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EFFECT OF ELEVATED CARBON DIOXIDE ON CELL WALL METABOLISM

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ABSTRACT

Climate change is the burning issue of the contemporary times. Elevated levels of CO_2, increased global temperatures, drought and salinity have impacted plant biodiversity and crop productivity in a big way. With global population explosion, the need of the hour is to increase plant productivity as well as improve the nutritional quality of the crop plants. It is mandatory to produce plants by genetically engineering them, in a manner that they are able to overcome the negative effects of these abiotic factors. Plant cell wall is a protective layer of the cell which counters the stress of external abiotic factors as well as the internal turgor pressure. Thus, it maintains the homeostasis in the cell. Elevated levels of CO_2 have been shown to affect the cell wall at the biochemical as well as molecular level. The study of effect of elevated CO_2 on plant cell wall is still in its infancy. It is essential to understand the mechanistic details of the biosynthetic pathway to elucidate the role of elevated CO_2 in making plants adapt to the various stresses of climate change. Plant sequesters CO_2 in the form of photosynthate. Plant cell wall is a great sink for the carbon assimilated in the plant. Additionally, it is also preparing the plant to adapt to the adversities of climate change. An in-depth knowledge of the biosynthetic pathway as well as resultant cell wall modifications will give us an insight into how to tackle the problem of climate change. The information received through these basic studies can help in designing genetically engineered plants which can undergo modifications in cell wall architecture to be able to tolerate the impact of climate change. The review helps us identify the target molecules in the cell wall which when produced by genetic engineering can help plant overcome the adverse effects of elevated levels of CO_2.

KEYWORDS: Elevated CO_2, Cell wall, Carbon Sequestration, Carbon Sink, Abiotic Stress, Homeostasis.

INTRODUCTION

Climate is changing at an alarming rate. The earth is warming up and the climatic events are becoming more and more erratic and intense. There are long periods of rain fall followed by intensive droughts. These events lead to increased soil salinity. There is continuous increase in the greenhouse gasses due to industrialization, deforestation, burning of fossil fuels and beyond all, the anthropogenic activities. Carbon dioxide exists as a trace gas in air. In the pre-industrial period, the concentration of carbon dioxide in atmosphere was 280 ppm and at present its concentration has increased to 414.7 ppm. It is estimated to further increase the temperature of atmosphere by 2 and 4 degrees centigrade in 2050 and 2100 respectively.[1] Such an alarming increase in the concentration of carbon dioxide has serious implications on our ecosystems. The change in the carbon dioxide levels in atmosphere has been shown to affect the structure of plant cell wall also.

Climate change has adversely affected environment in several aspects. It has resulted in increased temperatures, high concentration of greenhouse gasses, soil salinity and water deficit. All these factors are affecting the plant biodiversity and its productivity. There is global population explosion and extreme shortage of food. The need of the hour is to increase crop productivity together with the nutritional content of the crops. There is global emergency to counter these negative effects of the climate change. Plants are the natural sinks of CO_2. They are essential to sequester atmospheric CO_2. Increase in the concentration of atmospheric carbon dioxide has resulted in the increased photosynthetic rates. Under high temperature and conditions of water deficit the photosynthetic rates have been found to increase further. Synthesis of photosynthate increases in the plants exposed to the elevated CO_2.[2] Further studies have demonstrated that increased carbohydrate synthesis is translocated to plant parts below the ground.[3]

Effect of environmental factors on the growth of plants

Growth is a biophysical process. Plant growth and development is influenced by several endogenous and environmental factors. With the change in climatic conditions the levels of carbon dioxide have risen tremendously. It has been demonstrated that besides increased rates of photosynthesis and consequent increase in biomass, the carbon allocation to the storage areas of the plants is also affected under conditions of elevated CO_2. The change in this abiotic factor also results in lowering the levels of nitrogen content in leaves thereby reducing the nutritional content of the crop.[4] Further studies have also exhibited decreased protein content of leaves. This has resulted in changes in eating habits of insects feeding on leaves. They require much more quantity of leaves of such plants to maintain their protein intake.[5] Assimilation of CO_2 by the plants results in the production of photosynthate. The carbohydrates thus synthesized are structural as well as nutritional carbohydrates. The structural carbohydrates constitute the plant cell wall. The cell walls are made up of complex polysaccharides. Increased rates of photosynthesis are required not only for meeting the food requirements but are also essential for sequestering CO_2 to mitigate greenhouse effects.

Composition of cell wall

Plant cells are delimited by the presence of cell wall. The cell wall is composed of primary cell wall which is thin and extensible. The secondary cell wall is thick and rigid. The primary cell wall is chemically composed of cellulose which is embedded in a matrix of pectin which is essentially made up of polygalacturonic acid. Hemicellulose and several glycoproteins are also an important constituent of plant cell wall.[6] Secondary cell wall is deposited inside primary cell wall and is chemically composed of lignin. Lignin fills up the interstitial spaces in the cellulosic matrix of the cell wall and makes it hard. There is a middle layer known as middle lamella which is composed of magnesium and calcium salts of pectin. The remarkable properties of strength and plasticity are attributed to primary cell wall. The strength, composition and structural architecture depends largely on the cell type, age of plant and the plant species. These components interact amongst themselves and with the environment to contribute towards the maintenance of cell homeostasis. Cell wall faces external environmental stress and from within the turgor pressure of the cell. The mechanical strength is therefore required to counter these external stresses as well as the internal pressures.[7]

Therefore, cell wall is considered to be an extremely dynamic structure which is responding continuously to the changing environment by modifications and altered interactions of its various components.[8] Cell wall provides shape and offers protection to plant cells from various abiotic and biotic stresses. Several abiotic factors have been studied that affect cell wall metabolism.[9] It has been reported that several of these factors influence growth / expansion of the cell wall. The various components of the cell wall are synthesized at different locations in the cell. Golgi apparatus is the site of synthesis of hemicellulose and pectin. These are then sent to the apoplastic region of the cell. Cellulose synthesis occurs by the activity of the enzyme cellulase synthase located in the plasma membrane. The cell wall components are crucial for the purpose of cellular adhesion with the neighbouring cells and hence communication is established between the adjacent cells.

Effect of elevated CO_2 on the synthesis of cell wall components

Elevated carbon dioxide levels have been instrumental in altering plant metabolism to a great extent. These have exhibited enhanced rate of photosynthesis thereby resulting in increased biomass and greater synthesis of carbohydrates. Crop productivity has been shown to increase during elevated levels of carbon dioxide. The biotic and abiotic factors have also been observed to affect cell wall metabolism at the molecular as well as biochemical level.[10]

The effects of increased atmospheric carbon dioxide concentration have been reported to not only cause changes in photosynthetic rates but also in biosynthetic metabolism of cell wall. Elevated atmospheric carbon dioxide has been reported to trigger biosynthesis of cellulose and pectin leading to increase in cell size, cell wall thickness, dense wood and increased xylem hydraulic capacity but decrease in stomatal and leaf hydraulic conductance and therefore plants will become more prone to drought stress.[11]

The recent research has indicated role of receptor mediated signalling of cell wall metabolism. The oligosaccharide fragments of the cell wall play crucial role in the development of cell wall as well as the cell immunity. This contributes to the alteration in the structure of the cell wall in response to the various environmental factors. It is suggested that these cell surface receptors perceive the signal and in turn activate expression of certain genes responsible for the cell wall proteins. Hydroxyproline rich glycoproteins have a critical role to play in this signalling cascade. They also contribute towards stress tolerance and differentiation process of the plant cell wall.[12] These proteins play a pivotal role in cell enlargement and cell expansion. Some of the important proteins involved in structural modification of the cell wall are xyloglucan hydrolase, endoglucanase and expansins. In *Arabidopsis* about 2000 genes have been shown to be involved in the process of synthesis, structural alterations and turnover of the components of the cell wall. *Arabidopsis,* grown under conditions of elevated CO_2, exhibited increase in biomass before the onset of flowering. The precursor for the polysaccharide synthesis is the nucleotide sugar uridine diphosphate (UDP) glucose. Biochemical studies conducted in this plant revealed increased activity of the key enzyme UDP-Glucose dehydrogenase of the cell wall biosynthetic pathway. Although there was significant increase in the biomass of the plant there was no marked difference in the composition of the cell wall. In another experiment with the same plant long term exposure to increased concentration of atmospheric carbon dioxide resulted in up-regulation of expression of the cellulose synthase genes and pectin biosynthesis genes causing changes in plant cell wall composition.[13] A research study conducted on basil revealed that an increase in atmospheric carbon dioxide from 360 to 620 μL L−1 led to a significant increase in its biomass. It may have been due to the improved photosynthetic activity caused mainly by the suppression of oxygenation activity of Rubisco enzyme.[14]

The experimental work has demonstrated elevated CO_2 enhances plant growth and increases cell wall components by biochemically modulating the biosynthetic pathway. Studies have shown that the synthesis of cellulose, hemicellulose and pectins increase under conditions of elevated CO_2. However, lignin synthesis has been found to decrease. Further, lignin biosynthesis is known to be induced in plants which are unresponsive to elevated CO_2.

Climate change has also resulted in soil salinity which is extremely inhibitory to the growth of the plant. Increased salt concentration in the soil induces osmotic stress to the plant. Plants possess inherent systems to overcome these stresses. They accumulate ions at the expense of additional energy in order to maintain their endogenous water levels. These salt tolerant mechanisms are dependent on higher levels of endogenous carbohydrates which act as the energy source. Thus, conditions of elevated CO_2 provide additional photosynthate and source of energy to the plant to combat salinity stress. In a study in two cultivars of barley it was observed that under elevated conditions of CO_2 it could manage osmotic adjustments in soils showing high salt concentration.[15]

Modification of cell wall components in response to elevated CO_2

The four major impacts of climate change are elevated CO_2, increased temperature, water scarcity, and salinity. It has been observed that all these abiotic factors affect crop productivity. They also influence cell wall biosynthetic pathway there by modifying the cell wall. These modifications in the cell wall help overcome the impact of abiotic stresses and hence come up with adaptive mechanisms. CO_2 gains initial entry into the leaf through the stomatal aperture. The modified primary cell wall acts as a barrier and controls the permeability into the palisade tissue of the leaf. These modifications eventually affect the conductance of the mesophyll cells. Even leaf area has been shown to increase in response to elevated CO_2. Cell wall polysaccharides after synthesis have been shown to undergo structural modifications by the enzymatic activity of several enzymes. The modified polysaccharides make a difference towards cell cohesion and the firmness of the cell. These modifications play a critical role in fruit ripening or proper seed or root development. Balance between the nutritional and structural carbohydrates is very crucial for the growth of the plant.[16]

CONCLUSION

The study of effect of elevated CO_2 on plant cell wall biosynthesis is still in its infancy. It is essential to understand the mechanistic details of the biosynthetic pathway to elucidate the role of elevated CO_2 on making plants adapt to the abiotic stresses. Plant sequesters CO_2 in the form of photosynthates. Plant cell wall is a great sink for the carbon sequestration in the plant. Additionally, it is also preparing the plant to adapt to the adversities of climate change. An in-depth knowledge of the biosynthetic pathway as well as resultant cell wall modifications will give us an insight into how to tackle the problem of climate change. Another important issue is to find out the degree to which elevated CO_2 can increase photosynthetic rate to combat negative effects of greenhouse gasses being generated. The information received through these basic studies can help in designing genetically engineered plants which can under go modifications in cell wall architecture to be able to tolerate the impact of climate change. The review helps in identifying the target molecules in the cell wall. The attempts can be made in the direction of producing genetically engineered plants to aid in mitigating the impact of elevated levels of CO_2. Also, it is essential to understand the mechanism of in vivo balance between carbon assimilation and cell wall homeostasis.

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