Energising life on earth: the third way

Almost all living organisms on earth get their energy, ultimately, from the sun. Energy is fixed in carbohydrates by plants and cyanobacteria during photosynthesis, then both animals and plants release it by breaking down those carbohydrates. Until now, only two main routes of carbohydrate breakdown were thought to be present in cyanobacteria and plants. However, Dr Kirstin Gutekunst, of Christian-Albrechts-University of Kiel, Germany, has found a third pathway – the Entner-Doudoroff pathway – also plays a vital role in carbohydrate breakdown in cyanobacteria and plants.

The processes of fixing solar energy as carbohydrate by photosynthetic organisms (cyanobacteria, algae and plants), and its subsequent breakdown to release energy, water and carbon dioxide, are central to life on earth. They have been subject to great amounts of scientific study, and it was thought that the pathways and reactions of both had been well established.

However, Dr Gutekunst’s work found that, at least in cyanobacteria and plants, one glycolytic route has been previously overlooked.

**ENERGY FROM THE SUN**

All living organisms need two things to survive: a source of energy, and a source of organic carbon for building cells. Both of these are fixed by plants during photosynthesis – making this process essential to life on earth. During photosynthesis, energy from sunlight is used to combine water and atmospheric carbon dioxide into glucose sugars, a form of carbohydrate. The solar energy becomes stored as chemical energy in the bonds between carbon, hydrogen, and oxygen atoms in the glucose molecules.

Glucose and its derivatives can go on to be built into larger molecules, such as starch, protein, fat, and even DNA. Alternatively, it can be broken down completely again – either within the plant or in an animal that has eaten it – releasing water, carbon dioxide and, crucially, the stored energy. The energy is released in a molecule known as ‘adenosine triphosphate’ (ATP) which is the ubiquitous energy currency of all cells.

**ENERGY FROM SUGARS**

It has long been known that there are two different pathways by which animals, cyanobacteria and plants break down glucose: the Embden-Meyerhof-Parnas (EMP) pathway, also called simply ‘glycolysis’, and the oxidative pentose phosphate (OPP) pathway. However, simpler organisms such as bacteria and archaea are known to employ a variety of routes to release energy from glucose. One of these is the Entner-Doudoroff pathway.

Dr Gutekunst’s team has now found that the key enzyme of the Entner-Doudoroff pathway, known as KDPG aldolase, is in fact widespread amongst photosynthetic organisms such as cyanobacteria and plants, from mosses to higher plants including rice, barley, maize, banana, potato, spinach, soybean, cotton and tobacco. In barley, their analyses have shown that KDPG aldolase is functional during periods of active growth, such as germinating seeds and developing roots, suggesting an operating Entner-Doudoroff pathway is present.

Using the photosynthetic cyanobacterium, *Synechocystis*, Dr Gutekunst and colleagues have developed mutants in which each of the three pathways of glucose breakdown is disrupted. They found that growth in the presence of light and glucose was reduced most significantly in those mutants without a functional Entner-Doudoroff pathway. This indicates that the Entner-Doudoroff pathway is not only functional, but is a significant contributor to growth in *Synechocystis*. The team is now working, with Dr Götz Hansel from the Leibniz Institute of Plant Genetics and Crop Plant Research at Gatersleben, to develop similar ‘knockout’ mutants in barley to test the significance, behaviour and requirements of the pathway in higher plants.

**UNIQUE FEATURES**

So, how does the Entner-Doudoroff pathway differ from the other two pathways operating to break down glucose? There are two crucial differences.

First, the Entner-Doudoroff pathway releases less energy from glucose: one molecule of the energy currency ATP per glucose molecule, compared to two in the EMP pathway. Although this might seem disadvantageous at first sight, the Entner-Doudoroff pathway has some advantages. The pathways by which glucose is built up and broken down to some extent overlap, but with reactions occurring in opposite directions. Thus, during daylight when photosynthesis is active, the action of the EMP or OPP pathways can undo the reactions occurring in photosynthesis, causing futile cycling between the two processes. Previously, it was thought that cyanobacteria compartmentalise their cellular processes chronologically, focusing on photosynthesis during daylight hours and respiration in the dark, thus avoiding this problem. The big advantage of the Entner-Doudoroff pathway is that it does not overlap with any of the reactions of photosynthesis, allowing cyanobacteria to break down glucose and release energy and cellular building blocks during daylight as well as at night, without risk of futile cycling. This was exactly when Gutekunst’s mutant studies showed...
Glycogen

Running

The Entner-Doudoroff pathway was previously overlooked.

The Entner-Doudoroff pathway was transferred from cyanobacteria to plants via endosymbiosis and is especially important when photosynthesis is running.

Cyanobacteria and plants possess three alternative glycolytic routes.

The implications of this research extend beyond fundamental knowledge to important applications, including the potential to manipulate plants and cyanobacteria for biotechnological uses, such as producing fuels including hydrogen (H₂) as an energy source, pharmaceuticals or nutrients. It's high time this overlooked metabolic pathway got a look-in!