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Climate Resilient Future Crop: Development of C_4 Rice

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Rice is a staple food for more than half of the human population and a primary food source for the world's poorest people. Asia currently accounts for 90 percent of global rice production but it will need to increase this by 50 percent within the next 30 years. By that time the region will be home to nearly 90 percent of the global population increase and will likely be experiencing extreme climatic conditions. Agriculture will be challenged by diminishing water resources, reduced nutrient inputs and an increase in abiotic stresses. Rice yield increases have already stagnated and so a new paradigm is needed to meet these future challenges.

Most crop plants, like rice and wheat, have a simple and less efficient photosynthetic mechanism (C_3 photosynthesis) that as a consequence results in considerable loss of water through stomatal pores on their leaves that open widely to let in more carbon dioxide. They also make a large amount of photosynthetic protein to maximize their photosynthetic rate that requires a large investment of nitrogen and hence fertilizer application.

However, a few plants have evolved a more efficient C4 photosynthetic pathway that greatly alleviates these problems. The installation of a C4 photosynthetic pathway into major crops like rice could potentially increase yields by 50 percent, double the water-use efficiency and reduce fertilizer use by 40 percent. This is because plants with a C4 photosynthetic pathway concentrate CO2 within the leaf prior to photosynthetic fixation leading to increased photosynthetic efficiency and large reductions in the requirement for scarce resources like water and nitrogen (fertilizer). These modifications would be particularly advantageous in future climate scenarios where water scarcity and global temperature are predicted to increase.

Genome-wide identification and analysis of biotic and abiotic stress regulation of C_4 photosynthetic pathway genes in rice photosynthetic fixation of CO_2 is more efficient in C_4 than in C_3 plants. Rice is a C_3 plant and a potential target for genetic engineering of the C_4 pathway. It is known that genes encoding C_4 enzymes are present in C_3 plants. In this study Expression levels of C_4 specific gene family members in flag leaf during tillering stage were quantitatively analyzed in five rice genotypes. The results showed that all the identified genes expressed in rice and exhibited differential expression pattern during different growth stages, and in response to biotic and abiotic stress conditions and hormone treatments.

The physiological and molecular mechanisms of low-nitrogen (N) tolerance in transgenic plant lines containing C4 phosphoenolpyruvate carboxylase (C_4-PEPC) gene. The transgenic rice lines only over-expressing the maize C_4-PEPC) (PC) and their untransformed wild type, Kitaake (WT), were used in this study. The PC line, having lower total N and higher soluble sugar contents, was more tolerant to low-N stress than WT. The photosynthetic parameters, enzymatic activity levels, transcripts and products related to photorespiration in PC were also greater than in WT under low-N conditions. This study showed that increased carbon levels in transgenic rice lines overexpressing C_4-PEPC could help regulate the photorespiratory pathway under low-N conditions, conferring low-N tolerance and a higher grain yield per plant.

Engineering C_4 photosynthesis into rice is one of the many possibilities for improving photosynthetic capacity in rice. Future climates are expected to be more variable. A C_4 rice has the potential to deliver a very large improvement in yield for future conditions, it would double water-use efficiency and increase nitrogen use efficiency. Knowledge gained during the C_4 rice engineering will advance our understanding of C_3 and C_4 photosynthesis, and we can also use this knowledge to improve the efficiency of existing C_4 crops for food security and to provide novel biofuel feedstocks.

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