



Oxford Cambridge and RSA

# A Level Biology B (Advancing Biology)

**H422/02** Scientific literacy in biology

Insert

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**Time allowed: 2 hours 15 minutes**



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## TURBOCHARGED PHOTOSYNTHESIS?

As the world's population increases, the spectre of severe food shortages is growing, with the United Nations predicting that food production will need to double by 2050. Researchers have taken an important step towards enhancing photosynthesis. They have engineered plants using enzymes from cyanobacteria, which speeds up the process of converting carbon dioxide into sugars.

Researchers have long wanted to increase yields by targeting D-ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco), the key enzyme responsible for carbon dioxide fixation. Rubisco can account for up to half of the soluble protein found in a leaf. The reason for its abundance is to compensate for its slow catalysis. The enzyme is inefficient because it cannot discriminate between oxygen and carbon dioxide and so wastes energy by fixing oxygen.

The enzyme evolved at a time when oxygen levels in the atmosphere were much lower than they are today. There was little evolutionary pressure to select for an ability to discriminate between oxygen and carbon dioxide molecules. Photosynthetic organisms have evolved two solutions to cope with the problems of rising oxygen levels:

- a slower acting version of Rubisco with an improved ability to discriminate between carbon dioxide and oxygen
- carbon dioxide concentrating mechanisms (CCMs).

Researchers have estimated that tinkering with Rubisco and boosting the concentration of carbon dioxide around it could generate up to a 60% increase in the yields of rice and wheat. They are focused on introducing CCMs into crops to increase photosynthetic carbon dioxide fixation.

CCMs have evolved independently in cyanobacteria. One example involves a series of membrane-bound pumps for carbon dioxide and hydrogencarbonate ions ( $\text{HCO}_3^-$ ) and special compartments called carboxysomes, which contain Rubisco.  $\text{HCO}_3^-$  ions are pumped into the cell and then converted to  $\text{CO}_2$  in the carboxysomes by the enzyme carbonic anhydrase (CA). This increases the local  $\text{CO}_2$  concentration and increases Rubisco efficiency. Furthermore, cyanobacteria have retained an ancient form of Rubisco that is almost three times as efficient as that found in many crops.

Fig. 1a shows the arrangement of CCMs in cyanobacteria. Fig. 1b shows a plant cell after transfer of  $\text{HCO}_3^-$  pumps and carboxysomes.

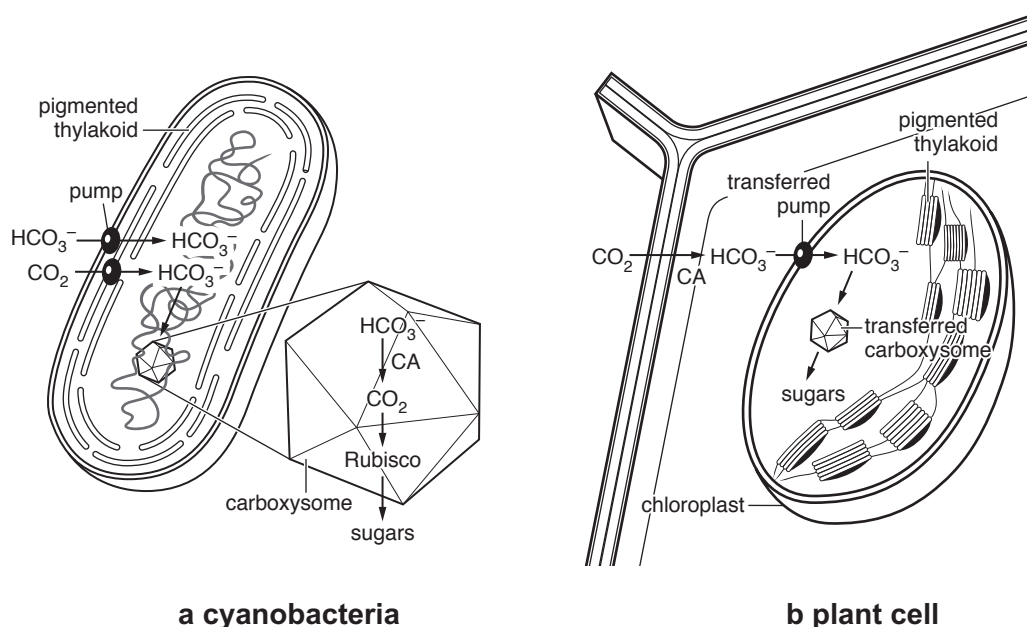


Fig. 1

Scientists from Cornell University in New York and Rothamsted Research in the UK have collaborated on work with tobacco plants (*Nicotiana tabacum*), a common model organism for genetic engineering research. They have taken the faster Rubisco genes from the cyanobacterium *Synechococcus elongatus* and inserted them into the genome of chloroplasts in the tobacco plants.

The ability of two strains of modified plants to carry out photosynthesis was assessed by measuring their rate of CO<sub>2</sub> fixation. Table 1 shows the results of these experiments with two modified strains of tobacco plant (Rbcx and M35) and the unmodified (wild-type, WT) tobacco.

CO <sub>2</sub> concentration ( $\mu\text{mol dm}^{-3}$ )	Rate of CO <sub>2</sub> fixation in tobacco plants (mol CO <sub>2</sub> fixed per mol active sites s <sup>-1</sup> )					
	Rbcx		M35		WT	
	Mean	SD	Mean	SD	Mean	SD
125	2.91	0.18	3.29	0.38	1.85	0.16
250	4.25	0.30	4.67	0.55	1.88	0.17
640	5.71	0.30	6.38	0.77	1.53	0.15

**Table 1**

Researchers now agree that two improvements are needed: a faster version of Rubisco as well as bacterial carboxysome membrane-bound pumps for CO<sub>2</sub> and HCO<sub>3</sub><sup>-</sup>. Scientists are working on the transfer of cyanobacterial carboxysomes or CCM pumps into the chloroplasts of tobacco plant cells. However, extending this to crop plants is still a long way off.

It now seems certain that supercrops with “turbocharged photosynthesis” will be growing in fields in a few decades. This seems like great news in a world where demand for food, biofuels and plant materials like cotton continues to increase, and where global warming will have an ever greater impact on crop production. However, critics of genetic modification have long argued that GM crops will have disastrous effects on ecosystems. So far these fears seem exaggerated. There are monster plants rampant through many countries, but they are not GM creations – they are invasive species.

This is not surprising; most GM traits are not useful to wild plants. A trait such as herbicide resistance is only useful to plants growing in areas where herbicides are used, such as in fields and road verges. However, if biologists succeed in boosting CO<sub>2</sub> fixation by 25 per cent or more, the upgraded plants will have a selective advantage over wild types. This may add fuel to the anti-GM campaign, with protests against the introduction of turbocharged crops and the debate of growing superplants in open fields.

The arguments in favour are also powerful. An ecosystem based on superplants would support more life overall.

If society decides to go ahead with this technology, further choices arise. Humans could just stand by and let boosted grains, vegetables and trees run wild. An alternative to this could be to upgrade many wild plants too. For many, this may seem like a shocking idea. However, the reality is that the areas we think of as wild and untouched are nothing like they were before our ancestors arrived.

Adapted text from:

'Should we upgrade photosynthesis and grow supercrops?' Michael Le Page; *New Scientist* Magazine issue 2989 published 4 October 2014

'A faster Rubisco with potential to increase photosynthesis in crops'. Linn et al; *Nature* **513**,547–550 (Published online 17 September 2014)

'Hacked photosynthesis could boost crop yields'; Heidi Ledford; *Nature*  
doi:10.1038/nature.2014.15949

'Towards turbocharged photosynthesis' G.Dean Price; S.M Howitt; *Nature* Volume 513; *Nature* 497. Pub Macmillan Publishers Ltd. 2014

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