proteinspotlight
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Issue 026, September 2002
www.proteinspotlight.org

twist and shift

Vivienne Baillie Gerritsen

While we frequently think of lobsters as being red, in the sea they are a magnificent blue-grey. It is only when a lobster is boiled, that its colour shifts from blue to an orange-red hue. How does this happen? The answer is astaxanthin. Astaxanthin is a carotenoid pigment which gives many sea animals their orange-like colour – such as the pink flesh of salmon, the exoskeletons of crayfish and shrimps, for instance. However, this same pigment, turns out to be responsible for the blue-green of a lobster's shell. Why lobsters turn red in boiling water is a question first raised over half a century ago, and to which we now have an answer. It is an intriguing phenomenon, which has to do with the nature of biological structure, optical properties and heat. As research progresses, it appears that astaxanthin could have beneficial effects on our health, as it seems to have on those who carry it naturally, and that the structure of crustacyanin itself could be particularly interesting in the field of drug design.

'Lobster Fest', © Will Rafuse

Courtesy of Encore Art Group, CAP & Winn Devon

Astaxanthin is a carotenoid, i.e. a pigment whose optical properties release an orangey hue in natural light. It is synthesized in plants and microalgae, and sea animals who need them have to rely on them for provision. When the Northern European lobster, *Homarus gammarus*, ingests astaxanthin, the pigment binds to a protein known as crustacyanin.

The discovery of astaxanthin, and consequently crustacyanin, follows the development of modern chromatography. The Russian botanist Mikhail Tsvet (1872-1920) was the first to separate plant pigments by pouring a mixture through a glass column of adsorptive material. Different pigments travel at different rates and, as Tsvet poured, coloured bands appeared down the column. In a 1906 publication, he baptised his method 'chromatography'. The method was largely ignored by his fellow scientists, however, who believed the technique was not good enough for refined analysis.

A few years later, in the 1930s, Tsvet's publication was brought to the attention of the Austrian biochemist Richard Kuhn (1900-1967). Kuhn showed it to his assistant Edgar Lederer (1908-1988) asking him to adapt the method and refine it to separate carotenoids. Lederer's adaptation of Tsvet's achievement turned out to be particularly successful and, together, they managed to isolate and purify a large number of carotenoids, amongst which: astaxanthin.

In *Homarus gammarus*, the chromophore is bound to a large protein complex, known as alpha-crustacyanin. Alpha-crustacyanin is in fact an aggregate of 16 crustacyanin monomers, each of which is bound to a molecule of astaxanthin. The 16 monomers are themselves arranged into 8 crustacyanin dimers: hence a combination of two crustacyanin monomers and their respective chromophores. Each dimer has been called beta-crustacyanin and it is this structure which has been studied closely.

The secret of the chromatic shift in lobsters lies within each dimer. A crustacyanin monomer acts as a pocket into which is deeply inserted one chromophore. While one end of the chromophore is hidden in the seat of the pocket, the other protrudes from it. When two crustacyanin monomers join, each protein caps the other's protruding chromophore. In this way, both astaxanthin molecules are protected from the outside world but, in so doing, they are squeezed into an unnatural molecular conformation. As a consequence, their optical properties are modified and, instead of giving off what would be their natural orangey-red hue, they release a blue-green one.

To date, it is not clear whether this structural squeeze is the sole cause for the change of colour; the chemical environment of each chromophore is such that it must also have something to do with the chromatic shift. When a lobster is plunged into boiling water, the structure of each dimer is denatured. As a result, the molecules of astaxanthin relax as they are given enough room to stretch and adopt what is actually their original conformation. The net result is a cooked red lobster. Why, one wonders, is a lobster blue in the first place? Does evolution have anything to do with this? There is a good chance, and it may well have to do with camouflage. It is far better to be blue-grey in a blue-grey sea than to shine a bright orange. So, with the help of time and natural selection, twist astaxanthin a little bit and a lobster becomes far less conspicuous than many of its relatives.

Besides camouflage, astaxanthin may well be involved in an organism's development. Research is indeed revealing that astaxanthin is a plus not only to lobsters but perhaps even to humans, as it is a powerful antioxidant and could act as a crutch for our immune and cardiovascular systems, as well as inhibit the development of certain types of cancer. The crustacyanin dimer could also be a choice means of delivering drugs into the body – let alone astaxanthin. Now that the structure and the optical basics of beta-crustacyanin are understood, scientists can lend their attention to the structure of the greater alpha-crustacyanin complex, which still remains a mystery and may prove to be a powerful drug delivery system too.

Cross-references to UniProt

Crustacyanin A1 subunit, *Homarus gammarus* (European lobster): P58989
Crustacyanin A2 subunit, *Homarus gammarus* (European lobster): P80007
Crustacyanin C1 subunit, *Homarus gammarus* (European lobster): P80029

References

1. Gamiz-Hernandez A.P., Angelova I.N., Send R. et al.
   Protein-induced color shift of carotenoids in beta-crustacyanin
   Angew. Chem. Int. 54: 11564-11566(2015)
   PMID: 26220698

2. Cianci M., Rizkallah P.J., Olczak A. et al.
   The molecular basis of the coloration mechanism in lobster shell: beta-crustacyanin
   Proc. Natl. Acad. Sci. USA, 99:9795-9800(2002)
   PMID: 12119396

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