whereas changes in *Ci* across WDS free/WDS conditions was statistically insignificant (CD=15.348). The interaction between CO_2 concentrations and the variety (CD=43.410), CO_2 concentrations and WDS free/WDS conditions (CD=30.696) as well as the variety and WDS free/WDS conditions (CD=30.696) have significant effect on *Ci* of sweet potato. *Ci* significantly depend on the interaction between CO_2 concentrations, the variety and WDS free/WDS conditions (CD=61.391).

Table 4.23. Intercellular CO_2 concentration (ppm) of sweet potato varieties as affected by WDS under eCO_2

Variety x CO_2 (ppm)	**Irrigation Condition**	
	WDS Free	**WDS**
Sree Arun 400	280.47	240.78
Sree Arun 600	459.90	345.94
Sree Arun 800	584.94	416.31
Sree Arun 1000	828.59	527.64
Bhu Krishna 400	280.50	271.13
Bhu Krishna 600	503.72	326.76
Bhu Krishna 800	689.41	670.05
Bhu Krishna 1000	868.74	490.57
Kanhangad 400	316.33	320.25
Kanhangad 600	378.70	510.49
Kanhangad 800	472.59	623.32
Kanhangad 1000	519.22	667.22
Sree Kanaka 400	198.00	236.24
Sree Kanaka 600	337.77	286.95
Sree Kanaka 800	356.75	586.75
Sree Kanaka 1000	248.62	511.12
Variety: CD=21.705	CO_2 : CD=21.705	Irrigation: NS
Variety x CO_2: CD=43.410	CO_2 x Irrigation: CD=30.696	Variety x Irrigation: CD=30.696
CO_2 x Variety x Irrigation: CD=61.391		

4.1.12 Changes in transpiration rate of sweet potato varieties as affected by WDS under eCO_2

Plants under WDS free conditions exhibited higher *Tr* rate than that of plants under WDS conditions (Fig. 4.24). At 400 ppm CO_2, *Tr* varied from 6.67 mmol in the variety Kanhangad to 8.09 mmol in the variety Sree Arun under

WDS free conditions. At 600 ppm CO_2, *Tr* varied from 6.47 mmol in the variety Sree Arun to 7.46 mmol in the variety Sree kanaka. At 800 ppm CO_2, *Tr* varied from 5.62 mmol in the variety Sree Kanaka to 7.30 mmol in the variety Bhu Krishna. At 1000 ppm CO_2, *Tr* varied from 2.29 mmol in the variety Sree Kanaka to 6.76 mmol in the variety Sree Arun under WDS free conditions.

Under WDS *Tr* varied from 2.50 mmol in the variety Sree Kanaka to 5.84 mmol in the variety Bhu Krishna at 400 ppm CO_2. At 600 ppm CO_2, *Tr* varied from 2.45 mmol in the variety Sree Kanaka to 4.25 mmol in the variety Kanhangad. At 800 ppm CO_2, *Tr* varied from 2.67 mmol in the variety Sree Kanaka to 4.25 mmol in the variety Kanhangad. At 1000 ppm CO_2, *Tr* varied from 2.76 mmol in the variety Sree Kanaka to 5.69 mmol in the variety Kanhangad.

At 400 ppm CO_2, per cent decrease in *Tr* rate under WDS varied from 16.97% in the variety Kanhangad to 66.40% in the variety Sree kanaka. At 600 ppm CO_2, per cent decrease in *Tr* rate under WDS varied from 26.98% in the variety Bhu Krishna to 67.09% in the variety Sree Kanaka. At 800 ppm CO_2, per cent decrease in *Tr* rate under WDS varied from 31.67% in the variety Kanhangad to 64.18% in the variety Sree Kanaka. At 1000 ppm CO_2, per cent decrease in *Tr* rate under WDS varied from 14.55% in the variety Kanhangad to 62.90% in the variety Sree Kanaka.

The changes in *Tr* across CO_2 concentrations (CD=0.210), varieties (CD=0.210) as well as WDS free/WDS conditions (CD=0.148) were statistically significant. The interaction between CO_2 concentrations and the variety (CD=0.420), CO_2 concentrations and WDS free/WDS conditions (CD=0.297) as well as the variety and WDS free/WDS conditions (CD=0.297) have significant effect on *Tr* of sweet potato. *Tr* significantly depend on the interaction between CO_2 concentrations, the variety and WDS free/WDS conditions (CD=0.594).

Table 4.24. Transpiration rate (mmol) of sweet potato varieties as affected by WDS under eCO_2

Variety x **CO_2 (ppm)**	**Irrigation Condition**	
	WDS Free	**WDS**
Sree Arun 400	8.01	4.54
Sree Arun 600	6.32	4.62
Sree Arun 800	6.09	4.13
Sree Arun 1000	7.39	3.60
Bhu Krishna 400	7.16	5.83
Bhu Krishna 600	6.96	5.33
Bhu Krishna 800	6.73	3.83
Bhu Krishna 1000	5.75	3.68
Kanhangad 400	6.59	5.55
Kanhangad 600	6.77	4.26
Kanhangad 800	5.87	4.61
Kanhangad 1000	5.68	5.73
Sree Kanaka 400	7.48	2.55
Sree Kanaka 600	7.46	2.41
Sree Kanaka 800	5.62	2.70
Sree Kanaka 1000	2.56	2.76
Variety: CD=0.210	CO_2 : CD=0.210	Irrigation: CD=0.148
Variety x CO_2: CD=0.420	CO_2 x Irrigation: CD=0.297	Variety x Irrigation: CD=0.297
CO_2 x Variety x Irrigation: CD=0.594		

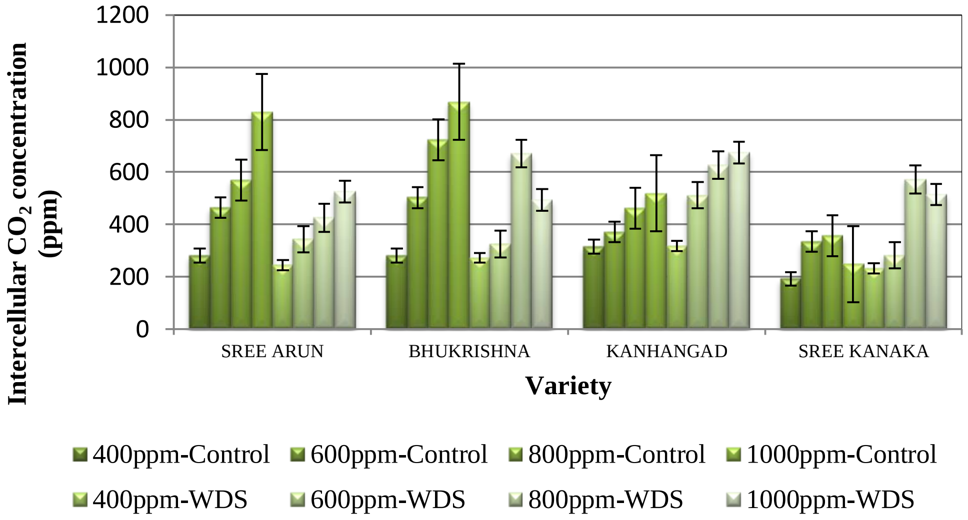

Fig. 4.23. Changes in intercellular CO_2 concentration at different CO_2 concentrations under WDS free conditions and WDS conditions in sweet potato varieties. The error bars indicates St. Dev.

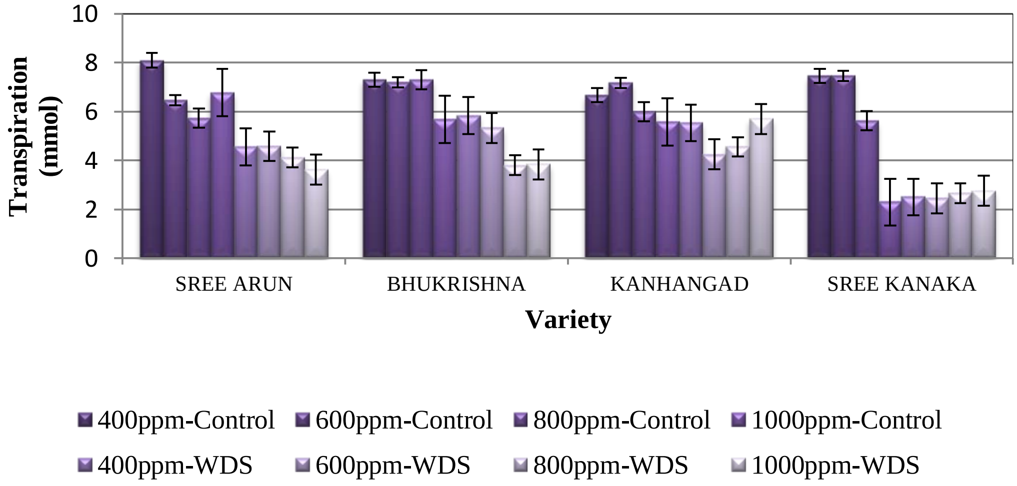

Fig. 4.24. Changes in transpiration rate at different CO_2 concentrations under WDS free conditions and WDS conditions in sweet potato varieties. The error bars indicates St. Dev.

4.1.13. Changes in photosynthetic rate of sweet potato varieties as affected by temperature under eCO$_2$

The *Pn* was recorded in 5th to 10th leaf of four sweet potato varieties during short term (10 minutes) exposure to CO$_2$ concentrations *viz.* 400, 600, 800 and 1000 ppm at 28, 30, 32, 34, 36, 38, 40, 42, 44 and 45°C and 1500 µmol/m^2/s PPFD inside controlled climate cuvette in a portable photosynthesis system.

At 400 ppm CO$_2$, *Pn* decreased from 26.88 µmol CO$_2$/m^2/s at 28°C to 26.78 µmol CO$_2$/m^2/s at 45°C in the variety Sree Arun, but increased from 23.39 µmol CO$_2$/m^2/s to 28.27 µmol CO$_2$/m^2/s in the variety Bhu Krishna, 29.45 µmol CO$_2$/m^2/s to 30.10 µmol CO$_2$/m^2/s in the variety Kanhangad and 24.44 µmol CO$_2$/m^2/s to 29.60 µmol CO$_2$/m^2/s in the variety Sree Kanaka (Fig. 4.25). In the variety Sree Arun the decrease in *Pn* rate at 45°C was 0.35% relative to 28°C. The per cent increase varied from 2.22 to 21.12% between 28 and 45°C in other varieties.

At 600 ppm CO$_2$, *Pn* increased from 25.97 µmol CO$_2$/m^2/s to 27.08 µmol CO$_2$/m^2/s in the variety Sree Arun, from 29.65 µmol CO$_2$/m^2/s to 34.19 µmol CO$_2$/m^2/s in the variety Bhu Krishna, from 30.76 µmol CO$_2$/m^2/s to 34.65 µmol CO$_2$/m^2/s in the variety Kanhangad and from 28.16 µmol CO$_2$/m^2/s to 30.22 µmol CO$_2$/m^2/s in the variety Sree Kanaka (Fig. 4.26). *Pn* rate increased in all varieties across temperatures and the per cent increase varied from 4.26% to 15.30% at 45°C relative to 28°C.

At 800 ppm CO$_2$, *Pn* rate decreased from 32.14 µmol CO$_2$/m^2/s to 31.36 µmol CO$_2$/m^2/s in the variety Sree Arun, but increased from 28.70 µmol CO$_2$/m^2/s to 35.15 µmol CO$_2$/m^2/s in the variety Bhu Krishna, from 28.76 µmol CO$_2$/m^2/s to 33.60 µmol CO$_2$/m^2/s in the variety Kanhangad and from 28.28 µmol CO$_2$/m^2/s to 34.78 µmol CO$_2$/m^2/s in the variety Sree Kanaka (Fig. 4.27). The variety Bhu Krishna (22.47%), Kanhangad (16.83) and Sree Kanaka (22.99%) had an increment in *Pn* rate at temperatures between 28 and 45°C while Sree Arun (2.40%) showed a decrease.

At 1000 ppm CO_2, *Pn* changed from 36.67 µmol $CO_2/m^2/s$ to 36.91 µmol CO_2 /m^2/s in the variety Sree Arun, 26.44 µmol $CO_2/m^2/s$ to 31.40 µmol $CO_2/m^2/s$ in the variety Bhu Krishna, 28.34 µmol $CO_2/m^2/s$ to 30.67 µmol $CO_2/m^2/s$ in the variety Kanhangad and 38.73 µmol $CO_2/m^2/s$ to 41.36 µmol $CO_2/m^2/s$ in the variety Sree Kanaka (Fig. 4.28). At 1000 ppm CO_2, all varieties had an increase in *Pn* rate across temperature and the per cent increase was 0.65% to 18.76% between 28 and 45^{o}C.

Sree Arun exhibited maximum *Pn* rate at a temperature range of 36 to 40^{o}C in 400, 600, and 800 CO_2 concentrations and at 44 to 45^{o}C in 1000 ppm. All other varieties have maximum *Pn* rate at a temperature range of 42 to 45^{o}C at 400, 600, 800 and 1000 ppm CO_2. At each CO_2 concentration differences in the *Pn* rate across 28 to 45^{o}C temperatures were statistically insignificant. However *Pn* significantly changed across CO_2 concentrations (CD=0.326), varieties (CD=0.326) as well as temperature (CD=0.516) was statistically significant. The interactive effect among temperature and the variety (CD=1.032) as well as CO_2 and the variety (CD=0.653) was significant. The interaction between CO_2, the variety and temperature have not significant effect on *Pn*.

Table 4.25. Changes in photosynthetic rate (CO_2 µmol/m^2/s) of sweet potato varieties as affected by temperature under eCO_2 in the variety Sree Arun

<table>
<tr><th rowspan="2">Temperature (^{o}C)</th><th colspan="4">Photosynthetic rate (CO_2 µmol/m^2/s)</th></tr>
<tr><th>400ppm CO_2</th><th>600ppm CO_2</th><th>800ppm CO_2</th><th>1000ppm CO_2</th></tr>
<tr><td>28</td><td>26.88</td><td>25.97</td><td>32.14</td><td>36.67</td></tr>
<tr><td>30</td><td>26.92</td><td>26.01</td><td>32.00</td><td>35.61</td></tr>
<tr><td>32</td><td>27.05</td><td>26.36</td><td>32.00</td><td>34.60</td></tr>
<tr><td>34</td><td>27.53</td><td>25.88</td><td>31.82</td><td>34.53</td></tr>
<tr><td>36</td><td>27.59</td><td>25.72</td><td>31.24</td><td>34.66</td></tr>
<tr><td>38</td><td>28.07</td><td>26.12</td><td>30.92</td><td>34.91</td></tr>
<tr><td>40</td><td>27.99</td><td>26.50</td><td>30.92</td><td>35.13</td></tr>
<tr><td>42</td><td>27.23</td><td>26.91</td><td>31.37</td><td>36.29</td></tr>
<tr><td>44</td><td>26.78</td><td>27.19</td><td>31.57</td><td>36.51</td></tr>
<tr><td>45</td><td>26.79</td><td>27.08</td><td>31.37</td><td>36.92</td></tr>
<tr><td colspan="2">Variety: CD=0.326</td><td colspan="2">CO_2 : CD=0.326</td><td>Temperature: CD=0.516</td></tr>
<tr><td colspan="2">Variety x CO_2: CD=0.653</td><td colspan="2">CO_2 x Temperature: NS</td><td>Variety x Temperature: CD=1.032</td></tr>
<tr><td colspan="5">CO_2 x Variety x Temperature: NS</td></tr>
</table>

Table 4.26. Changes in photosynthetic rate (CO_2 µmol/m^2/s) of sweet potato varieties as affected by temperature under eCO_2 in the variety Bhu Krishna

<table>
<tr><th rowspan="2">Temperature (^{o}C)</th><th colspan="4">Photosynthetic rate (CO_2 µmol/m^2/s)</th></tr>
<tr><th>400ppm CO_2</th><th>600ppm CO_2</th><th>800ppm CO_2</th><th>1000ppm CO_2</th></tr>
<tr><td>28</td><td>23.39</td><td>29.65</td><td>28.71</td><td>26.44</td></tr>
<tr><td>30</td><td>23.67</td><td>29.38</td><td>28.83</td><td>27.12</td></tr>
<tr><td>32</td><td>24.49</td><td>29.41</td><td>29.53</td><td>27.24</td></tr>
<tr><td>34</td><td>25.52</td><td>29.66</td><td>30.12</td><td>27.98</td></tr>
<tr><td>36</td><td>25.84</td><td>30.24</td><td>30.81</td><td>27.79</td></tr>
<tr><td>38</td><td>27.07</td><td>30.62</td><td>30.53</td><td>28.16</td></tr>
<tr><td>40</td><td>27.78</td><td>31.28</td><td>31.48</td><td>28.17</td></tr>
<tr><td>42</td><td>28.48</td><td>32.39</td><td>32.92</td><td>28.22</td></tr>
<tr><td>44</td><td>28.70</td><td>34.01</td><td>34.35</td><td>29.71</td></tr>
<tr><td>45</td><td>28.27</td><td>34.19</td><td>35.16</td><td>31.40</td></tr>
<tr><td colspan="2">Variety: CD=0.326</td><td colspan="2">CO_2 : CD=0.326</td><td>Temperature: CD=0.516</td></tr>
<tr><td colspan="2">Variety x CO_2: CD=0.653</td><td colspan="2">CO_2 x Temperature: NS</td><td>Variety x Temperature: CD=1.032</td></tr>
<tr><td colspan="5">CO_2 x Variety x Temperature: NS</td></tr>
</table>

Table 4.27. Changes in photosynthetic rate (CO_2 µmol/m^2/s) of sweet potato varieties as affected by temperature under eCO_2 in the variety Kanhangad

Temperature (°C)	**Photosynthetic rate (CO_2 µmol/m^2/s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	29.45	30.77	28.77	28.34
30	29.45	30.50	29.09	27.71
32	29.95	31.61	30.00	27.57
34	30.75	32.13	30.17	26.90
36	30.79	32.83	31.11	27.18
38	31.28	33.02	31.70	27.00
40	31.19	33.93	32.30	27.89
42	31.40	33.57	33.21	28.57
44	30.84	34.69	33.13	29.73
45	30.11	34.65	33.61	30.67

Variety: CD=0.326	CO_2 : CD=0.326	Temperature: CD=0.516
Variety x CO_2: CD=0.653	CO_2 x Temperature: NS	Variety x Temperature: CD=1.032
CO_2 x Variety x Temperature: NS		

Table 4.28. Changes in photosynthetic rate (CO_2 µmol/m^2/s) of sweet potato varieties as affected by temperature under eCO_2 in the variety Sree Kanaka

Temperature (°C)	**Photosynthetic rate (CO_2 µmol/m^2/s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	24.44	28.17	28.29	38.74
30	24.48	28.36	29.65	38.02
32	24.20	29.62	29.93	38.45
34	24.22	30.43	31.52	38.86
36	24.80	30.81	32.53	39.67
38	25.36	31.89	33.63	40.11
40	26.34	29.80	33.54	40.73
42	27.77	31.04	34.89	41.44
44	29.00	30.03	34.42	41.53
45	29.61	30.23	34.78	41.36

Variety: CD=0.326	CO_2 : CD=0.326	Temperature: CD=0.516
Variety x CO_2: CD=0.653	CO_2 x Temperature: NS	Variety x Temperature: CD=1.032
CO_2 x Variety x Temperature: NS		

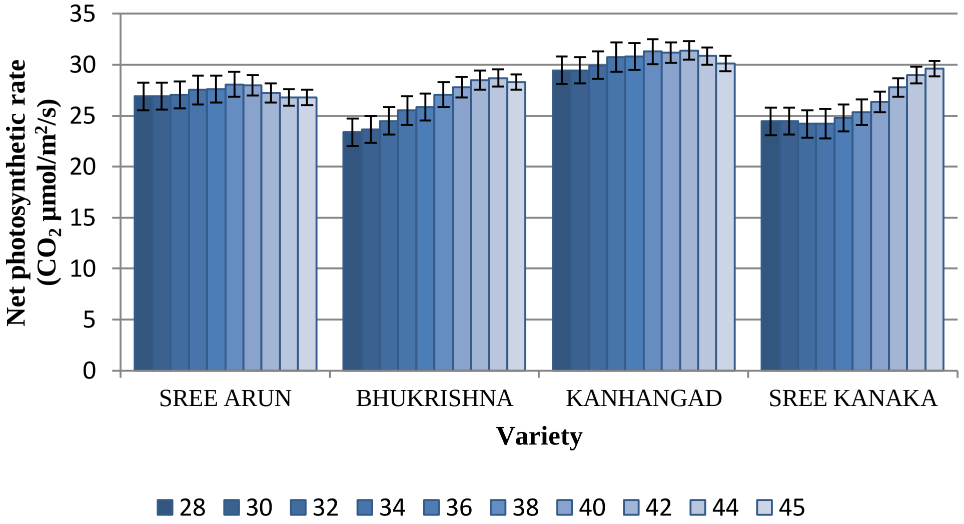

Fig. 4.25 Changes in photosynthetic rate at different temperatures at 400 ppm CO$_2$ in sweet potato varieties. Error bars shows St. Dev.

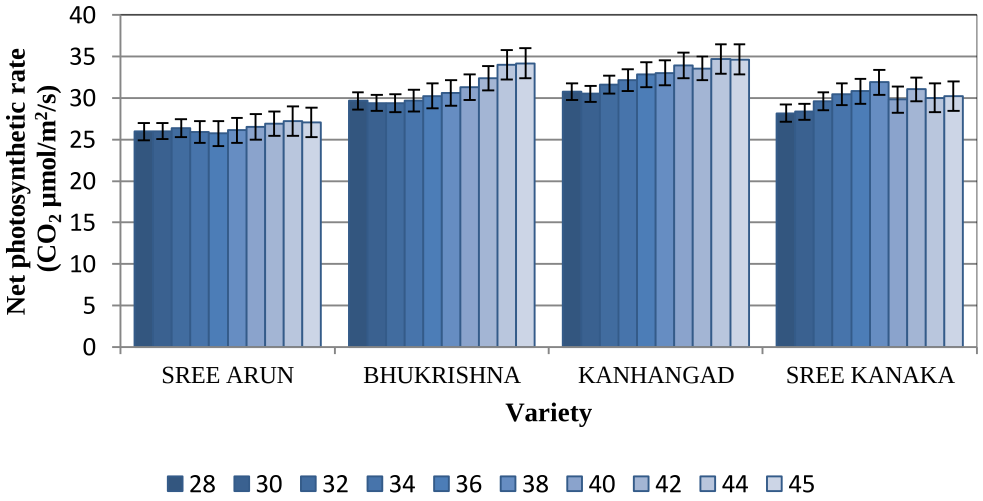

Fig. 4.26 Changes in photosynthetic rate at different temperatures at 600 ppm CO$_2$ in sweet potato varieties. Error bars shows St. Dev.

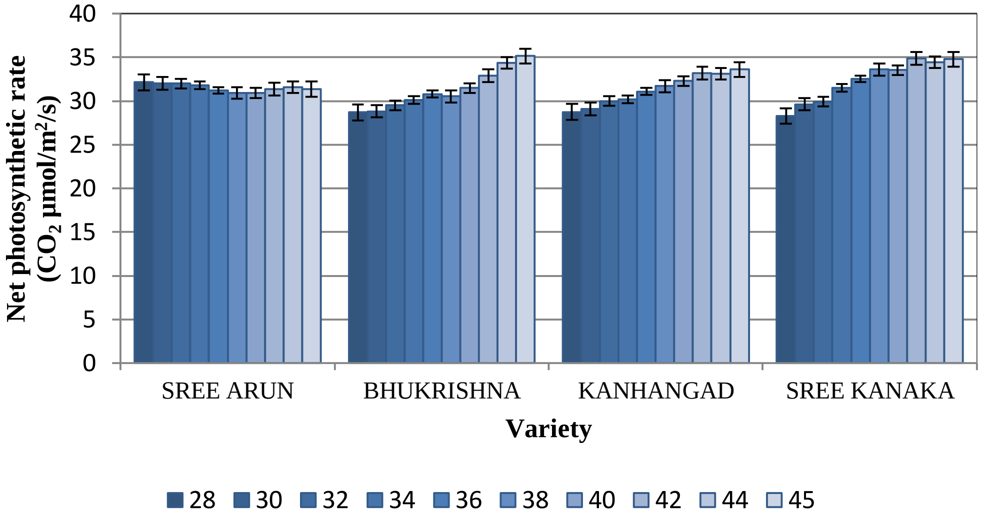

Fig. 4.27 Changes in photosynthetic rate at different temperatures at 800 ppm CO2, in sweet potato varieties. Error bars shows St. Dev.

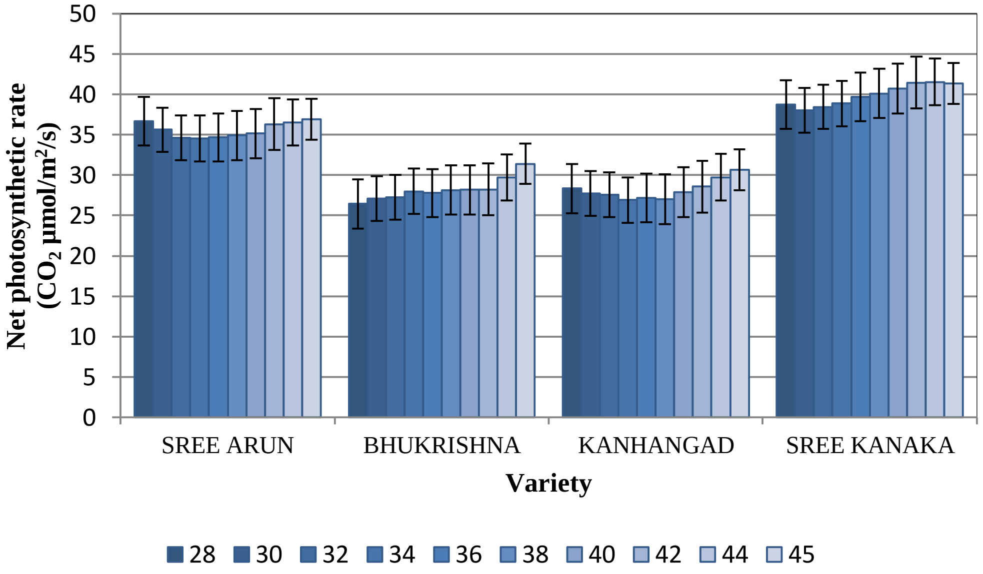

Fig. 4.28 Changes in photosynthetic rate at different temperatures at 1000 ppm CO_2 in sweet potato varieties. Error bars shows St. Dev.

4.1.14. Changes in stomatal conductance of sweet potato varieties as affected by temperature under eCO_2

The g_s increased in Sree Kanaka at 400, 800 and 1000 ppm CO_2 and at 400 ppm CO_2 in Kanhangad from 28 to 45^{o}C. In other varieties the *gs* decreased with increase in temperature at every CO_2 concentrations. All varieties exhibited maximum g_s at a temperature range of 28 to 30^{o}C in each CO_2 concentrations except the variety Sree Kanaka, which has maximum g_s at 42 to 45^{o}C.

At 400 ppm CO_2, g_s decreased from 1.47 mol $H_2O/m^2/s$ at 28^{o}C to 0.17 mol $H_2O/m^2/s$ at 45^{o}C in the variety Sree Arun and from 0.71 mol $H_2O/m^2/s$ to 0.39 mol $H_2O/m^2/s$ in the variety Kanhangad but increased from 0.44 mol $H_2O/m^2/s$ to 0.48 mol $H_2O/m^2/s$ in the variety Bhu Krishna, and from 0.29 mol $H_2O/m^2/s$ to 0.33 mol $H_2O/m^2/s$ in the variety Sree Kanaka. The per cent decrease at 45^{o}C compared to 28^{o}C was 45.19% in the variety Kanhangad and 88.34% in the variety Sree Arun (Fig. 4.29). The per cent increase in g_s at 45^{o}C was 8.23% relative to 28^{o}C in the variety Bhu Krishna and 11.77% in the variety Sree Kanaka.

At 600 ppm CO_2, g_s increased from 1.09 mol $H_2O/m^2/s$ to 0.13 mol $H_2O/m^2/s$ in the variety Sree Arun but decreased from 0.57 mol $H_2O/m^2/s$ to 0.41 mol $H_2O/m^2/s$ in the variety Bhu Krishna, from 0.77 mol $H_2O/m^2/s$ to 0.39 mol $H_2O/m^2/s$ in the variety Kanhangad and from 0.28 mol $H_2O/m^2/s$ to 027 mol $H_2O/m^2/s$ in the variety Sree Kanaka (Fig. 4.30). The per cent decrease in g_s between temperatures 28 and 45^{o}C varied from 0.89% in the variety Sree Kanaka to 87.45% in the variety Sree Arun.

At 800 ppm CO_2, *gs* decreased from 1.50 mol $H_2O/m^2/s$ to 0.13 mol $H_2O/m^2/s$ in the variety Sree Arun, from 0.59 mol $H_2O/m^2/s$ to 0.48 mol $H_2O/m^2/s$ in the variety Bhu Krishna, from 0.77 mol $H_2O/m^2/s$ to 0. 44 mol $H_2O/m^2/s$ in the variety Kanhangad and from 0.19 mol $H_2O/m^2/s$ to 0.22 mol $H_2O/m^2/s$ in the variety Sree Kanaka (Fig. 4.31). The per cent decrease in g_s between temperatures

28 and 45°C varied from 0.89% in the variety Sree Kanaka to 87.45% in the variety Sree Arun.

At 1000 ppm CO_2, g_s increased from 0.55 mol $H_2O/m^2/s$ to 0.28 mol $H_2O/m^2/s$ in the variety Sree Arun, but decreased from 0.46 mol $H_2O/m^2/s$ to 0.23 mol $H_2O/m^2/s$ in the variety Bhu Krishna, from 0.44 mol $H_2O/m^2/s$ to 0. 23 mol $H_2O/m^2/s$ in the variety Kanhangad and from 0.11 mol $H_2O/m^2/s$ to 0.18 mol $H_2O/m^2/s$ in the variety Sree Kanaka (Fig. 4.32). The per cent decrease in g_s between temperatures 28 and 45°C varied from 47.46% in the variety Sree Kanhangad to 49.50% in the variety Bhu Krishna.

At each CO_2 concentration differences in the g_s across 28 to 45°C temperatures were statistically significant (CD=0.025). g_s significantly changed across CO_2 concentrations (CD=0.0.008), varieties (CD=0.0.008) as well as temperature (CD=0.0.012). The interactive effect among temperature and the variety (CD=0.025) as well as CO_2 and the variety (CD=0.016) was also significant. g_s significantly depend on the interaction between CO_2 concentrations, the variety and temperature (CD=0.051).

Table 4.29. Changes in stomatal conductance (mol H_2O/m^2 /s) of sweet potato varieties as affected by temperature under eCO_2 in the variety Sree Arun

Temperature (°C)	**Stomatal conductance (mol H_2O/m^2 /s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	1.47	1.10	1.50	0.55
30	0.82	0.61	0.71	0.45
32	0.54	0.39	0.44	0.44
34	0.41	0.28	0.31	0.34
36	0.33	0.24	0.25	0.33
38	0.28	0.20	0.21	0.33
40	0.24	0.17	0.18	0.33
42	0.21	0.16	0.16	0.28
44	0.19	0.14	0.15	0.28
45	0.17	0.14	0.14	0.28

Variety: CD=0.008	CO_2 : CD=0.008	Temperature: CD=0.012
Variety x CO_2: CD=0.016	CO_2 x Temperature: CD=0.025	Variety x Temperature: CD=0.025
CO_2 x Variety x Temperature: CD=0.051		

Table 4.30. Changes in stomatal conductance (mol H_2O/m^2 /s) of sweet potato varieties as affected by temperature under eCO_2 in the variety Bhu Krishna

Temperature (°C)	**Stomatal conductance (mol H_2O/m^2 /s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	0.45	0.58	0.60	0.79
30	0.48	0.55	0.61	0.44
32	0.47	0.54	0.61	0.36
34	0.47	0.54	0.60	0.31
36	0.47	0.53	0.60	0.29
38	0.51	0.51	0.60	0.27
40	0.48	0.48	0.61	0.26
42	0.48	0.47	0.60	0.25
44	0.48	0.44	0.58	0.24
45	0.48	0.42	0.49	0.23

Variety: CD=0.008	CO_2 : CD=0.008	Temperature: CD=0.012
Variety x CO_2: CD=0.016	CO_2 x Temperature: CD=0.025	Variety x Temperature: CD=0.025
CO_2 x Variety x Temperature: CD=0.051		

Table 4.31. Changes in stomatal conductance (mol H_2O/m^2 /s) of sweet potato varieties as affected by temperature under eCO_2 in the variety Kanhangad

Temperature (^{o}C)	**Stomatal conductance (mol H_2O/m^2 /s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	0.71	0.77	0.77	0.44
30	0.72	0.79	0.77	0.42
32	0.66	0.67	0.67	0.39
34	0.56	0.65	0.66	0.28
36	0.55	0.56	0.55	0.28
38	0.47	0.50	0.55	0.28
40	0.45	0.50	0.45	0.28
42	0.44	0.45	0.45	0.26
44	0.39	0.39	0.44	0.23
45	0.39	0.39	0.44	0.23

Variety: CD=0.008	CO_2 : CD=0.008	Temperature: CD=0.012
Variety x CO_2: CD=0.016	CO_2 x Temperature: CD=0.025	Variety x Temperature: CD=0.025
CO_2 x Variety x Temperature: CD=0.051		

Table 4.32. Changes in stomatal conductance (mol H_2O/m^2 /s) of sweet potato varieties as affected by temperature under eCO_2 in the variety Sree Kanaka

Temperature (^{o}C)	**Stomatal conductance (mol H_2O/m^2 /s)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	0.30	0.28	0.19	0.12
30	0.28	0.27	0.20	0.10
32	0.23	0.25	0.20	0.12
34	0.21	0.23	0.20	0.14
36	0.20	0.22	0.19	0.14
38	0.20	0.23	0.18	0.16
40	0.21	0.22	0.19	0.16
42	0.26	0.22	0.20	0.17
44	0.31	0.26	0.21	0.18
45	0.33	0.27	0.23	0.18

Variety: CD=0.008	CO_2 : CD=0.008	Temperature: CD=0.012
Variety x CO_2: CD=0.016	CO_2 x Temperature: CD=0.025	Variety x Temperature: CD=0.025
CO_2 x Variety x Temperature: CD=0.051		

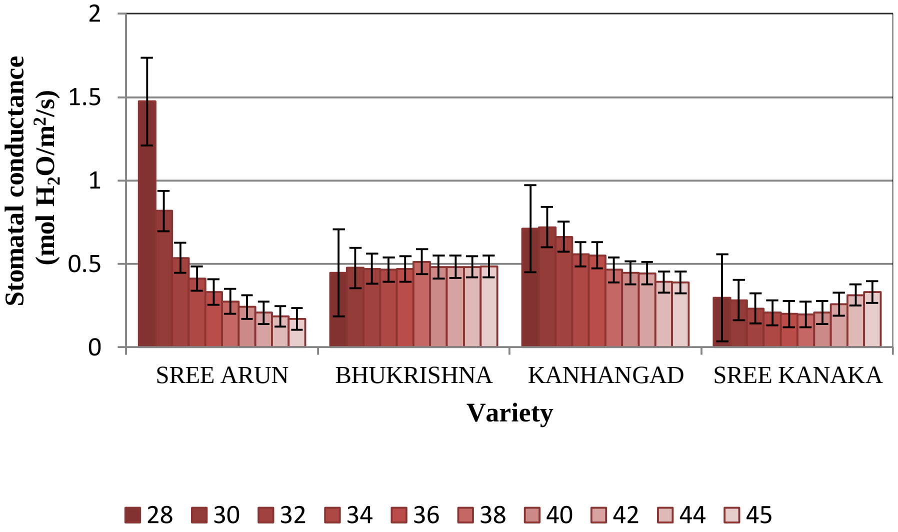

Fig. 4.29 Changes in stomatal conductance at different temperatures at 400 ppm CO_2 in sweet potato varieties. Error bars shows St. Dev.

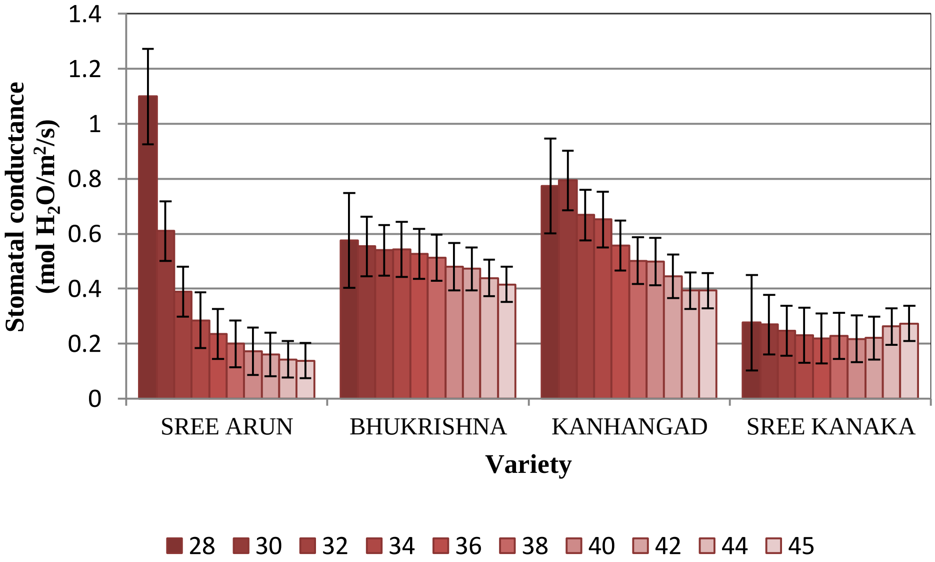

Fig. 4.30 Changes in stomatal conductance at different temperatures at 600 ppm CO_2 in sweet potato varieties. Error bars shows St. Dev.

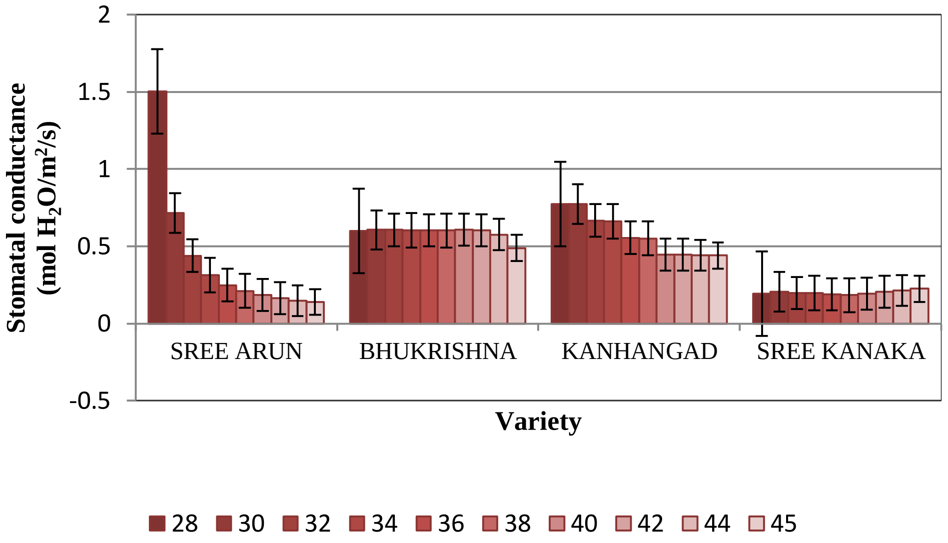

Fig. 4.31 Changes in stomatal conductance at different temperatures at 800 ppm CO2, in sweet potato varieties. Error bars shows St. Dev.

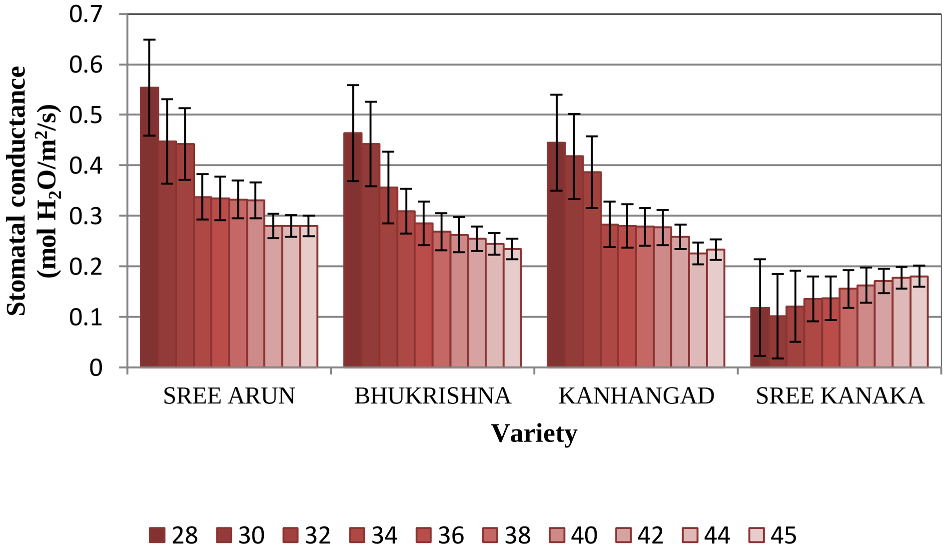

Fig. 4.32 Changes in stomatal conductance at different temperatures at 1000 ppm CO_2 in sweet potato varieties. Error bars shows St. Dev.

4.1.15. Changes in intercellular CO_2 concentration of sweet potato varieties as affected by temperature under eCO_2

At each CO_2 concentration *Ci* steadily decreased from 28 to 45°C temperatures. All the varieties exhibited maximum *Ci* at a temperature range of 28 to 30°C in each CO_2 concentrations. At 400 ppm CO_2, *Ci* decreased from 344.52 ppm to 101.08 ppm in the variety Sree Arun, from 267.83 ppm to 248.69 ppm in the variety Bhu Krishna, from 477.45 ppm to 240.41 ppm in the variety Kanhangad and from 238.28 ppm to 197.60 ppm in the variety Sree Kanaka (Fig. 4.33). The per cent decrease varied from 7.14% to 70.66% between 28 and 45°C at 400 ppm CO_2.

At 600 ppm CO_2, *Ci* decreased from 534.65 ppm to 225.81 ppm in the variety Sree Sree Arun, from 477.52 ppm to 403.96 ppm in the variety Bhu Krishna, from 619.74 ppm to 267.50 ppm in the variety Kanhangad and from 389.01 ppm to 333.94 ppm in the variety Sree Kanaka (Fig. 4.34). At 600 ppm CO_2, *Ci* decreased in all varieties across temperatures and the per cent decrease varied from 14.15% to 57.76% between 28 and 45°C.

At 800 ppm CO_2, *Ci* decreased from 728.01 ppm to 343.57 ppm in the variety Sree Arun, from 675.15 ppm to 615.82 ppm in the variety Bhu Krishna, but increased from 592.22 ppm to 639.44 ppm in the variety Kanhangad and 513.99 ppm to 525.56 ppm in the variety Sree Kanaka (Fig. 4.35). In varieties Sree Arun and Bhu Krishna *Ci* decreased with increase in temperature and the per cent decrease was 52.80% and 8.78 respectively. But varieties Kanhangad and Sree Kanaka had a higher *Ci* at 45°C than at 28°C. The per cent increase was 7.97% for the variety Kanhangad and 2.25% for the variety Sree Kanaka between 28 and 45°C at 800 ppm CO_2.

At 1000 ppm CO_2, *Ci* decreased from 965.51 ppm to 343.56 ppm in the variety Sree Sree Arun, 900.60 ppm to 544.10 ppm in the variety Bhu Krishna, 859.27 ppm to 486.77 ppm in the variety Kanhangad and 651.52 ppm to 613.42

ppm in the variety Sree Kanaka (Fig. 4.36). At 1000 ppm CO_2, all varieties had an increase in *Ci* across temperature and the per cent increase varied from 5.84% to 64.41% between 28 and 45^oC.

At each CO_2 concentration, differences in the *Ci* across 28 to 45^oC temperatures were statistically significant (CD=17.030). *Ci* significantly changed across CO_2 concentrations (CD=5.385), varieties (CD=5.385) as well as temperature (CD=8.515). The interactive effect among temperature and the variety (CD=17.030) as well as CO_2 and the variety (CD=10.771) was also significant. *Ci* significantly depends on the interaction between CO_2 concentrations, the variety and temperature.

Table 4.33. Changes in intercellular CO_2 concentration (ppm) of sweet potato varieties as affected by temperature under eCO_2 in the variety Sree Arun

Temperature (^oC)	**Intercellular CO_2 concentration (ppm)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	344.52	534.66	728.02	181.15
30	318.68	503.03	684.46	284.20
32	287.21	455.90	632.62	405.85
34	257.16	414.83	579.78	561.03
36	227.49	382.20	533.30	663.04
38	193.04	339.48	496.74	770.81
40	167.08	309.23	455.04	857.90
42	140.99	291.01	407.75	947.19
44	117.54	241.01	365.50	958.43
45	101.08	225.81	343.57	966.72
Variety: CD=5.385	CO_2 : CD=5.385	Temperature: CD=8.515		
Variety x CO_2: CD=10.771	CO_2 x Temperature: CD=17.030	Variety x Temperature: CD=17.030		
CO_2 x Variety x Temperature: CD=34.060				

Table 4.34. Changes in intercellular CO_2 concentration (ppm) of sweet potato varieties as affected by temperature under eCO_2 in the variety Bhu Krishna

Temperature (°C)	**Intercellular CO_2 concentration (ppm)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	267.84	477.53	675.15	900.61
30	272.22	472.73	678.48	853.16
32	266.82	469.58	675.20	817.34
34	262.46	467.91	670.59	774.75
36	260.73	462.29	668.36	742.25
38	264.10	456.87	667.52	706.74
40	255.44	445.85	664.27	662.90
42	250.69	437.06	657.61	636.42
44	249.75	415.33	644.78	574.81
45	248.69	403.96	615.82	544.10

Variety: CD=5.385	CO_2 : CD=5.385	Temperature: CD=8.515
Variety x CO_2: CD=10.771	CO_2 x Temperature: CD=17.030	Variety x Temperature: CD=17.030
CO_2 x Variety x Temperature: CD=34.060		

Table 4.35. Changes in intercellular CO_2 concentration (ppm) of sweet potato varieties as affected by temperature under eCO_2 in the variety Kanhangad

Temperature (°C)	**Intercellular CO_2 concentration (ppm)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	303.31	252.69	117.76	123.26
30	308.33	255.07	197.01	178.05
32	395.34	293.22	197.01	390.03
34	467.70	318.76	208.38	373.95
36	549.63	379.86	218.55	409.25
38	618.39	466.26	292.24	466.39
40	668.17	555.22	378.30	577.24
42	704.56	608.16	457.11	703.96
44	720.28	697.90	557.49	834.20
45	747.09	735.66	624.29	849.48

Variety: CD=5.385	CO_2 : CD=5.385	Temperature: CD=8.515
Variety x CO_2: CD=10.771	CO_2 x Temperature: CD=17.030	Variety x Temperature: CD=17.030
CO_2 x Variety x Temperature: CD=34.060		

Table 4.36. Changes in intercellular CO_2 concentration (ppm) of sweet potato varieties as affected by temperature under eCO_2 in the variety Sree Kanaka

Temperature (°C)	**Intercellular CO_2 concentration (ppm)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	238.28	389.01	513.99	250.42
30	225.60	388.59	450.14	254.43
32	191.20	390.51	464.81	254.01
34	166.78	328.75	466.79	277.84
36	156.38	330.30	428.36	324.22
38	149.25	324.77	415.36	328.33
40	154.39	375.18	449.03	335.28
42	177.90	383.58	472.71	338.48
44	195.78	365.91	477.09	346.65
45	197.61	333.94	525.56	357.62

Variety: CD=5.385	CO_2 : CD=5.385	Temperature: CD=8.515
Variety x CO_2: CD=10.771	CO_2 x Temperature: CD=17.030	Variety x Temperature: CD=17.030
CO_2 x Variety x Temperature: CD=34.060		

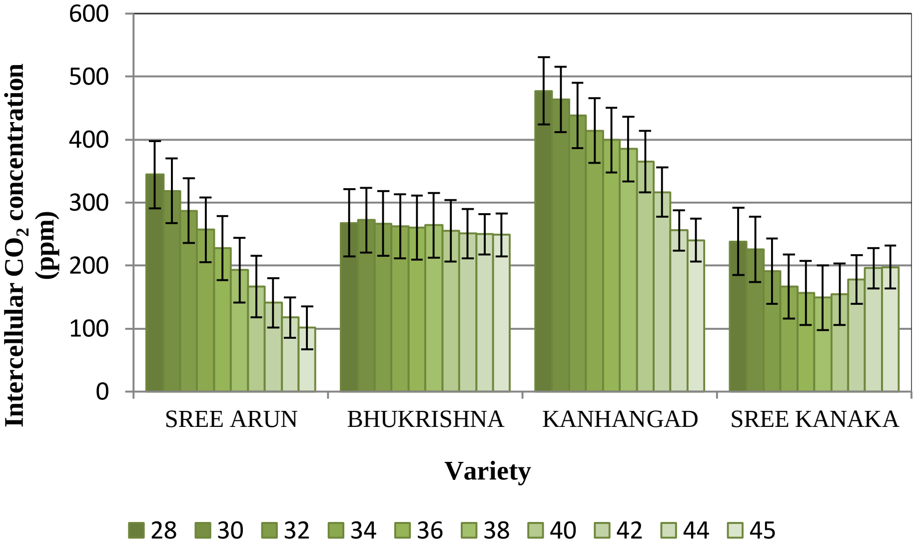

Fig. 4.33 Changes in intercellular CO_2 concentration at different temperatures at 400 ppm CO_2 in sweet potato varieties. Error bars shows St. Dev.

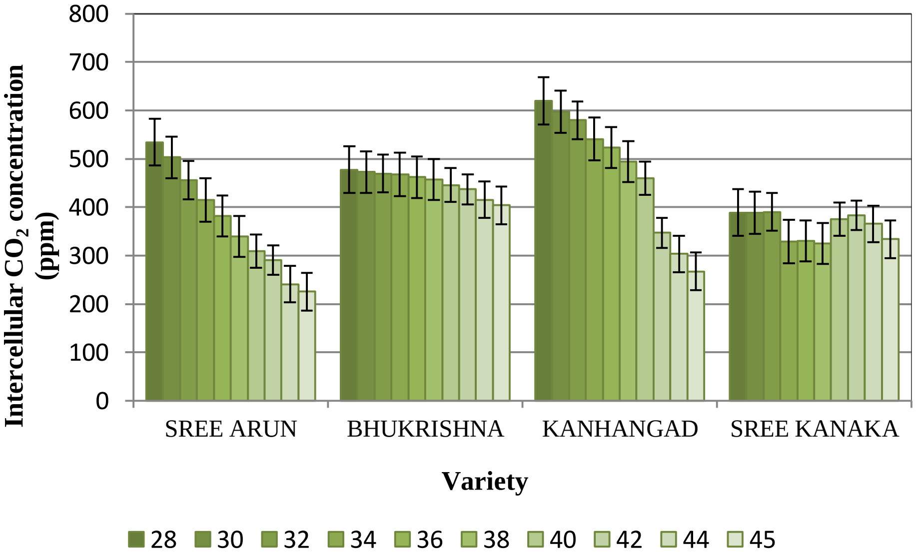

Fig. 4.34 Changes in intercellular CO_2 concentration at different temperatures at 600 ppm CO_2 in sweet potato varieties. Error bars shows St. Dev.

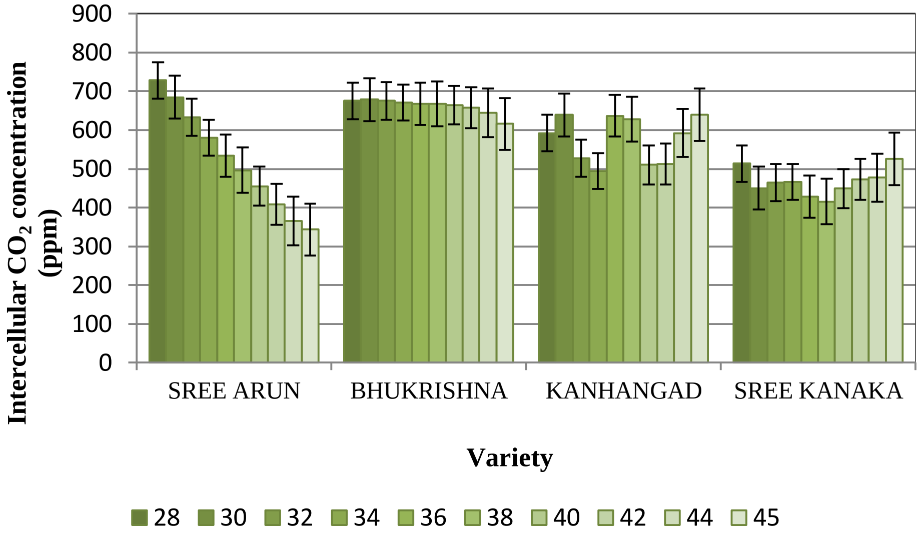

Fig. 4.35 Changes in intercellular CO_2 concentration at different temperatures at 800 ppm CO2, in sweet potato varieties. Error bars shows St. Dev.

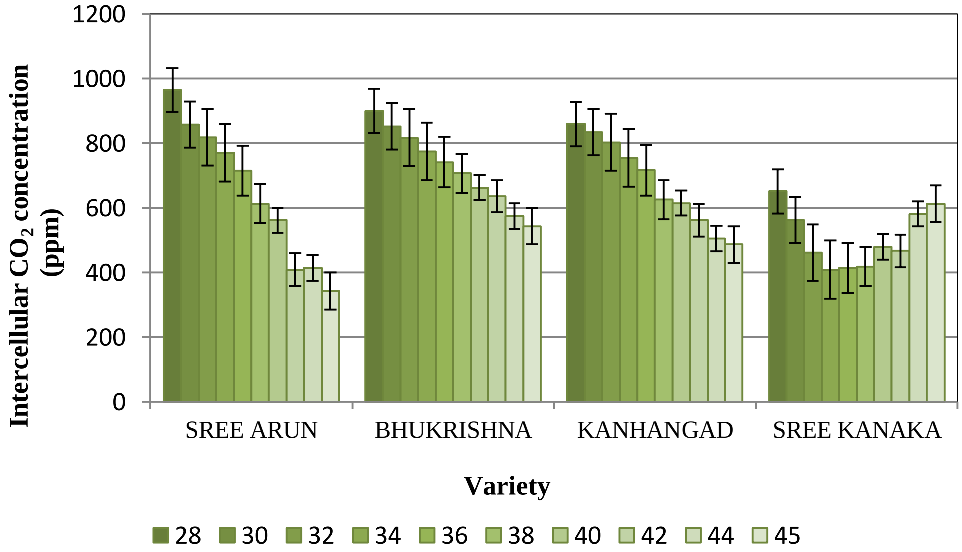

Fig. 4.36 Changes in intercellular CO_2 concentration at different temperatures at 1000 ppm CO_2 in sweet potato varieties. Error bars shows St. Dev.

4.1.16. Changes in transpiration rate of sweet potato varieties as affected by temperature under eCO_2

The *Tr* increased with increase in temperature from 28 to 45°C in all varieties at every CO_2 concentrations tested. All the varieties exhibited maximum *Tr* rate at a temperature range of 42 to 45°C in every CO_2 concentrations. At 400 ppm CO_2, *Tr* increased from 6.57 mmol at 28°C to 11.05 mmol at 45°C in the variety Sree Arun, from 7.30 mmol to 13.58 mmol in the variety Bhu Krishna, from 6.56 mmol to 10.66 mmol in the variety Kanhangad and from 8.02 mmol to 13.48 mmol in the variety Sree Kanaka (Fig. 4.37). The per cent increase varied from 62.43% to 85.88% between 28 and 45°C in other varieties.

At 600 ppm CO_2, *Tr* increased from 5.00 mmol to 8.82 mmol in the variety Sree Arun, from 8.24 mmol to 12.41 mmol in the variety Bhu Krishna, from 6.69 mmol to 10.88 mmol in the variety Kanhangad and from 6.76 mmol to 11.71 mmol in the variety Sree Kanaka (Fig. 4.38). At 600 ppm CO_2, *Tr* increased in all varieties across temperatures and the per cent increase varied from 50.62% to 76.16% between 28 and 45°C.

At 800 ppm CO_2, *Tr* rate increased from 6.55 mmol to 9.05 mmol in the variety Sree Arun, from 8.53 mmol to 12.83 mmol in the variety Bhu Krishna, from 6.79 mmol to 10.91 mmol in the variety Kanhangad and from 6.05 mmol to 8.07mmol in the variety Sree Kanaka (Fig. 4.39). The per cent increase varied from 33.20% to 60.61% between 28 and 45°C.

At 1000 ppm CO_2, *Tr* increased from 5.20 mmol to 7.94 mmol in the variety Sree Arun, from 6.96 mmol to 11.87 mmol in the variety Bhu Krishna, from 4.26 mmol to 6.79 mmol in the variety Kanhangad and from 2.67 mmol to 6.03 mmol in the variety Sree Kanaka (Fig. 4.40). At 1000 ppm CO_2, all varieties had an increase in *Tr* across temperature and the per cent increase varied from 52.61% to 125.72% between 28 and 45°C.

At each CO_2 concentration, differences in the *Tr* across 28 to 45°C temperatures were statistically significant (CD=0.237). *Tr* significantly changed across CO_2 concentrations (CD=0.075), varieties (CD=0.075) as well as temperature (CD=0.118). The interactive effect among temperature and the variety (CD=0.237) as well as CO_2 and the variety (CD=0.150) was also significant. *Ci* significantly depend on the interaction between CO_2 concentrations, the variety and temperature (CD=0.474).

Table 4.37. Changes in transpiration rate (mmol) of sweet potato varieties as affected by temperature under eCO_2 in the variety Sree Arun

Temperature (°C)	**Transpiration rate (mmol)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	6.57	5.01	6.55	5.21
30	7.26	5.65	6.63	5.20
32	7.47	5.59	6.53	5.24
34	7.99	5.66	6.51	5.28
36	8.58	6.17	6.68	5.60
38	9.13	6.63	7.14	5.96
40	9.87	7.10	7.67	6.39
42	10.27	7.95	8.28	7.03
44	10.95	8.39	8.80	7.69
45	11.05	8.82	9.06	7.95

Variety: CD=0.075	CO_2 : CD=0.075	Temperature: CD=0.118
Variety x CO_2: CD=0.150	CO_2 x Temperature: CD=0.237	Variety x Temperature: CD=0.237
CO_2 x Variety x Temperature: CD=0.474		

Table 4.38. Changes in transpiration rate (mmol) of sweet potato varieties as affected by temperature under eCO_2 in the variety Bhu Krishna

Temperature (^{o}C)	**Transpiration rate (mmol)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	6.76	9.05	8.53	6.38
30	7.33	9.13	9.23	6.32
32	7.58	9.30	9.55	6.33
34	8.01	9.79	10.37	6.46
36	8.40	9.95	11.32	6.63
38	9.42	10.49	11.77	6.96
40	9.61	10.89	12.27	7.39
42	10.31	11.63	12.83	7.87
44	11.21	11.98	13.52	8.49
45	11.76	12.12	12.83	8.89

Variety: CD=0.075	CO_2 : CD=0.075	Temperature: CD=0.118
Variety x CO_2: CD=0.150	CO_2 x Temperature: CD=0.237	Variety x Temperature: CD=0.237
CO_2 x Variety x Temperature: CD=0.474		

Table 4.39. Changes in transpiration rate (mmol) of sweet potato varieties as affected by temperature under eCO_2 in the variety Kanhangad

Temperature (^{o}C)	**Transpiration rate (mmol)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	6.57	6.70	6.80	4.27
30	7.34	8.07	7.52	4.53
32	7.52	7.98	8.03	4.56
34	7.95	8.21	8.25	4.60
36	8.15	8.68	8.49	4.78
38	8.67	8.98	8.94	5.04
40	9.11	9.53	9.42	5.53
42	9.89	10.10	10.16	5.84
44	10.65	10.71	10.64	6.44
45	10.67	10.89	10.91	6.80

Variety: CD=0.075	CO_2 : CD=0.075	Temperature: CD=0.118
Variety x CO_2: CD=0.150	CO_2 x Temperature: CD=0.237	Variety x Temperature: CD=0.237
CO_2 x Variety x Temperature: CD=0.474		

Table 4.40. Changes in transpiration rate (mmol) of sweet potato varieties as affected by temperature under eCO_2 in the variety Sree Kanaka

Temperature (^{o}C)	**Transpiration rate (mmol)**			
	400ppm CO_2	**600ppm** CO_2	**800ppm** CO_2	**1000ppm** CO_2
28	8.02	6.77	6.06	2.67
30	8.23	7.56	5.06	2.70
32	7.74	10.29	7.27	4.28
34	7.54	9.25	7.61	4.78
36	7.72	9.36	7.84	4.36
38	8.05	9.27	7.77	5.47
40	8.77	8.69	7.89	5.11
42	10.48	8.57	7.72	5.35
44	12.51	11.22	8.00	5.76
45	13.49	12.05	8.07	6.04

Variety: CD=0.075	CO_2 : CD=0.075	Temperature: CD=0.118
Variety x CO_2: CD=0.150	CO_2 x Temperature: CD=0.237	Variety x Temperature: CD=0.237
CO_2 x Variety x Temperature: CD=0.474		

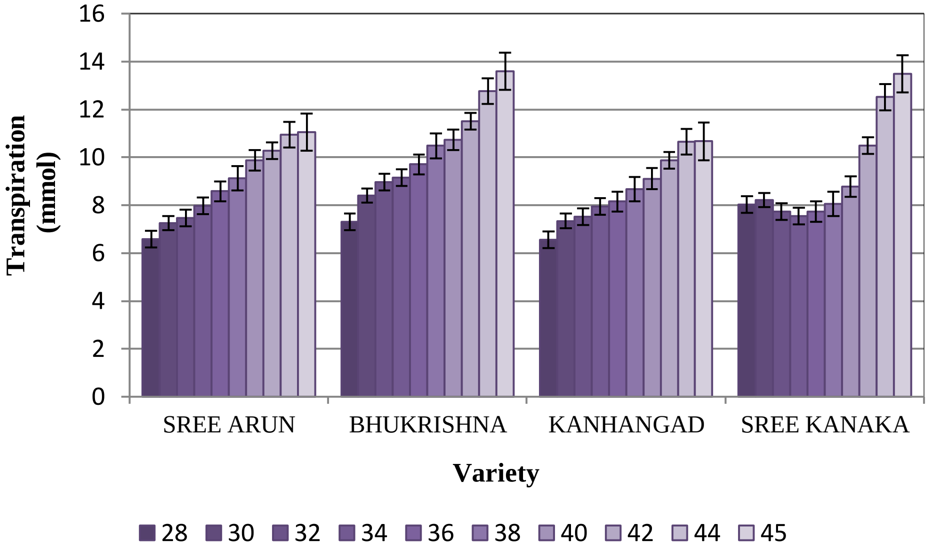

Fig. 4.37 Changes in transpiration at different temperatures at 400 ppm CO_2 in sweet potato varieties. Error bars shows St. Dev.

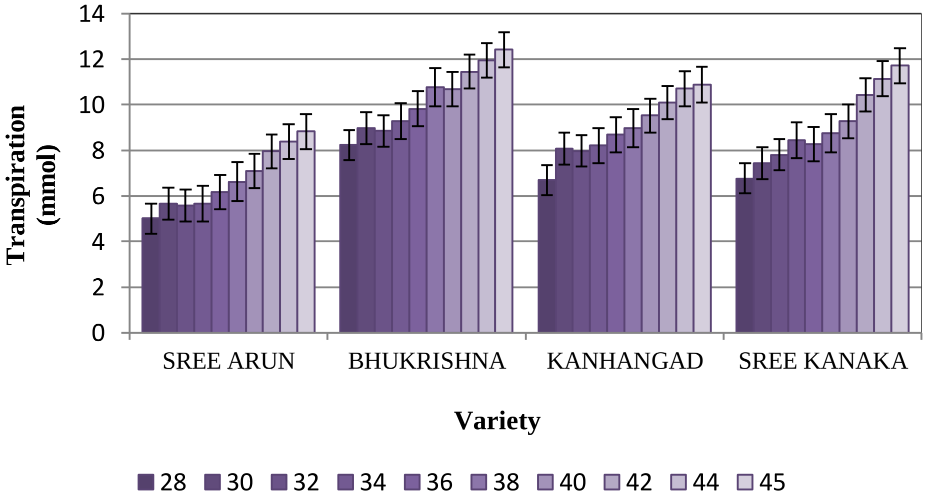

Fig. 4.38 Changes in transpiration at different temperatures at 600 ppm CO_2 in sweet potato varieties. Error bars shows St. Dev.

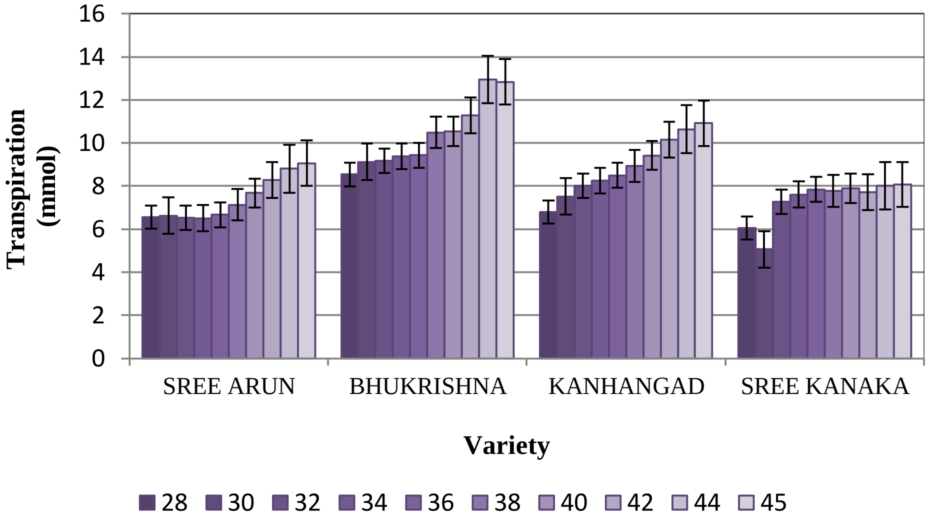

Fig. 4.39 Changes in transpiration at different temperatures at 800 ppm CO2, in sweet potato varieties. Error bars shows St. Dev.

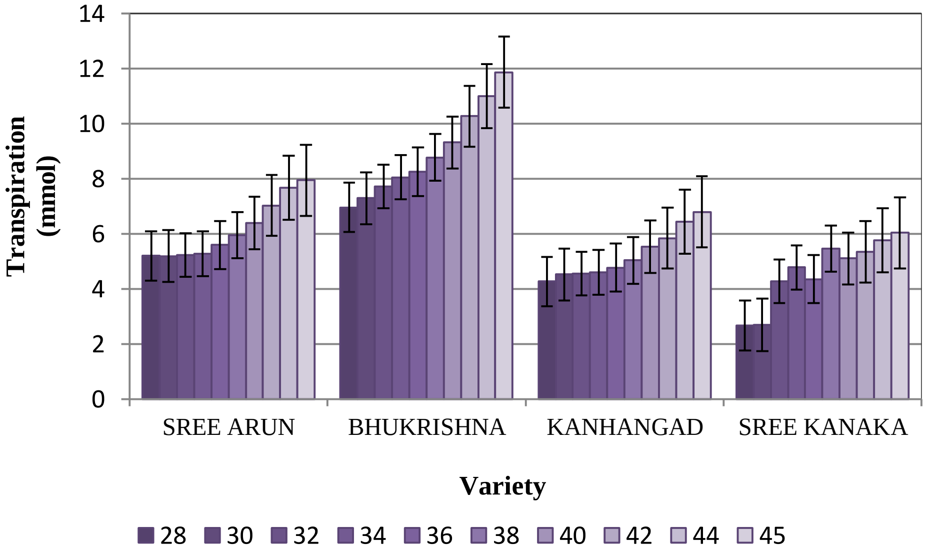

Fig. 4.40 Changes in transpiration at different temperatures at 1000 ppm CO_2 in sweet potato varieties. Error bars shows St. Dev.

4.2. Chlorophyll and carotenoid content in leaves of cassava varieties

The total chlorophyll and carotenoid content in the leaves of four varieties of Cassava viz. Sree Athulya, H226, Sree pavithra and Sree Vijaya under irrigated conditions are depicted in Table. 4.1. H226 had maximum Chlorophyll a and Chlorophyll b content in leaves than other varieties. Whereas Sree Vijaya had maximum carotenoid content in leaves than other varieties.

4.3. Chlorophyll and carotenoid content in leaves of sweet potato varieties

The total chlorophyll and carotenoid content in the leaves of four varieties of sweet potato viz. Sree Arun, Bhu Krishna, Kanhangad and Sree Kanaka irrigated conditions are depicted in Table. 4.1. Sree Arun had maximum Chlorophyll a, total chlorophyll and carotenoid content in leaves than other varieties. Whereas Kanhangad had maximum chlorophyll b content in leaves than other varieties. Maximum carotenoid content was observed in Bhu Krishna.

Table 4.41. Chlorophyll and Carotenoid content (µg/g fresh leaf) in the leaves of cassava varieties

Variety	Chl.a	Chl. b	Total Chl.	Carotenoids
Sree Athulya	2650.51	706.27	3356.77	439.30
H-226	3416.63	970.37	4387.00	509.93
Sree pavithra	2907.09	773.42	3680.52	466.97
Sree Vijaya	2914.61	774.54	3689.15	585.23

Table 4.42. Chlorophyll and Carotenoid content (µg/g fresh leaf) in the leaves of sweet potato varieties

Variety	Chl.a	Chl. b	Total Chl.	Carotenoids
Sree Arun	1380.78	468.34	1849.11	266.55
Bhu Krishna	1233.29	453.21	1686.49	268.13
Kanhangad	1206.79	487.31	1694.10	220.49
Sree Kanaka	1043.41	402.84	1446.24	208.16

DISCUSSION

CHAPTER 5
DISCUSSION

The projected climate change scenarios will largely affect crop growth, productivity and thus food production. Elevated atmospheric CO_2 concentrations, increasing temperature and changes in the distribution and intensity of precipitation are some of the most important climate change scenarios. These changes can affect the crop growth and production positively as well as negatively according to crop type and physiological characters. Generally, it is concluded that C_3 crops can benefit from higher atmospheric CO_2 concentrations than C_4 crops. Along with atmospheric CO_2 concentration, temperature also shows an increasing trend. Hence many studies reported a negative impact of climate change on crop growth and production. Tropical root and tuber crops, being C_3 plants have a positive effect from the eCO_2 concentrations. They can also adapt to higher temperatures and water deficit conditions. However, studies regarding to the response of tropical root and tuber crops under future changing climate scenarios is very less compared to other crops such as rice, wheat, cotton and soybean. The major objective of this study was to determine the interactive effect of elevated CO_2, higher temperature and drought stress on various photosynthetic parameters of cassava and sweet potato varieties.

5.1 Effect of eCO_2 on *Pn, g_s, Ci* and *Tr* under WDS and WDS free conditions in cassava

The present study clearly indicates that all varieties of cassava have an increase in photosynthetic rate with increase in CO_2 concentration under WDS free conditions. At current CO_2 concentration, *Pn* rate showed significant difference among four varieties. But as the CO_2 concentration increased the difference among varieties narrowed and at 1000 ppm *Pn* rate was almost equal in Sree Athulya, Sree Vijaya and H-226. This indicates that eCO_2 can reduce the difference among varieties in *Pn* rate.

Pn rate significantly depend on interaction between irrigation conditions and the variety. Under WDS condition *Pn* rate increased with elevated CO_2 concentration in all varieties of cassava. The variety Sree Vijaya had higher *Pn* rate under ambient CO_2 concentration as well as at 1000 ppm CO_2 concentration under WDS. All other varieties *viz.* Sree Athulya, H-226, Sree Pavithra had at par *Pn* rates at 400 ppm CO_2 concentration under WDS conditions. Sree Athulya had minimum *Pn* rate at 1000 ppm under WDS. Overall, as the CO_2 concentration increased, the percent increase in *Pn* rate at WDS decreased. However the *Pn* rate increased with e CO_2. This evinces that eCO_2 benefits *Pn* under WDS conditions.

At eCO_2 concentrations *Pn* increased significantly in many crops under short term as well as long term exposure. Allen and Prasad in 2004 reported ~48% increase in *Pn* in C_3 plants at 800 ppm as compared to 400 ppm. In rice *Pn* increased by ~54% at 700 ppm CO_2 compared to 350 ppm CO_2 under short term exposure (Vu *et al.*, 2008). Under long term exposure *Pn* increased 24.2 to 25.4% at 570±50 ppm CO_2 compared to 360 ppm CO_2 (Razzaque *et al.,* 2009). Sujatha *et al.* (2008) also reported significant increase in *Pn* at 550 ppm compared to 370 ppm CO_2 in rice. In soybean *Pn* increased by ~33% at 700 ppm compared to 350 ppm CO_2 (Vu *et al.,* 2008) by ~30% at 550 to 700 ppm in soybean as compared to 360 ppm CO_2 (Bernacchi *et al,.* 2005, Prior *et al.,* 2011) by 66% in soybean at 1000 ppm as compared to 400 ppm CO_2 (Prasad *et al.*, 2005) by 78% at 700 ppm CO_2 under short term exposure and by 42% under long term exposure (Ratnakumar *et al.*, 2011). Under short term exposure *Pn* increased by 45% at 700 ppm as compared to 350% in sunflower (Tezara *et al.*, 2002) and under long term exposure to eCO_2 (700 ppm) *Pn* exhibited significant increase compared to380 ppm CO_2 (Vanaja *et al.*, 2011). At eCO_2 *Pn* increased by 22 and 9% at 700 and 450 ppm as compared to 350 ppm CO_2 in cotton (Reddy *et al.*, 2005) by 60% at 700 ppm CO_2 under short term exposure and by 13% under long term exposure (Ratnakumar *et al.*, 2011). In sugarcane *Pn* increased 30 to 60% at 720 ppm compared to 370 ppm CO_2 (de Souza *et al.*, 2008). Compared to 370 ppm CO_2 *Pn* increased 70% at 550 ppm CO_2 in chickpea (Madan Pal and Sangeeta, 2009). At

eCO_2(1000 ppm) the *Pn* increased by 61.80 to 113.3% in taro (Ravi *et al*., 2019) and by 56.71 to 82.51% in elephant foot yam as compared to 400 ppm CO_2 (Ravi *et al*., 2018). At 550 ±60 ppm CO_2 *Pn* increased *by* 11.7% in mung bean leaf compared to 389±40 ppm CO_2 (Hao *et al*., 2011). An increase of 78% and 30% in *Pn* at 700 and 550 ppm CO_2 was reported in black gram under long-term exposure (Sathish *et al*., 2014). Under long term exposure to eCO_2 (600±50 ppm) oats (*Avena sativa*) exhibit 21-61% increase in *Pn* compared to360 ppm CO_2 (Bhatt *et al*., 2010). The *Pn* significantly increased in maize under long-term exposure to eCO_2 (450 and 550 ppm) as compared to 390 ppm (Meng *et al*., 2014). Photosynthesis under eCO_2 increased by 50% under less than one week exposure and by 14% under long term exposure in barley (Ratnakumar *et al*., 2011).

It is unsure that the drought limits photosynthesis through stomatal closure or through metabolic impairment (Lawson *et al*., 2003; Anjum *et al*., 2003). In general both stomatal and non-stomatal limitations are accepted to be the main determinant of reduced photosynthesis under drought stress (Farooq *et al*., 2009). As the relative water content and leaf water potential decreases photosynthetic rate decreases (Lawlor and Cornic, 2002). A reduction in chlorophyll content was also reported under drought stress conditions in plants like cotton, *Catharanthus roseus,* sunflower and *Vaccinium myrtillus* (Massacci *et al*., 2008; Jaleel *et al*., 2008a-d; Kiani *et al*., 2008; Tahkokorpi *et al*., 2007). In rice elevated CO_2 reduces the harmful effects of drought by improving plant water relations, increasing canopy photosynthesis, reducing stomatal opening, decreased transpiration, shortening crop growth period and increasing the antioxidant metabolic activities (Kumar *et al*., 2018). Elevated CO_2 significantly ($P \leq 0.01$) improved the *Pn* in moisture stressed sunflower plants. Under drought stress in sunflower *Pn* values were significantly ($P \leq 0.01$) higher (60%) in elevated compared to ambient CO_2 (32%) (Vanaja *et al*., 2011). Difference in *Pn* of maize was not significant under moisture stress conditions, though significant ($P \leq 0.01$) reduction in *Pn* with drought stress was observed under both elevated and ambient CO_2 (Vanaja *et al*., 2011).

Under WDS free conditions, cassava varieties Sree Athulya, H-226 and Sree Vijaya exhibited a gradual rise in stomatal conductance from 400 ppm to 800 ppm and a decline at 1000 ppm. The variety Sree Vijaya had higher g_s at 1000 ppm than at 400 ppm CO_2. The g_s decreased at eCO_2 in cassava variety Sree Pavithra. Increase in g_s indicates eCO_2 is not cause stress and thereby stomatal closure in cassava varieties Sree Athulya, H-226 and Sree Vijaya up to 800 ppm CO_2. This increasing trend evinces better adaptation of these varieties to eCO_2.

Various studies reported a decrease in stomatal conductance (g_s) under eCO_2. Because of the depolarization of the membrane potential of guard cells and stomatal closure stomatal aperture generally shrink in response to high CO_2 during the short term exposure to eCO_2 (Ainsworth and Rogers 2007). Decrease in stomatal conductance to water due to partial closure of stomata is one of the most important responses to increasing CO_2. Xu *et al.* (2016) reported a decrease of 21-50% in g_s at eCO_2 across plant species. Under long term exposure to eCO_2 (65 Pa CO_2) the g_s decreased by 32% in cotton leaves than at 35 Pa CO_2 (Harley *et al.*, 1992). In soybean the g_s decreased by 31% at 450-550 ppm CO_2, 36% at 660 to 800 ppm CO_2, and 51%at 850 CO_2 as compared to 330 to 360 CO_2 (Ainsworth *et al.*, 2002). The g_s decreased by 37% at eCO_2 (720 ppm) as compared to 370 ppm in sugarcane (De Souza *et al.*, 2008). The *gs* decreased by ~50% at 700 ppm in sunflower as compared to 350 ppm CO_2 (Tezara *et al.*, 2002). Vanaja *et al.*, 2011 also reported significant decrease in g_s in sunflower at 700 ppm CO_2 as compared to 380 ppm. In green gram leaf eCO_2 (550±60 ppm) decreased g_s by 32% compared to 389±40 ppm CO_2 (*Hao et al.*, 2011). Due to partial stomatal closure the g_s decreased by ~25% at 700 ppm CO_2 in *Arabidopsis thaliana* than ambient CO_2 (350 ppm) (Teng *et al.*, 2006). In elephant foot yam g_s increased at 600 and 800 ppm CO_2, concentrations but declined at 1000 ppm with respect to 400 ppm under short term exposure to e CO_2 (Ravi *et al.*, 2018). In sweet potato the g_s decreases with eCO_2 and per cent of decrease in g_s significantly increased at 1000 ppm CO_2 (Ravi *et al.*, 2017). Some taro varieties exhibited increase in the g_s at eCO_2 compared to 400 ppm CO_2 (Ravi *et al.*, 2019). In present study, cassava was grown under ambient CO_2 (400 ppm), therefore there was decrease in the g_s in its leaves during short-term measurements at eCO_2 (1000 ppm) compared to 400 ppm is attributed to partial closure of stomata and not due to a decrease in stomatal density (SD) and the stomatal index (SI). The increase in g_s in cassava varieties Sree Athulya, H-226 and Sree Vijaya from 400 ppm CO_2 to 800 ppm CO_2 evidences greater tolerance to eCO_2 environment.

Under WDS, all varieties had a decreasing trend in stomatal conductance with increasing CO_2 concentration. Changes in g_s across CO_2 were statically not significant. This evinces that cassava varieties can get benefits of eCO_2 even under WDS. At each CO_2 concentrations g_s decreased under WDS conditions than g_s under WDS free conditions. This is due to the partial closure of stomata under WDS. Stomatal conductance (g_s) significantly affected in sunflower and maize plants under drought stress and eCO_2 ($P \leq 0.01$). The g_s in sunflower and maize significantly reduced under eCO_2 and WDS (Vanaja *et al.*, 2011).

Intercellular CO_2 concentration (*Ci*) increased from 400 ppm to 1000 ppm CO_2 under both WDS free and WDS conditions. H-226 had highest *Ci* under WDS free as well as WDS conditions at 400 ppm CO_2. The *Ci* was significantly reduced under WDS relative to WDS free conditions. Per cent decrease in *Ci* under WDS relative to WDS free condition increased with increase in CO_2 concentration. Several studies reported higher *Ci* at eCO_2 levels. In mung bean leaf *Ci* increased by 9.8% at 550 ±60 ppm compared to 389±40 ppm CO_2 (Hao *et al.*, 2011). In elephant foot yam *Ci* increased with increase in CO_2. However the per cent increment was declined for every 200ppm between 400 and 1000 ppm (Ravi *et al.*, 2018).The *Ci* increased at eCO_2 in sweet potato compared to400 ppm CO_2 (Ravi *et al.*, 2017). Compared to 400 ppm CO_2 at 1000 ppm CO_2 taro had increased *Ci* (Ravi *et al.*, 2019).

Plants under WDS free conditions exhibited higher transpiration (*Tr)* rate than that of plants under WDS conditions. Elevated CO_2 reduced transpiration by 18% and 32% in sunflower and maize under well watered condition (Vanaja *et* *al.*, 2011). Under drought stress at eCO_2 sunflower (4%) and maize (42%) exhibited a reduction in transpiration (Vanaja *et al.*, 2011).

5.2 Effect of eCO_2 on *Pn, gs, Ci* and *Tr under* WDS and WDS free conditions in sweet potato

The present study clearly indicates that all varieties of sweet potato have an increase in photosynthetic rate with increase in CO_2 concentration under WDS free conditions. Maximum photosynthetic rate was observed at 1000 ppm CO_2 concentration. Sweet potato variety Sree Arun exhibited maximum *Pn* rate at ambient CO_2 concentration. Sree Kanaka had minimum *Pn* rate at ambient CO_2 concentration but at 1000 ppm it had maximum *Pn* rate among four varieties under study. It indicates that the sweet potato variety Sree Kanaka can perform maximum under eCO_2, compared to ambient CO_2 concentrations. The variety Bhu Krishna had minimum variation in *Pn* rate between 400 ppm and 1000 ppm. This evinces better adaptation of the sweet potato variety Bhu Krishna eCO_2. The per cent increase in *Pn* at eCO_2 for every 200 ppm between 400 and 1000 ppm significantly declined. The *Pn* increased 12.18 to 72.23% at 1000 ppm as compared to 400 ppm CO_2 in sweet potato under WDS free conditions. Ravi *et al.* (2018) reported 31.10 to 74.30% increase in *Pn* at 1000 ppm as compared to 400 ppm CO_2 in sweet potato varieties. Studies reported that crops like rice, soybean (Vu *et al.*, 2008), sunflower (Tezara *et al.*, 2002), cotton (Reddy *et al.*, 2005), sugarcane (de Souza *et al.*, 2008), chickpea (Madan Pal and Sangeeta, 2009), taro (Ravi *et al.*, 2019), elephant foot yam (Ravi *et al.*, 2018), mung bean(Hao *et al.*, 2011), black gram (Sathish *et al.*, 2014), Sunflower (Bhatt *et al.*, 2010), maize (Meng *et al.*, 2014), Field grown rice plants (Razzaque *et al.*, 2009) and barley (Ratnakumar *et al.*, 2011) exhibit an increase in photosynthetic rate at eCO_2 concentrations as compared to ambient CO_2 concentrations.

Under WDS condition *Pn* rate increased with elevated CO_2 concentration in all varieties of sweet potato. The variety Bhu Krishna had higher *Pn* rate under ambient CO_2 concentration as well as at 1000 ppm CO_2 concentration under

WDS. Sree Kanaka had minimum *Pn* rate at 400 as well as 1000 ppm under WDS. Overall, as the CO_2 concentration increased, the percent increase in *Pn* rate at WDS decreased. However, *Pn* rate increased with eCO_2 under WDS condition. This evinces that eCO_2 benefits *Pn* under WDS conditions. Studies reported decrease in *Pn* rate under WDS as compared to WDS free conditions in crops like sunflower and maize (Vanaja *et al.*, 2011). Under WDS *Pn* rate decreases as a result of both stomatal and non-stomatal limitation (Farooq *et al.*, 2009). Lawlor and Cornic, 2002 reported decline in *Pn* rate with decrease in relative water content and leaf water potential. A reduction in chlorophyll content was also reported under drought stress conditions in plants like cotton, *Catharanthus roseus,* sunflower and *Vaccinium myrtillus* ((Massacci *et al.*, 2008; Jaleel *et al.*, 2008a-d; Kiani *et al.*, 2008; Tahkokorpi *et al.*, 2007). Elevated CO_2 can reduce the depressing effects of drought in rice by decreased transpiration, improving plant water relations, increasing canopy photosynthesis, reducing stomatal opening, shortening crop growth period and increasing the antioxidant metabolic activities (Kumar *et al.,* 2018). Increase in *Pn* rate with eCO_2 under drought stress was reported in sunflower (Vanaja *et al.*, 2011).

Under WDS free conditions sweet potato varieties showed an initial increase and then a gradual decrease in stomatal conductance with eCO_2. The g_s decreased at eCO_2 in sweet potato variety Sree Arun. The decrease in g_s is the result of partial closure of stomata. Sweet potato variety Kanaka showed an increasing trend in g_s with increase in CO_2 concentration. Increasing trend indicates better adaptation of the variety Sree Kanaka to eCO_2 under WDS free conditions. Under WDS g_s increased between 400 and 1000 ppm CO_2 in the variety Kanhangad. In all other varieties g_s decreased between 400 and 1000 ppm CO_2. Increasing trend in g_s evinces better adaptation of the variety Kanhangad to eCO_2 under WDS conditions. Under WDS g_s decreased significantly compared to WDS free conditions. During short term exposure to eCO_2 stomatal conductance (g_s) decreases due to depolarization of the membrane potential of guard cells and stomatal closure in response to high CO_2 (Ainsworth and Rogers 2007). Partial stomatal closure and associated decrease in stomatal conductance to H_2O is one of the most important responses to increasing CO_2. Many studies carried out in crops like cotton (Harley *et al*., 1992), soybean (Ainsworth *et al.*, 2002), sugarcane (De Souza *et al.*, 2008), sunflower (Tezara *et al.*, 2002), green gram leaf (*Hao et al*., 2011), sunflower (Vanaja *et al*., 2011) and *Arabidopsis thaliana* (Teng *et al*., 2006) reported a decrease in stomatal conductance under eCO_2. Ravi *et al*. in 2017 reported decreases in g_s with eCO_2 in sweet potato and per cent of decrease in g_s significantly increased at 1000 ppm CO_2. In elephant foot yam g_s increased at 600 and 800 ppm CO_2, concentrations but declined at 1000 ppm with respect to 400 ppm under short term exposure to e CO_2 (Ravi *et al*., 2018). Some taro varieties exhibit increase in g_s at eCO_2 compared to 400 ppm CO_2 (Ravi *et al*., 2019). In present study, sweet potato was grown in ambient CO_2 (400 ppm), therefore there was decrease in g_s in its leaves during short-term measurements at eCO_2 (800 and 1000 ppm) compared to 400 ppm is attributed to partial closure of stomata and not due to a decrease in SD and the SI. The increase in g_s in sweet potato variety Sree Kanaka evidences greater tolerance to eCO_2 environment. Vanaja *et al*., 2011 reported significant reduction in stomatal conductance in sunflower and maize plants under drought stress.

Inter cellular CO_2 concentration increased from 400 ppm to 1000 ppm under both WDS free and WDS conditions. Sweet potato varieties Sree Arun and Kanhangad have higher *Ci* under WDS free conditions relative to WDS conditions. But the variety Kanhangad and Sree Kanaka have higher *Ci* under WDS conditions relative to WDS free conditions, at every CO_2 concentrations. The CO_2 is accumulated in leaves and as a result inter cellular CO_2 concentration increases. In mung bean (Hao *et al.*, 2011), elephant foot yam (Ravi *et al.*, 2018), sweet potato (Ravi *et al.*, 2017) and taro (Ravi *et al.*, 2019) *Ci* increased with e CO_2.

The *Tr* decreased with increase in CO_2 concentration under WDS free conditions. Under WDS condition Sree Arun and Bhu Krishna exhibited decrease in *Tr* with eCO_2. But Sree Kanaka and Kanhangad exhibited an increasing trend.

Plants under WDS free conditions exhibited higher *Tr* rate than that of plants under WDS conditions. Under stress conditions plants close the stomata. Here eCO_2 causes partial closure of stomata. As a result *Tr* decreased with eCO_2 under WDS free conditions. Sree Kanaka and Kanhangad exhibited an increasing trend in *Tr* under WDS condition with eCO_2. This indicates that eCO_2 is not a stress for these varieties under WDS. Elevated CO_2 reduced transpiration in sunflower and maize under watered condition (Vanaja *et al.,* 2011). Under drought stress sunflower and maize exhibited a reduction in transpiration at eCO_2 (Vanaja *et al.,* 2011).

5.3 Effect of temperature on photosynthetic parameters under eCO_2 in cassava

In the present study all varieties of cassava exhibited only insignificant differences in *Pn* rate with increasing temperature at CO_2 concentrations between 400 ppm to 1000 ppm, whereas, changes in *Pn* across eCO_2 was significant. All the varieties exhibited maximum *Pn* rate at a temperature range of 36 to 40^{o}C in 400, 600, and 800 ppm CO_2 concentration. At 1000 ppm CO_2, three varieties except Sree Vijaya had maximum *Pn* rate at 42-44^{o}C. Photosynthetic rate of cassava leaves had been reported to be highest between 25-35^{o}C (El-Sharkawy and Cock, 1990). Studies by Mahon *et al.* (1977) under controlled climate growth chamber revealed maximum *Pn* at 25^{o}C and thereafter *Pn* was declined. At high temperatures (40^{o}C) cassava may sustain vegetative growth and biomass under WDS free conditions. Results from the present study indicate that under eCO_2 cassava can adapt to wide temperature ranges.

Temperature affects many physiological and developmental processes of plants, the interactive effect of CO_2 and temperature are presently being investigated in various crop species. The CO_2 enrichment of plant growth is strongly temperature reliant and response to temperature vary with species. Studies done on rice and soybean have been reported that, the CO_2 enhancement can balance unfavourable effects of high temperatures on photosynthesis and these responses are species specific (Vu *et al.*, 2008). Results from present study also exhibit such trend. Cassava varieties exhibited no significant variations in *Pn*, which means rising temperature does not adversely affect *Pn* of cassava under eCO_2 and WDS free conditions.

Rubisco is modulated by growth at elevated CO_2. Rising CO_2 increases the temperature of the atmosphere. Therefore eCO_2 reduces the quantity of Rubisco by 15 to 25%. But it will not have undesirable effect as the amount of Rubisco required for utmost activity is reduced as the temperature rises. About 10% of Rubisco is only needed for normal photosynthetic rate at 45°C. Elevated CO_2 results higher foliar temperatures while leaves compensate for increased air temperature and this interactive effect of CO_2 versus temperature has crucial effect on photosynthesis. Increase in temperature enhances saturation vapour pressure of air, thus increasing evaporative demand. As a response plants close their stomata to increased evaporative demand, in this manner reducing photosynthesis rate and increasing vulnerability to heat injury (Lobell and Gourdji, 2012). Stomata of most plant species partially close (about 40%) with rising CO_2 and this may cause about 20-60% reduction of stomatal conductance but devoid of reduction in intercellular CO_2 concentration. Decline of stomatal aperture and conductance in turn reduces leaf transpiration by 17 to 46% and increase water use efficiency by 40 to 100% under elevated CO_2. This delays the commencement of midday water stress and extends the period of most active photosynthesis. In the present study all cassava varieties exhibited decrease in g_s and increase in *Tr* with increase in temperature. Leaf temperature was also increased with increase in temperature. It indicates that partial closure of stomata had occurred due to eCO_2. But increase in temperature increased leaf temperature and thereby transpiration. It helped to maintain the *Pn* at rising temperature.

In cassava, high CO_2 (700 ppm) along with high day/night temperature (33/26°C) increased tuber yield relative to plants grown at 350 ppm CO_2 (Ravi *et al.*, 2008). Being a C_3 plant cassava had a special partial Krant'z anatomical feature in leaf. Cassava had 15 to 25% phosphoenol pyruvate carboxylase

(PEPcase) activity of maize and sorghum. The PEPcase activity of cassava is higher than that of other C_3 plants and equivalent to PEPcase activity of C_3- C_4 intermediates. Under WDS and high temperature conditions RUBPcase activity decreased by 42% but, PEPcase activity of cassava increased by 13%, (El-Sharkawy, 2006). Hence cassava exhibits a greater benefit to respond to eCO_2 concentrations. Tuber weight of cassava increased significantly with eCO_2 (700 ppm) compared to 350 ppm CO_2 along with increase in day/night temperature from 28/21^{o}C to 33/21^{o}C under WDS free conditions (Imai *et al.,* 1984). Irikura *et al.* (1979) reported that the response of cassava varieties to increasing temperature differ among varieties. The present study also found differential responses of cassava varieties to increasing temperature.

The g_s decreased with increase in temperature at every CO_2 concentrations in all cassava varieties. All the cassava varieties exhibited maximum g_s rate at a temperature range of 28 to 30^{o}C in each CO_2 concentration. This is due to the partial closure of stomata due to high temperature stress. eCO_2 (700 ppm) decreased the g_s of individual leaves by 43% at 26°C, 45% at 31°C, and 20% at 36°C as compared to 350 ppm in cotton (Reddy *et al*., 2005).

At each CO_2 concentration differences in the *Ci* across 28 to 45^{o}C temperatures steadily decreased in all varieties of cassava. All varieties exhibited maximum *Ci* at a temperature range of 28 to 30^{o}C in each CO_2 concentration tested. The decrease in *Ci* and increase in *Pn* with increasing temperature evinces higher temperature and eCO_2 will benefits cassava varieties. The *Tr* rate increased with increase in temperature from 28 to 45^{o}C in all varieties of cassava at every CO_2 concentration tested. Maximum *Tr* rate was observed at a temperature range of 42 to 45^{o}C in every CO_2 concentrations.

Studies revealed that the rise in temperature can affect beneficially as well as adversely the crop plants. As respiration over ruled the *Pn* rate, rice grain yield decreased 10% for each 1^{o}C increase in minimum temperature due to high night temperatures (Peng *et al*., 2004). Smith *et al.* (2008) reported that yield increased up to 29^{o}C for corn, 30^{o}C for soybean and 32^{o}C for cotton. 1°C increase in temperature above normal reduces wheat yield by 10% (Brown, 2009).) Maize yield improved with an increase in temperature up to 29°C followed by a sharp decline in yield with additional temperature increases (Schlenker and Roberts, 2009). Wortmann *et al*. (2009) reported increase in production of sorghum that grown in the region with slight increases in temperature. However Lobell and Field (2007) reported 8.4% decrease of yield in sorghum for 1°C increase in temperature than normal conditions. Similarly, Hatfield *et al*. (2008) reported a 7.8% decrease in sorghum yield for 1°C rise in temperature from 18.5°C to 27.5°C. Ringler *et al.* (2010) projected 1.06% gain in eastern Africa and 1.14% gain in southern Africa in sweet potato yield by 2050. Cotton yield is projected to increase by 2050 as a result of slight increase in temperature under eCO_2 and WDS free conditions (Gerardeaux *et al.*, 2013). In sugar cane sucrose yield have a positive impact due to 2 to 3°C increase in temperature, while WDS had a negative impact on sucrose yield (Kiker, 2002). It was found that in C_3 plants, temperature optimum for light-saturated photosynthesis increased by 5^{o}C with an increase of CO_2 concentration to 650 ppm (Long 1991).

5.4 Effect of temperature on photosynthetic parameters under eCO_2 in sweet potato

Increasing temperature had significant effect on *Pn* of sweet potato varieties. Sree Arun exhibited maximum *Pn* rate at a temperature range of 36 to 40^{o}C in 400, 600, and 800 ppm CO2, concentrations and at 44-45^{o}C in1000 ppm. All other varieties have maximum *Pn* rate at a temperature range of 42 to 45^{o}C at 400, 600, 800 and 1000 ppm CO_2. This clearly indicates the adaptability of sweet potato to wide temperature ranges.

In sweet potato activation state of Rubisco declined with raise in temperature above and decline in temperature below optimum level. Both electron transport system and photosynthesis enzyme Rubisco activase in sweet potato leaves are susceptible to high temperature above 35^{o}C (Cen and Sage, 2005). Cen and Sage (2005) reported an increase in *Pn* with increase in temperature up to 34°C and increase in CO_2 up to 560 ppm in sweet potato. However, temperature above 34°C did not enhance *Pn* rate. Increase in CO_2 above 540 ppm as well as temperature above 34°C was found to increase the *Pn* rate of sweet potato in present study. Similarly Ravi *et al*. (2017) reported an increase in *Pn* due to increase in CO_2 from 400 ppm to 1000 ppm in the leaves of twelve sweet potato varieties.

Sweet potato variety Sree Kanaka exhibited an increment in the *gs* with increase in temperature at ambient (400 ppm) and eCO_2 (1000 ppm). In other varieties the g_s decreased with increase in temperature at every CO_2 concentration tested. All the varieties exhibited maximum g_s rate at a temperature range of 28 to 30°C in each CO_2 concentration except the variety Sree Kanaka, which had maximum g_s at a temperature range of 42 to 45°C. The increasing trend in g_s of Sree Kanaka evinces rising temperature and eCO_2 benefits it.

At each CO_2 concentration differences in the *Ci* rate across 28 to 45°C temperatures steadily decreased in all varieties of sweet potato. All the varieties exhibited maximum *Ci* at a temperature range of 28 to 30°C in each CO_2 concentration tested. The decrease in *Ci* and increase in *Pn* with increasing temperature evinces higher temperature and eCO_2 will benefit sweet potato varieties. The *Tr* rate increased with increase in temperature from 28 to 45°C in all varieties of sweet potato at every CO_2 concentration tested. Maximum *Tr* rate was observed at a temperature range of 42 to 45°C in every CO_2 concentration. . In the present study all sweet potato varieties except Sree Kanaka exhibited decrease in g_s and increase in *Tr* with increase in temperature. Leaf temperature was also increased with increase in temperature. It indicates that partial closure of stomata had occurred due to eCO_2. But increase in temperature increased leaf temperature and thereby transpiration. It helped to maintain the *Pn* at rising temperature. Increase in g_s as well as *Tr* with increase in temperature in the sweet potato variety Sree Kanaka evinces better adaptation of this variety to higher temperatures under eCO_2.

From this study it is clear that eCO_2 concentration can benefit cassava as well as sweet potato under both WDS free and WDS conditions. The photosynthetic rate significantly increased for all studied cassava and sweet potato varieties with increase in CO_2 concentration. WDS significantly reduces *Pn* rate, compared to WDS free condition. However, they get benefits of eCO_2 even under WDS. Higher *Pn* rate of cassava variety Sree Vijaya and sweet potato variety Bhu Krishna at WDS and eCO_2 evinces future scope of these varieties. The increase in g_s in sweet potato variety Sree Kanaka and cassava variety Sree Vijaya evidences greater tolerance to eCO_2 environment. Overall, even under WDS conditions, cassava and sweet potato can perform well at eCO_2 concentrations.

Increase in temperature also not adversely affected cassava and sweet potato varieties. *Pn* rate not significantly varied in cassava for a temperature range of 28 to 45^{o}C. However significant increase in *Pn* rate was observed in sweet potato varieties. All the cassava varieties exhibited decrease in stomatal conductance and increase in *Ci* and *Tr.* All the sweet potato varieties except Sree Kanaka also exhibited similar trend. It evinces better adaptation of the under higher temperature and eCO_2. Cassava variety Sree Athulya and sweet potato variety Bhu Krishna exhibited maximum performance under higher temperature and eCO_2.

SUMMARY

CHAPTER 6

SUMMARY

Crops grown in future environments will be subjected to projected climate changes. It affects a number of variables that can determine how much plants can grow. Assessment of impacts of climate change on growth and productivity and thus food production requires an improved scientific basis for detecting and evaluating the consequences of multiple climate changes on agriculturally important crops. The main objective of the present study was to figure out the impact of adverse conditions of climate change such as water deficit stress and high temperature stress on photosynthetic potential of tropical tuber crops under elevated CO_2 and there by identify crop/varieties suitable for changing climate conditions.

Four varieties of cassava *viz*. Sree Athulya, H-226, Sree Pavithra and Sree Vijaya and four varieties of sweet potato *viz*., Sree Arun, Bhu Krishna, Kanhangad and Sree Kanaka were used for the study. The photosynthetic parameters were recorded in 6th to 15th leaf of four cassava varieties and 5th to 10th leaf of four sweet potato varieties, during short term (10 minutes) exposure to CO_2 concentrations *viz*. 400, 600, 800 and 1000 ppm, at 30ºC and 1500 $\mu mol/m^2/s$ Photosynthetic Photon Flux Density (PPFD) inside controlled climate cuvette using LI6400 portable photosynthesis system, LI-COR Inc, Lincoln, USA under WDS free and WDS conditions. To study the interactive effect of eCO_2 and temperature photosynthetic parameters were recorded at CO_2 concentrations *viz*., 400, 600, 800 and 1000 ppm at 28, 30, 32, 34, 36,38, 40, 42, 44 and 45ºC and 1500 $\mu mol/m^2/s$ PPFD using LI6400 portable photosynthesis system LICOR Inc, Lincoln, USA. The data were collected during three distinct active growing periods.

WDS free and WDS conditions have significant effect on photosynthetic parameters such as Photosynthetic rate (*Pn*), Stomatal conductance (g_s), Intercellular CO_2 concentration (*Ci*) and Transpiration (*Tr*) in cassava. Elevated

CO_2 have significant effect on photosynthetic parameters such as *Pn, Ci and Tr* in cassava. Impact of eCO_2 on g_s of cassava was not significant. Photosynthetic parameters also highly depend on the variety of cassava. However the variety was insignificant for *Pn* of cassava. The combined effect of eCO_2 and WDS was also found to be significant for all photosynthetic parameters. Temperature was an important factor and affected major photosynthetic parameters. The effect of temperature on *Pn* of cassava was not significant. However the combined effect of temperature and eCO_2 was significant.

In general elevated CO_2 have positive effects on photosynthetic potential of cassava. WDS reduces photosynthetic potential of cassava relative to WDS free conditions. However plants get benefits of eCO_2 even under WDS. Variations in temperature can become positive if plants are not under WDS. The variety is found to be an important factor and the responses of crops to WDS and higher temperature changed considerably with respect to the variety under eCO_2.

In India where cassava is largely grown under rain fed conditions, either the initial 6 months (as in Tamil Nadu) or the last 3-4 months (as in Andhra Pradesh and Kerala) of its growth period coincides with a seasonal drought (December-May) as well as contingent drought (failure of rain during normal monsoon) causing significant reduction in photosynthesis, dry matter production, tuber and starch yield. Besides drought, cassava crop is subject to high temperatures ($>30^oC$) in Southern and central India which imposes an additional stress for cassava growth.

Among cassava varieties the variety Sree Athulya had higher *Pn* at eCO_2 as well as at increasing temperature. However its performance was considerably affected by WDS. Sree Athulya can be recommended for places where temperature is high and water is available. Among the cassava varieties studied the variety Sree Vijaya had maximum performance under WDS compared to other varieties. Cassava variety Sree Vijaya also exhibited an increase in g_s under eCO_2

and it exhibit greater tolerance to eCO_2 environment. Sree Vijaya can be recommended for places where water is minimum.

WDS free and WDS conditions have significant effect on photosynthetic parameters such as *Pn*, g_s and *Tr* in sweet potato. However its effects were not significant on *Ci*. eCO_2 have significant effect on all major photosynthetic parameters in sweet potato. Photosynthetic parameters also highly depend on the variety of sweet potato. The combined effect of eCO_2 and WDS was also found to be significant for all photosynthetic parameters. Temperature was also an important factor and affected major photosynthetic parameters. *Pn* significantly increased with rise in temperature in sweet potato. The combined effect of temperature and eCO_2 was also significant.

Photosynthetic parameters have positive effects in sweet potato due to elevated CO_2. It also highly affected by WDS. However they get benefits of eCO_2 even under WDS. Increase in *Pn* with temperature can become positive if they are under WDS free conditions. The variety is also found to be an important factor and the responses of crops to WDS and higher temperature changed considerably with respect to the variety.

Among sweet potato varieties Sree Arun had maximum *Pn* under WDS free conditions. Bhu Krishna responds well to WDS under eCO_2. All sweet potato varieties exhibited an increasing trend in *Pn* with increase in temperature. Bhu Krishna is better adapted to higher temperature as well as drought conditions. Sweet potato variety Sree Kanaka exhibited an increase in g_s under $eCO_2$and it evinces greater tolerance to eCO_2 environment.

Tropical tuber crops like cassava and sweet potato are considered as “food security crops for future”. Findings from this study strongly support this statement. Because they can ameliorate the negative impacts caused by WDS and rising temperature with benefits attained from eCO_2. Compared to other important staple food crops they can be cultivated with low cost under adverse climate conditions such as WDS and rising temperature.

REFERENCES

REFERENCES

Ainsworth, E. A. and Rogers, A. 2007. The response of photosynthesis and stomatal conductance to rising [CO_2]: mechanisms and environmental interactions. *Plant, Cell Environ.* 30: 258-270.

Ainsworth, E. A., and Long, S. P. 2005. What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A metaanalytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. *New Phytol.* 165: 351-72.

Ainsworth, E. A., Davey, P. A., Bernacchi, C. J., Dermody, O. C., Heaton, E. A., Moore, D. J., Morgan, P. B., Naidu, S. L., Ra, H. S. Y., Zhu, X. G., Curtis, P. S. and Long, S. P. 2002. A meta analysis of elevated CO_2 effects on soybean (Glycine max) physiology, growth and yield. *Glob. Chang. Biol.* 8(8): 695-709.

Ainsworth, E. A., Rogers, A., Blum, H., Nosberger, J., and Long, S. P. 2003. Variation in acclimation of photosynthesis in *Trifolium repens* after eight years of exposure to free air CO_2 enrichment (FACE). *J. Exp. Bot.* 54: 2769-2774.

Allen, L. H., and Prasad, P. V. V. 2004. Crop responses to elevated carbon dioxide. *Encyclopedia of Plant and Crop Sci.* 346-348.

Allen, L. H., Pan, D., Boote, K. J., Pickering, N. B., Jones, J. W. 2003. Carbon dioxide and temperature effects on evapotranspiration and water-use efficiency of soybean. *Agron. J.* 95(4): 1071-1081.

Anjum, F., Yaseen, M., Rasul, E., Wahid, A. and Anjum, S. 2003. Water stress in barley (*Hordeum vulgare L.*). II. Effect on chemical composition and chlorophyll contents. *Pakistan J. Agric. Sci.* 40: 45-49.

Araus, J., Slafer, G., Reynolds, M. and Royo, C. 2002. Plant breeding and drought in C_3 cereals: What should we breed for? *Ann. Bot.* 89: 925-940.

Asher. C. J., Edawards, D. C. and Howler, R. H. 1980. *Nutritional disorders of Cassava*. St.Lucia, Queensland.

Baker, J. T. and Allen, L. H. 1993. Contrasting Crop Species Responses to CO_2 and Temperature: Rice, Soybean and Citrus. In: Rozema, J., Lambers, H., Van de Geijn, S. C. and Cambridge, M. L. (eds.), *CO_2 and Biosphere*. Kluwer Academic Publishers, Dordrecht, pp. 239-260.

Barnabas, B., Jager, K. and Feher, A. 2008. The effect of drought and heat stress on reproductive processes in cereals. *Plant Cell Environ*. 31: 11-38.

Baroowa, B. and Gogoi, N. 2014. Biochemical changes in black gram and green gram genotypes after imposition of drought stress. *J. Food Legum* . 27: 350-353.

Bernacchi, C. J., Morgan, P. B., Ort, D. R. and Long, S. P. 2005. The growth of soybean under free air CO_2 enrichment (FACE) stimulates photosynthesis while decreasing in vivo Rubisco capacity. *Planta* 220: 434-446.

Bhatt, R. K., Baig, M. J. and Tiwari, H. S. 2010. ECO_2 influences photosynthetic characteristics of *Avena sativa* L cultivars. *J. Environ. Biol.* 31: 813-818

Bolin, B. and Kheshgi, H. S. 2001. On strategies for reducing greenhouse gas emissions. *Proc. Natl. Acad. Sci. USA*. 98: 4850-4854.

Boyer, J. S. 1982. Plant productivity and environment. *Sci*. 218: 443-448.

Brown, L. 2009. *Plan B 4.0: mobilizing to save civilization*. W.W. Norton and Company, New York.

Burke, E. J., Brown, S. J. and Christidis, N. 2006. Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. *J. Hydrometeorol.* 7: 1113-1125.

Canadell, J. G., Le Quere, C. Raupach, M. R. Field, C. B., Buitenhuis, E. T., Ciais, P., Conway, T. J., Gillett, N. P., Houghton, R. A., and Marland, G.

2007. Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proc. Natl. Acad. Sci. USA* 104: 18866-18870.

Cen, Y. P. and Sage, R. F. 2005. The regulation of Rubisco activity in response to variation in temperature and atmospheric CO_2 partial pressure in sweet potato. *Plant Physiol.* 139: 979-990.

Chowdhury, R. S., Karim, M. A., Haque, M. M., Hamid, A. and Hidaka, T. 2005. Effects of enhanced level of CO_2 on photosynthesis, nitrogen content and productivity of mungbean (*Vigna radiata L. Wilczek*). *S. Pac. Stud.* 25: 97-103.

Cruz, J. L., Alves, A. A. C., Le Cain, D. R., Ellis, D. D. and Morgan, J. A. 2016. Elevated CO_2 concentrations alleviate the inhibitory effect of drought on physiology and growth of cassava plants. *Scientia Horticultura.* 210: 122-129.

Cruz, J. L., Alves, A. A. C., LeCain, D. R., Ellis, D. D., Morgan, J. A., 2014. Effect of elevated CO_2 concentration and nitrate: ammonium ratios on gas exchange and growth of cassava (*Manihot esculenta* Crantz). *Plant Soil* 374: 33-43.

Czeck, B. C., Jahren, A. H., Deenik, J. L., Crow, S. E., Schubert, B. A. and Stewart, M. 2012. Growth, yield, and nutritional responses of chamber-grown sweet potato to ecarbon dioxide levels expected across the next 200 years [abstract]. In: *Abstracts, American Geophysical Union, Fall Meeting* 2012.

Dai, A. 2013. Increasing drought under global warming in observations and models. *Nature Clim. Change* 3: 52-58.

De Oliveira, E. D., Bramley, H. Siddique, K. H., Henty, S., Berger, J., Palta, J. A. 2013. Can elevated CO_2 combined with high temperature ameliorate the effect of terminal drought in wheat? *Funct. Plant Biol*. 40: 160-171.

De Souza, A. P., Gaspar, M., Da Silva, E. A., Ulian, E. C., Waclawovsky, A. J., Nishiyama. M. Y., Dos Santos, R. V., Teixeira, M. M., Souza, G. M. and Buckeridge, M. S. 2008. ECO_2 increases photosynthesis, biomass and productivity, and modifies gene expression in sugarcane. *Plant Cell Environ.* 31: 1116-1127.

Drake, B. G., Gonzalez, M. A., and Long, S. P. 1997. More efficient plants: a consequence of rising atmospheric CO_2? *Annu. Rev. Plant Physiol. Plant Mol. Biol.* 48: 609-639.

Easterling, W. E., Aggarwal, P. K., Batima, P., Brander, L. M., Erda, L., Howden, S. M. 2007. Food, Fiibre And Forest Products. In: Parry, L. M., Canziani, O. F., Paultikof, J. P., Van der Linden, P. J. and Hanson, C. E. (eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the fourth assessment report of the intergovernmental panel on the climate change.* Cambridge University Press, Cambridge, pp. 273-313

El-Sharkawy, M. A. and Cock, J. H. 1990. Photosynthesis of cassava (*Manihot esculenthai*). *Exp. Agr.* 26: 325-340.

El-Sharkawy, M. A. 2006. International research on cassava photosynthesis, productivity, eco-physiology and responses to environmental stresses in tropics. *Photosynthetica* 44: 481-512.

Farooq, M., Basra, S. M. A., Wahid, A., Cheema, Z. A., Cheema, M. A. and Khaliq, A. 2008. Physiological role of exogenously applied glycinebetaine in improving drought tolerance of fine grain aromatic rice (*Oryza sativa L.*). *J. Agron. Crop Sci.* 194: 325-333.

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D. and Basra, S. M. A. 2009. Plant drought stress: effects, mechanisms and management. *Agron. Sustain. Dev.* 29: 185-212.

Fernandez, M. D., Tezara, W., Rengifo, E. and Herrera, A. 2002. Lack of downregulation of photosynthesis in a tropical root crop, cassava, grown under an elevated CO_2 concentration. *Funct. Plant Biol*. 29: 805-814.

Gerardeaux, E., Sultan, B. Palaï, O., Guiziou, C., Oettli, P. and Naudin, K. 2013. Positive effect of climate change on cotton in 2050 by CO_2 enrichment and conservation agriculture in Cameroon. *Agron. Sustain. Dev.* 33: 485-495.

Hao, X. Y., Han, X., Li, P., Yang, H. B. and Lin, E. D. 2011. Effects of elevated atmospheric CO_2 concentration on mung bean leaf photosynthesis and chlorophyll fluorescence parameters. *Ying Yong Sheng Tai Xue Bao* 22: 2776-80.

Harley, P. C., Thomas, R. B., Reynold, J. F., and Strain, B. R.1992. Modeling photosynthesis of cotton grown in eCO_2. *Plant Cell Environ*. 15: 271-282.

Hatfield, J. L., Boote, K. J., Kimball, B. A., Wolfe, D. W., Ort, D. R., and Izaurralde, C. 2008. Agriculture. In: Backlund, P., Janetos, A., Schimel, D. and Walsh, M. (eds.), *The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States*. U.S. Climate Change Science Program and the Subcommittee on Global Change Resources, Washington, D.C, pp. 21-74

Hatfield, J. L., Boote, K. J., Kimball, B. A., Ziska, L. H., ., Izaurralde, R. C., Ort, D., Thomson, A. M., Wolfe, D. W., 2011. Climate impacts on agriculture: implications for crop production. *Agron.. J.* 103: 351-370.

Hungershoefer, K., Breon, F. M., Peylin, P., Chevallier, F., Rayner, P., Klonecki, A., Houweling, S. and Marshall, J. 2010. Evaluation of various observing systems for the global monitoring of CO_2 surface fluxes. *Atmos. Chem. Phys*. 10: 10503-10520.

Imai, K., Coleman, D. F., Yanagisawa, T. 1984. Elevated atmospheric partial pressure of carbon-dioxide and dry matter production of Cassava (*Manihot esculenta Crantz*). *Jpn. J. Crop Sci.* 53: 479-485.

Intergovernmental Panel on Climate Change (IPCC, 2007) Climate change. 2007. The physical science basis. Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge

IPCC, 2001Retrieved on 05.05.2018 from https://www.ipcc.ch/ipccreports/far/wg_I/ipcc_far_wg_I_chapter_02.pdf

IPCC. 2007. Fourth Assessment Report. Intergovernmental Panel on Climate Change Secretariat. Geneva, Switzerland. http://www.ipcc.ch/

IPCC. 2014. Summary for policymakers. In: Field, C. B., Barros, V. R., and Dokken, D. J. (eds.), *Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, pp. 1-32.

IPCC. Climate Change 2014: Synthesis Report. 2014. Available from: http://www.ipcc.ch/ report/ar5/syr/ [Accessed: February 25, 2018]

Irikura, Y., Cock, J. H. and Kawano, K. 1979. The physiological basis of genotype temperature in cassava. *Field Crops Res.* 2: 227-239.

Jaleel, C. A., Gopi, R., Sankar, B., Gomathinayagam, M. and Panneerselvam, R. 2008a. Differential responses in water use efficiency in two varieties of *Catharanthus roseus* under drought stress. *Comp. Rend. Biol*. 331: 42-47.

Jaleel, C. A., Manivannan, P., Lakshmanan, G. M. A., Gomathinayagam, M. and Panneerselvam, R. 2008b. Alterations in morphological parameters and photosynthetic pigment responses of Catharanthus roseus under soil water deficits. *Colloids Surf. B: Biointerfaces*. 61: 298-303

Jaleel, C. A., Manivannan, P., Murali, P. V., Gomathinayagam, M. and Panneerselvam, R. 2008c. Antioxidant potential and indole alkaloid profile variations with water deficits along different parts of two varieties of Catharanthus roseus. *Colloids Surf. B: Biointerfaces* 62: 312-318.

Jaleel, C. A., Manivannan, P., Sankar, B., Kishorekumar, A. Gopi, R., Somasundaram, R. and Panneerselvam, R. 2007a. Pseudomonas fluorescens enhances biomass yield and ajmalicine production in Catharanthus roseus under water deficit stress. *Colloids Surf. B: Biointerfaces*. 60: 7-11.

Jaleel, C. A., Manivannan, P., Sankar, B., Kishorekumar, A., Gopi, R., Somasundaram and R. Panneerselvam, 2007b. Induction of drought stress tolerance by ketoconazole in *Catharanthus roseus* is mediated by enhanced antioxidant potentials and secondary metabolite accumulation. *Colloids Surf. B: Biointerfaces*. 60: 201-206.

Jaleel, C. A., Manivannan, P., Sankar, B., Kishorekumar, A., Sankari S. and Panneerselvam, R. 2007c. Paclobutrazol enhances photosynthesis and ajmalicine production in *Catharanthus roseus. Process Biochem*. 42: 1566-1570.

Jaleel, C. A., Sankar, B., Murali, P. V., Gomathinayagam, M., Lakshmanan, G. M. A. and Panneerselvam, R. 2008d. Water deficit stress effects on reactive oxygen metabolism in Catharanthus roseus; impacts on ajmalicine accumulation. *Colloids Surf. B: Biointerfaces* 62: 105-111.

Jata, S. K., Nedumchezhiyan, M. and Sivakumar, P. S. 2010. Adoptability and Adoption of Tropical Tuber Crops to Climate Change. *Orissa Rev.* 83-85.

Katayama, K., Kobayashi, A., Sakai, T., Kuranouchi, T. and Kai, Y. 2017. Recent progress in sweetpotato breeding and cultivars for diverse applications in Japan. *Breed. Sci.* 67:3-14.

Kauder, F., Ludewig, F. and Heineke, D. 2000. Response of potato plants to elevated carbon dioxide. *J. Expl. Bot.* 51: 429-437.

Keeling, K., Chin, J. F. S. and Whorf, T. P. 1996. Increased activity of northern vegetation inferred from atmospheric CO_2 measurements. *Nature* 382: 146-149.

Khan, A., Ijaz, M., Muhammad, J., Goheer, A., Akbar, G. and Adnan, M. 2016. Climate Change Implications for Wheat Crop in Dera Ismail Khan District of Khyber Pakhtunkhwa. *Pak. J. Meteorol.* 13: 17-27.

Kiani, S. P., Maury, P., Sarrafi, A. and Grieu, P. 2008. QTL analysis of chlorophyll fluorescence parameters in sunflower (*Helianthus annuus L.*) under well-watered and water-stressed conditions. *Plant Sci*. 175: 565-573.

Kiker , G. A. 2002 . CANEGRO-DSSAT linkages with geographic information systems: Applications in climate change research for South Africa. Proceedings of International CANGRO Workshop , Mount Edgecombe, South Africa.

Kumar, S., Muthusamy, S. K., Mishra, C. N., Gupta, V. and Venkatesh, K. 2018. Importance of Genomic Selection in Crop Improvement and Future Prospects. In: *Advanced Molecular Plant Breeding: Meeting the Challenge of Food Security*. CRC Press, Boca Raton, FL, USA. 275 p.

Lal, A., Gopikrishna, V. G. and Amalraj, M. 2014. A Study on the Scope and Importance of Tuber Crops with Special Reference to Cassava as Resilient Crop towards Climate change-Kerala. *J. Agric. Environ. Sci.s* 3: 157-174.

Lawlor, D. W. and Cornic, G. 2002. Photosynthetic carbon assimilation and associated metabolism in relation to water deficits in higher plants. *Plant Cell Environ*. 25: 275-294

Lawlor, D. W. and Mitchell, R. A. C. 2000. Crop Ecosystem Responses to Climatic Change: Wheat. In: Reddy, K. R. and Hodges, H. F. (eds.), *Climate Change and Global Crop Productivity*. CABI Publishing, UK, USA, pp. 57-80.

Lawson, T., Oxborough, K., Morison, J. I. L. and Baker, N. R. 2003. The responses of guard andmesophyll cell photosynthesis to CO2, O2, light and water stress in a range of species are similar. *J. Exp. Bot*. 54: 1743-1752.

Levitt, J. 1972. Responses of Plants to Environmental Stresses. Academic Press, New York. 698 p.

Lobell, D. B. and Field, C. B. 2007. Global scale climate-crop yield relationships and the impacts of recent warming. *Environ. Res. Lett.* 2:1-7.

Lobell, D. B. and Gourdji, S. M. 2012. The influence of climate change on global crop productivity. *Plant Physiol.*160: 1686-1697 .

Long, S. P., Ainsworth, E. A., Rogers, A. and Ort, D. R. 2004. Rising atmospheric carbon dioxide: Plants FACE the future. *Annu. Rev. Plant Biol.* 55: 591-628.

Madan, P. and Sangeetha, K. 2009. Impact of elevated CO_2 concentratration on growth and yield of chickpea. In: Aggarwal, P. K. (ed), *Global Climate Change and Indian Agriculture*: *Case studies from the ICAR Network Project.* ICAR, New Delhi, pp. 28-31.

Mahon, J. D., Lowe, S. B., Hunt, L. A. and Thiagaraja, M. 1977. Environmental effects on photosynthesis and transpiration in attached leaves of cassava (*Manihot esculenthai* Crantz). *Photosynthetica* 11: 121-130.

Makino, A. and Mae, T. 1999. Photosynthesis and plant growth at elevels of CO_2. *Plant Cell Physiol.* 40: 999-1006.

Maleki, A., Naderi, A. Naseri, R., Fathi, A., Bahamin, S. and Maleki, R. 2013. Physiological performance of soybean cultivars under drought stress. *Bull. Environ. Pharmacol. Life Sci.* 2: 38-44.

Massacci, A., Nabiev, S. M., Pietrosanti, L., Nematov, S. K., Chernikova, T. N., Thor, K. and Leipner, J. 2008. Response of the photosynthetic apparatus of cotton (*Gossypium hirsutum*) to the onset of drought stress under field conditions studied by gas-exchange analysis and chlorophyll fluorescence imaging. *Plant Physiol. Biochem*. 46: 189-195.

Medvigy, D. and Beaulieu, C. 2012. Trends in daily solar radiation and precipitation coefficients of variation since 1984. *J. Clim.* 25: 1330-1339.

Meehl, G. A., Stocker, T. F., Collins, W. D., Friedlingstein, P., Gaye, A. T., Gregory, J. M., Kitoh, A., Knutti, R., Murphy, J. M., Noda, A., Raper, S. C. B., Watterson, I. G., Weaver, A. J. and Zhao, Z. C. 2007. Global Climate Projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L. (eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 747-845.

Meng F, Zhang J, Yao F and Hao C. 2014. Interactive effects of ECO_2 concentration and irrigation on photosynthetic parameters and yield of maize in northeast China. *PLOS ONE* 9: 1-13.

Mishra, B., Babel, M. S. and Tripathi, N. K. 2014. Analysis of climatic variability and snow cover in the Kaligandaki River Basin, Himalaya, Nepal. *Theor. Appl. Climatol*. 116: 681-694.

Mortley, D., Hill, J., Loretan, P., Bonsi, C., Hill, W., Hileman, D. and Terse, A. 1996. Ecarbon dioxide influences yield and photosynthetic responses of hydroponically-grown sweetpotato. *Acta Horticulturae* 440: 31-36.

Nayar, N. M. 2014. The contribution of tropical tuber crops towards food security. *J. Root Crops* 40: 1.

Nelson, G. C. 2010. Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options, IFPRI Research Monograph. International Food Policy Research Institute, Washington, DC.

Nguyen, C. T., Hiroyuki, S., Etsushi, K. and Michio, K. 2017. Effects of elevated CO_2 concentration on growth and photosynthesis of Chinese yam under different temperature regimes. *Plant Prod. Sci*. 20(2): 227-236,

O'Leary, G. J., Christy, B., Nuttall, J., Huth, N., Cammarano, D., Stockle, C., Basso, B., Shcherbak, I., Fitzgerald, G. Luo, Q., Farre-Codina, I., Palta, J. and Asseng, S. 2015. Response of wheat growth, grain yield and water use to eCO_2 under a Free-Air CO_2 Enrichment (FACE) experiment and modeling in a semi-arid environment. *Glob. Chang. Biol.* 21: 2670-2686.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q. and Dasgupta, P. 2014. Climate Change 2014: Synthesis Report; Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC: Geneva, Switzerland.

PAGES 2k Consortium. 2013. Continental-scale temperature variability during the past two millennia. *Nat. Geosci.* 6: 339-346.

Peng, S., Huang, J., Sheehy, J. E., Laza, R. C., Visperas, R. M., Xuhua, Z., Centeno, G. S., Khush, G. S. and Cassmann, K. G. 2004. Rice yields decline with higher night temperature from global warming. *Proc. Natl. Acad. Sci. USA*. 101(27): 9971-9975.

Peters, W., Jacobson, A. R., Sweeney, C. A. E., Conway, T. J., Masarie, K., Miller, J. B., Bruhwiler, Lori, M. P., Petron, G., Hirsch, A. I., Worthy, D. E. J., van der Werf, G. R., Randerson, J. T., Wennberg, P. O., Krol, M. C., and Tans, P. P. 2007. An atmospheric perspective on North American carbon dioxide exchange: Carbon Tracker. PNAS, 104, 18925-18930.

Polley, H. W. 2002. Implications of atmospheric and climate change for crop yield. *Crop sci.* 42: 131-140.

Prasad, P. V. V., Allen, J. L. H. and Boote, K. J. 2005. Crop responses to ecarbon dioxide and interaction with temperature: Grain legumes. *J. Crop Improv.* 13: 113-155.

Prentice, I. C., Farquhar, G. D., Fasham, M. J. R. 2001. The carbon cycle and atmospheric carbon dioxide. In: Houghton, J. T., Ding, Y., Griggs, D. J. (eds.), *Climate Change: The Scientific Basis*. Cambridge University Press, Cambridge, pp. 183-237.

Prior S A, Runion G B, Marble S C, Rogers H H, Gilliam C H and Torbert H A. 2011. A Review of eatmospheric CO_2 effects on plant growth and water relations: implications for Horticulture. *Hort. Sci.* 46: 158-162.

Prior, S. A., Runion, G. B., Marble, S. C., Rogers, H. H., Gilliam, C. H. and Torbert, H. A. 2011. A Review of eatmospheric CO_2 effects on plant growth and water relations: implications for Horticulture. *Hort Sci.* 46: 158-162.

Ramanujam, T. 1990. Effect of moisture stress on photosynthesis and productivity of cassava. *Photosynthetica* 24: 217-224.

Ratnakumar, P., Vadez, V., Krishnamurthy, L. and Rajendrudu, G. 2011. Semi-arid crop responses to atmospheric eCO_2. *Plant Stress* 5: 42-51.

Ravi, V. and James, G. 2003. Studies on drought management in cassava. In: Annual Report, Central Tuber Crops Research Institute, Trivandrum. pp. 41-42.

Ravi, V. and Saravan, R. 2001a. Photosynthesis and productivity of cassava under water deficit stress and stress free conditions. *J. Root crops* 27: 214-218.

Ravi, V. and Saravanan, R. 2001b. Characteristics of photosynthesis and respiration in cassava and sweet potato. *J. Root Crops* 27: 258-62.

Ravi, V., More, S. J., Saravanan, R., Byju, G., Nedunchezhiyan, M., Devi, A. A. and Nair, K. P. 2019. Potential increase in photosynthetic response of taro (*Colocasia esculenta* L.) to photon flux density and elevated CO_2. *J. Environ. Biol.* 20(40)

Ravi, V., More, S. J., Saravanan, R., Nair, K. P. and Byju, G. 2018. Evaluation of photosynthetic efficiency of elephant-foot yam (*Amorphophallus paeoniifolius*) to photon flux density and elevated CO_2. *Current Hortic.* 6(1): 55-63.

Ravi, V., Ravindran, C. S., Ramesh, V. 2011. The impacts of climate change on photosynthesis and productivity of cassava and sweet potato: Effect of rise in temperature, CO_2 and UV-B radiation: an overview. *J. Root Crops*. 34(2): 95-107.

Ravi, V., Ravindran, C.S. and Ramesh, V. 2008. The impact of climate change on photosynthesis and productivity of cassava and sweet potato: Effect of high CO_2 , temperature and UV-B radiation: An overview. *J. Root Crops*, 34 (2): 1-13.

Ravi, V., Saravanan, R., Byju, G., Nair, K. P. and James, G. 2017. Photosynthetic response of sweet potato (*Ipomoea batatas*) to photon flux density and elevated carbon dioxide. *Indian J. Agric. Sci.* 87(9): 123-129.

Razzaque, M. A., Moynul, H. M. and Hamid, A. 2009. ECO_2 and nitrogen interaction in photosynthesis and productivity of modern and local rice (*Oryza sativa* L.) cultivars. *Agric.* 7: 105–12.

Razzaque, M. A., Moynul, H. M. and Hamid, A. 2009. ECO_2 and nitrogen interaction in photosynthesis and productivity of modern and local rice (*Oryza sativa L.)* cultivars. *Agriculturists* 7: 105-12.

Reddy, K. R. and Hodges, H. F. 2000. *Climate Change and Global Crop Productivity.* CABI Publishing, UK, USA, pp. 241-243.

Reddy, K. R., Prasad, P. V. V. and Kakani, G. V. 2005. Crop responses to e-carbon dioxide and interactions with temperature. *J. Crop Improv.* 13: 157-191.

Ringler, C., Zhu. T., Cai, X., Koo, J., and Wang. D. 2010.*Climate Change Impacts on Food Security in Sub-Saharan Africa: Insights from Comprehensive Climate Change Scenarios (No. 1042).* International Food Policy Research Institute (IFPRI), Washington, DC.

Rosenthal, D. M., Slattery, R. A., Miller, R. E., Grennan, A. K., Cavagnaro, T. R., Fauquet, C. M. and Ort, D. R. 2012. Cassava about-FACE: Greater than expected yield stimulation of cassava (*Manihot esculenta*) by future CO_2 levels. *Global Change Biol.* 18: 2661-2675.

Rosenzweig, R. and Hillel, D. 1995. Potential impacts of climate change on agriculture and food supply. *Consequences* 1(2): 1-25

Sathish, P., Kumar, V. G., Lakshmi, J. N., Vanaja, M., Yadav, S. K. and Vagheera, P. 2014. Impact of CO_2 enhancement on photosynthesis and protein profile-response studies with a CO_2 responsive blackgram genotype. *Int. J. Appl. Biol. Pharma. Technol.* 5: 93-98.

Schlenker, W., Roberts, M. J. 2009. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proc. Natl. Acad. Sci. USA* 106: 15594-15598.

Settele, J., Scholes, R., Betts, R. 2014. Terrestrial and inland water systems. In: Field, C. B., Barros, V. R. and Dokken, D. J. (eds.), *Climate Change 2014:*

Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge. pp. 271-359.

Sheehy, J. E., Mabilangan, A. E., Dionora, M. J. A. and Pablico, P. P. 2007. Time of day of flowering in wild species of the genus *Oryza*. *Int. Rice Res. Newsl.* 32: 12-13.

Singh, A. and Jasrai, Y. T. 2012. Response of crops to eatmospheric carbondioxide. *Proc. Indian Nat.l Sci. Acad.* 78: 45-49.

Singh, A., Phadke, S. V., Patwardhan, A. and Mehtha, J. S. 2011.Impact of drought and flood on Indian food grain production.10.1007/978-3-642-19360-6_32.

Sivaraman, S. 2015. Global Warming and Climate change causes, impacts and mitigation. Retrieved on 05.07.2019 from https://www.researchgate.net/publication/280548391

Smirnoff, N. 1993. The role of active oxygen in the response of plants to water deficit and desiccation. *New Phytol*. 125: 27-58.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., towprayoon, S., Wattenbach, M. and Smith, J. 2007. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* 363(1492): 789-813.

Sujatha, K. B., Uprety, D. C., Nageswara, R. D., Raghuveer, R. P. and Dwivedi, N. 2008. Up-regulation of photosynthesis and sucrose-P synthase in rice under ecarbon dioxide and temperature conditions. *Plant Soil Environ.* 54: 155-162.

Sun, J., Yang, L., Wang, Y. and Ort, D. R. 2009. FACE-ing global change: opportunities for improvement in photosynthetic radiation use efficiency and crop yield. *Plant Sci.* 177: 511-522.

Tahkokorpi, M., Taulavuori, K., Laine, K. and Taulavuori, E. 2007. Aftereffects of drought-related winter stress in previous and current year stems of *Vaccinium myrtillus L. Environ. Exp. Bot.* 61: 85-93.

Tans, P., and Keeling, R. 2016. Trends in Atmospheric Carbon Dioxide [Online]. NOAA. Available online at: http://www.esrl.noaa.gov/gmd/ccgg/trends

Taub, D. R., Miller, B., and Allen, H. 2008. Effects of elevated CO_2 on the protein concentration of food crops: a meta-analysis. *Glob. Chang. Biol.* 14, 565–575.

Teng, N., Wang, J., Chen, T., Wu X, Wang, Y. and Lin, J. 2006. ECO_2 induces physiological, biochemical and structural changes in leaves of *Arabidopsis thaliana*. *New Phytologist.* 172: 92-103.

Tezara, W., Mitchell, V., Driscoll, S. P. and Lawlor, D. W. 2002. Effects of water deficit and its interaction with CO_2 on the biochemistry and physiology of photosynthesis in sunflower. *J. Exp. Bot.* 53: 1781-1791.

Tezara, W., Mitchell, V., Driscoll, S. P. and Lawlor, D. W. 2002. Effects of water deficit and its interaction with CO_2 on the biochemistry and physiology of photosynthesis in sunflower. *J. Exp. Bot*. 53: 1781-1791.

Thinh, N. C., Shimono, H., Kumagai, E. and Kawasaki, M. 2017. Effects of elevated CO2 concentration on growth and photosynthesis of Chinese yam under different temperature regimes. *Plant Prod. Sci.* 20(2): 227-236.

Vanaja, M., Jyothi, M., Ratnakumar. P., Raghuram, R. P, Jyothi L. N., Yadav, S. K., Maheshwari, M. and Venkateshwarlu, B. 2008. Growth and yield response of castor bean (*Ricinus communis L.*) to two enhanced CO_2 levels. *Plant, Soil and Environ.* 54: 38-46.

Vanaja, M., Yadav, S. K., Archana, G., Lakshmi, J. N., Reddy, R. P. R., Vagheera, P., Razak, A. S. K., Maheswari, M. and Venkateswarlu, B. 2011. Response of C_4 (maize) and C_3 (sunflower) crop plants to drought stress and enhanced carbon dioxide concentration. *Plant Soil Environ.*57: 207-215.

Vu, J. C. V., Allen, L. H., Boote, K. J. and Bowes, G. 2008. Effects of eCO_2 and temperature on photosynthesis and Rubisco in rice and soybean. *Plant, Cell and Environ.* 20: 68-76.

Wang, D., Heckathorn, S. A., Wang, X., and Philpott, S. M. 2012. A meta analysis of plant physiological and growth responses to temperature and elevated CO_2. *Oecologia* 169: 1-13.

Wang, Z. and Huang, B. 2004. Physiological recovery of Kentucky bluegrass from simultaneous drought and heat stress. *Crop Sci*. 44: 1729-1736.

Warren, J. M., Jensen, A. M., Medlyn, B. E., Norby, R. J., and Tissue, D. T. 2014. Carbon dioxide stimulation of photosynthesis in *Liquidambar styraciflua* is not sustained during a 12-year field experiment. *AoB Plants* 7:plu074. doi: 10.1093/aobpla/plu074

Wheeler, R. M., Mackowiak, C. L., Sager, J. C. and Knott, W. M. 1994. Growth of soybean and potato at high CO_2 partial pressure. *Adv. in Space Res.* 14: 251-255.

Winkel, T., Renno, J. F. and Payne, W. 1997. Effect of the timing of water deficit on growth, phenology and yield of pearl millet (*Pennisetumglaucum (L.*) *R. Br.*) grown in Sahelian conditions. *J. Exp. Bot.*, 48: 1001-1009.

Wortmann , C. S., Mamo, M., Mburu, C., Letayo, E., Abebe, G. and Kayuki, K. C. 2009. *Atlas of sorghum production in eastern and southern Africa*. Univ. of Nebraska-Lincoln, Lincoln, NE .

Xu, Z. Z. and Zhou, G. S. 2006. Combined effects of water stress and high temperature on photosynthesis, nitrogen metabolism and lipid peroxidation of a perennial grass *Leymus chinensis. Planta* 224: 1080-1090.

Xu, Z., Jiang, Y., Jia, B. and Zhou, G. 2016. Elevated-CO_2 response of stomata and its dependence on environmental factors. *Frontiers in Plant Sci*. 7: 657.

Zhang, G., Sakai, H., Usui, Y., Tokida, T., Nakamura, H., Zhu, C., Fukuoka, M., Kobayashi, K. and Hasegawa, T. 2015. Grain growth of different rice cultivars under eCO_2 concentrations affects yield and quality. *Field Crops Res.*. 179: 72-80.

Ziska, L. H. and Bunce, J. A. 1997. Influence of increasing carbon dioxide concentration on the photosynthetic and growth stimulation of selected C_4crops and weeds. *Photosynth. Res.*. 54: 199-208.

APPENDIX-I

Meteorological data in the field for the experimental period
(01-10-2018 to 30-04-2019- monthly average)

Month and Year	Temperature (°C)		Relative Humidity (%)	Mean Solar radiation (W/m^2)	Soil Moisture (%)	Rainfall (mm)
	Minimum	Maximum				
October 2018	23.27	31.18	84.82839	179.90	20.24	296.7
November 2018	22.98	31.24	83.43	181.94	22.14	222.4
December 2018	23.05	31.42	81.23	193.31	14.19	30.9
January 2019	20.77	32.46	68.09	237.49	9.15	0
February 2019	23.04	32.88	72.49	245.34	11.49	35.5
March 2019	24.29	34.17	72.84	266.16	8.32	0.7
April 2019	25.33	34.37	74.73	247.37	9.63	35.2

STUDY THE IMPACT OF ABIOTIC STRESS ON PHOTOSYNTHETIC POTENTIAL OF TROPICAL TUBER CROPS UNDER ELEVATED CO$_2$

by

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ABSTRACT OF THE THESIS

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ABSTRACT

Climate change and agriculture are interconnected processes, both of which take place on a universal scale. Global warming is expected to have significant impacts on agriculture. Most of the studies reported a positive impact in photosynthetic rate of C_3 plants due to eCO_2. However other players of climate change such as drought and rising temperature can harmfully affect crops. Cassava and sweet potato are two major tropical root crops grown in India. The main objective of the present study was to figure out the impact of adverse conditions of climate change such as water deficit stress and high temperature stress on photosynthetic potential of tropical tuber crops under elevated CO_2 and there by identify crop/varieties suitable for changing climate conditions. The study was conducted during the period of October 2018 to July 2019 on four contrasting cassava and four contrasting sweet potato varieties. Observations on photosynthetic parameters *viz.*, the net photosynthetic rate (*Pn*), stomatal conductance (g_s) transpiration and sub-stomatal/intercellular CO_2 concentration (*Ci*) were recorded using a LI6400 portable photosynthesis system, LI-COR Inc, Lincoln, USA.

Elevated CO_2 have positive effects on photosynthetic parameters under WDS free as well as WDS conditions in cassava as well as sweet potato. Even though WDS reduces photosynthetic rate, eCO_2 could sustain greater *Pn* rate than ambient CO_2 under WDS. Under eCO_2 rising temperature can benefit cassava and sweet potato only under WDS free conditions. For cassava *Pn* was not significantly affected by temperatures. For sweet potato *Pn* significantly increased with rise in temperature. It indicates that increasing temperature is not a limiting factor for cassava and sweet potato, but beneficial for them under WDS free conditions. Responses of cassava and sweet potato to WDS and rising temperature are also influenced by the variety. Cassava variety Sree Athulya responses well to eCO_2 as well as to rising temperature under WDS free conditions. Cassava variety Sree Vijaya can perform well under WDS compared to other varieties. Sweet

potato variety Sree Arun exhibits higher *Pn* under WDS free conditions. Bhu Krishna and Kanhangad had high *Pn* under WDS as well as at higher temperature.

From this study it can be concluded that tropical root and tuber crops especially cassava and sweet potato have a great potential for better adaptation at elevated CO_2 environment under adverse climate conditions such as water deficit stress and increasing temperature. They can become crops providing food security for future environment under climate change.