Approaches that could be used to enhance Photosynthesis to ensure Future Global Food Security

Name:

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Introduction

Janssen et al. (2014) argue that photosynthesis efficiency impacts the global demand of nutrition with previous data showing poor crop yields far below the projected output. This has led to an imbalance between the yield and the projected population increase thus global food insecurity (Federoff et al., 2010; Long, 2014). The inspiration behind modern photosynthesis research is sustainable agriculture (Nair, 2014) with the main challenge remaining on increasing the yields in the midst of shrinking water and land resources. Further, human activities and industrialization have increased the greenhouse gas effects (GHGs) implying a significant change in the global climate and weather patterns. With this background in mind, alternative biotechnological procedures have to be developed to improving the photosynthesis process hence higher yields (Edwards & Huber, 2014). The paper will be exploring the probable reasons why C3 and C4 plant crops lack in the ability to increase yield besides providing reasons for enhancing photosynthesis.

Background

Globally, there is a high demand for food because of population growth, changing diets, and increasing affluence. According to the United Nation's Food and Agricultural Organisation forecast, there will be a need to have a 40% increase in food production in the next decade and 70% increase in 2050. In response, the UK and U.S. have invested significant resources through the funding of bodies such as the US National Science Foundation (NSF) and the Biotechnology and Biological Sciences Research Council (BBSRC) to promote scientific research projects. The objective of this research is to transform and enhance the photosynthetic process by way of increasing its rate hence higher crop yields (Tai, Heald, & Martin, 2014). Concisely, the inefficient Rubisco has been attributed to poor crop performance, and enhancement can be

performed by increasing CO_2 around Rubisco or modification of its kinetic properties (Raines, 2011). The C4 photosynthetic pathway assists the CO2-concentrating process, and this is likely to attain higher effectiveness in their utilisation of light, water as well as nitrogen in comparison to C3 plants.

Naturally, photosynthesis is considered as one of the most sustainable and efficient processes where water in the presence of chlorophyll, CO_2 and light produces oxygen and carbohydrates. Therefore, carbohydrates are dependent on the efficiency of the reaction. Biochemical and physical modification facilitated natural optimization of the breakdown process so that it adapts to particular ecological niches (Yamori et al., 2016). For example, plants that had C3 pathways evolve to C4 under certain conditions experienced a 50% efficiency increase in their photosynthetic process (Janssen et al. 2014). However, the rate of plant evolution from C3 to C4 has not been commensurate to population explosion even going into the future. The incorporation of CO_2 into ribulose 1,5-biphosphate (RµBP) by ribulose 1,5-biphosphate carboxylase/oxygenase (RµBisCO) initiates carbohydrate synthesis within the Calvin-Benson cycle, and this influences biomass production and plant growth (Whitney et al., 2011a).

The C_3 Cycle

Raines (2011) intuit that photosynthetic organisms use this type of cycle as the main pathway of carbon integration in the photosynthetic process. Therefore, it is important to note that it absorbs 100 billion tons of carbon every year hence the solitary largest component of biological carbon in the environment (Long, Marshall-Colon, & Zhu, 2015). Comprehending how the Calvin cycle responds to external environmental circumstances and altered demands for the plant's photosynthate is important for attempts to improve crop yield and to redirect carbon to essential products. The cycle uses the "products of the light reactions of photosynthesis, ATP

and NADPH, to fix atmospheric CO2 into carbon skeletons that are used to fuel the rest of plant metabolism" (Stitt et al., 2010). The carboxylation of ribulose-1,5 is catalyzed (RuBP) (which is a CO_2 acceptor molecule) to initiate the cycle. Two products are known as the dihydroxyacetone phosphate and triose phosphates glyceraldehyde phosphate (G-3-P) are formed through two reactions and resulting from 3-GPA had been formed from the initial reaction. In the said reaction, NADPH and ATP are consumed (Ort et al., 2015). There is a re-forming phase of the cycle where a sequence of reactions occurs to transform the triose phosphates into RuBP (Carbon dioxide acceptor molecule). Consequently, carbon composites resulting from this cycle are important plant progress and development. Therefore the more the formation of RuBP, the higher absorption of CO_2 thus higher crop yields. Figure 1 below shows a schematic diagram of the C3 cycle.

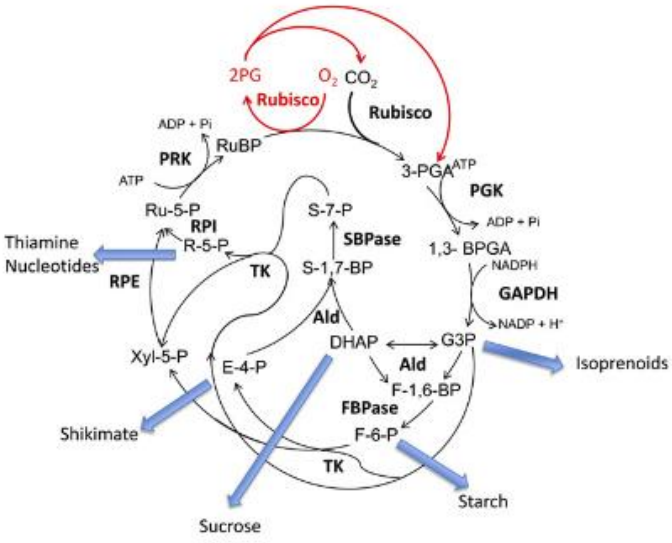

Fig. 1 shows a C3 cycle by Stitt et al. (2010)

From the figure above there are two key reactions namely carboxylation and oxygenation reactions. The carboxylation process has been explained in summary above. The process of oxygenation of Rubisco fixes oxygen into RuBP producing 2-phosphoglycolate (2PG) and PGA

which is complemented by the photorespiration process (indicated in red), and this releases PGA and CO_2.

Increasing photosynthesis in plants

The incorporation of carbon dioxide into biological compounds is catalyzed by Rubisco. Unfortunately, Rubisco reacts with Oxygen but wastefully causing the previously assimilated, nitrogen, energy, and CO_2 to be released (Lin et al., 2014). Another reason for inefficiencies caused by Rubisco is that it is very slow and large amounts of leaf soluble protein and leaf N are required to lead to enough photosynthetic rates (Slattery & Ort, 2015). Apparently, some variation in Rubisco's catalytic properties has been performed and exploiting this variation is likely to lead to better photosynthetic characteristics to specific environments and crops (Zhu, Long, and Ort, 2010). In their report, "*A faster Rubisco with the potential to increase photosynthesis in crops",* Whitney, Houtz, and Alonso, 2011 affirm that,

> "C4 plants, cyanobacteria, and hornworts have evolved forms of CO2-concentrating mechanisms (CCM) that allow them to utilize faster forms of Rubisco that have lower CO2 affinity, whereas C3 plants, which lack a CCM, are constrained to express forms of Rubisco with higher CO2 affinity but a relatively low rate of turnover" (p. 2).

The C4 pathway

It refers to the mechanism of photosynthesis that takes place in two adjoining categories of cells that are the bundle sheath and the mesophyll cells in plants species known as C4 plants. The C4, as well as C3 cycles, function in the dark reactions of the photosynthetic process; however spatially, meaning that this occurs in diverse cells that include C4 in the mesophyll layer, which is followed by the C3 cycle that takes place in the sheath tissues (Edwards & Huber, 2014).

Carbon (II) oxide initially gets into the leaf and the mesophyll layer of cells. Afterward, it is hydrated to give HCO_3^- located in the cytoplasm where the catalyst is carbonic anhydrase. It is the leading step in the C4 pathway, and then the carboxylation reaction follows using HCO_3^- in place of Carbon (II) oxide as the inorganic carbon substrate (Edwards & Huber, 2014).

HCO_3^- fuses with the three-carbonic acid phosphoenolpyruvate to create ($C_4H_4O_5$). The carboxylating enzyme phosphoenolpyruvate carboxylase catalyzes the fusion. Oxaloacetic acid is a 4-carbon product; therefore, the phrase C4 photosynthesis pathway.

i. Hydration of CO_2 (carbonic anhydrase as the catalyst)

$CO_2 + H_2O$ ----------> H_2CO_3 ----------> $HCO_3^- + H^+$

ii. Carboxylation of HCO_3^- (catalyzed by PEPcase)

HCO_3^- + PEP ----------> oxaloacetic acid

The resultant product is mainly presented as illustrated where the hydration activities are resulting in the production of HCO_3^-:

PEPcase

(Carbon dioxide) CO_2 + PEP----------> OAA

Oxaloacetic acid is reduced to $C_4H_6O_5$ and can also be transaminated to $C_4H_7NO_4$ and transmitted to the neighboring sheath cells. For the malic acid, it is used in two manners: to distribute the carbon (II) oxide and for regenerations of PEP for the subsequent reactions (Edwards & Huber, 2014).

Initially, the malate or the malic acid is decarboxylated where CO_2 is isolated, and the (pyruvic acid= $C_3H_4O_3$) is generated. Pyruvic acid or pyruvate is taken back to the mesophyll cell for the phosphorylation process to convert it to PEP, the carbon dioxide acceptor in the C4 cycle. CO_2 that is released go into the C3 cycle photosynthesis in the sheath cells (Wheeler & Von Braun, 2013).

Just like in the C3 cycle, the result of the reactions in the vascular bundle sheath is the (G_3P, $C_3H_7O_6P$). Likewise, other molecules of the C3H7O6P go through reactions to produce RuBP, which is the carbon (II) oxide acceptor in the C3 cycle (Edwards & Huber, 2014). Other particles leave the reaction and progress the creation of glucose as well as other organic molecules that florae require.

The C4 pathway is efficient regarding resistance to photorespiration that is a wasteful process. The first carbon (II) oxide-fixing enzyme PEPcase in the reaction it has no activities as oxygenase and; hence, it does not contribute to oxygen fixation even the time it is in high concentration in the cell.

Hence, the C4 acts as a carbon dioxide-concentrating instrument for the sheath tissue. Increased concentration of carbon dioxide encourages the fixation of carbon (II) oxide rather than oxygen, by rubisco. Therefore, photorespiration is repressed (Edwards & Huber, 2014). Nonetheless, the pathway of CO_2 decrease expends more energy concerning 5ATP as compared with the C3 photosynthesis process that releases 3ATP.

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