A Level Biology B

H422/02 Scientific literacy in biology

Question Set 1

1. This question is based on the **Advance Notice Article** TURBOCHARGED PHOTOSYNTHESIS?

(a) **(i)** Use Fig. 1 from the Advance Notice Article to help you answer the following questions.

State the precise location of the photosystems involved in the light-dependent reaction of photosynthesis.

[1]

(ii) Describe how the structures containing the photosystems are arranged differently in plant cells and cyanobacteria.

[2]

(iii) State the precise location of Rubisco in:

- unmodified plant cells
- cyanobacteria

[2]

(iv) Explain how cyanobacteria are able to almost eliminate oxygen (O_2) fixation by Rubisco.

[3]

(b) **(i)** Table 1 on the Advance Notice Article shows the results of experiments to measure carboxylase activity in wild type (WT) tobacco plants and two lines of modified tobacco plant at different concentrations of carbon dioxide (CO_2).

Explain why the units of carboxylase activity are 'mol CO_2 fixed per mol active sites s^{-1} 'rather than just 'mol CO_2 fixed s^{-1}'.

[1]

(ii) Plot a graph of these results. Include error bars showing two standard deviations.

[4]

(iii) Using Table 1 and your graph in **(b)(ii)**, analyse whether the researchers successfully demonstrated that replacing Rubisco in tobacco plants with the cyanobacterial enzyme increased the effectiveness of photosynthesis.

Explain your conclusions. **[3]**

(iv) A student made the following statement:

"Photosynthesis is more effective in the M35 strain than the Rbcx strain."

Use Table 1 and your graph in **(b)(ii)** to evaluate the validity of the student's statement.

Explain your conclusions. **[2]**

(c)* Evaluate the risks and benefits of growing supercrops. **[6]**

Total Marks for Question Set 1: 24

Advance Notice Article

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 (HCO_3^-) and special compartments called carboxysomes, which contain Rubisco. HCO_3^- ions are pumped into the cell and then converted to CO_2 in the carboxysomes by the enzyme carbonic anhydrase (CA). This increases the local 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 HCO_3^- pumps and carboxysomes.

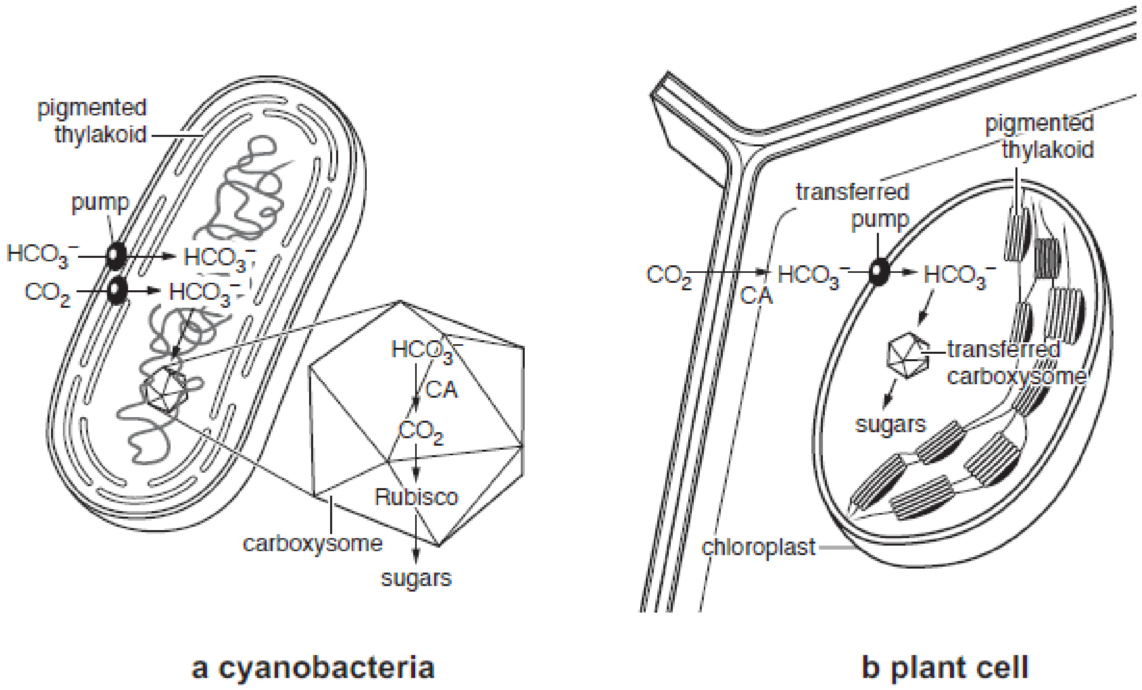

Fig. 1

Scientists from Cornell University in New York and Rothamsted Research in the UK have collaboratedon 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_2 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_2 concentration (μmol dm^{-3})	**Rate of CO_2 fixation in tobacco plants (mol CO_2 fixed per mol active sites s^{-1})**					
	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_2 and HCO_3^-. 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 running 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_2 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.