proteinspotlight
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Issue 2, September 2000

www.proteinspotlight.org

Sticky business

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Mussels live in turbulent niches in the intertidal zone of the ocean. Their survival depends on their ability to attach to rocks. They adhere tightly to surfaces under water using a structure at the base of the foot, which consists of a bundle of threads: the byssus. At the end of each thread is an adhesive plaque that contains water-resistant glue which enables mussels to anchor to solid surfaces.

The threads and plaques are made of several types of protein, amongst which collagenous proteins and at least four mussel adhesive proteins or foot proteins (MAP or fp). All contain dihydroxyphenylalanine (DOPA) (derived from the hydroxylation of tyrosine) and other hydroxylated amino acids. Fp1 consists of decapeptide motif repeats and is rich in dihydroxyproline. Its expression is not restricted to plaque and it forms a cuticle covering the collagens in the threads. Repeat motifs differ from species to species. Plaque contains fp1, fp2 and fp3. Fp2 is a cystine-rich element of the plaque matrix and consists of EGF-like motif tandem repeats. Fp3 is related to a family of small non-repetitive proteins containing hydroxyarginine. In *Mytilus edulis* there are at least 20 variants of fp3. Different types of fp3 could serve to adapt to different structures.

Water resistance of the mussel glue could be due to the high content of hydroxylated amino acids. Indeed, the OH- groups of 1,2-dihydroxybenzene (catechol) are known to form strong hydrogen bonds thus competing with water. Moreover curing is crucial in the development of a cohesive strength and involves the introduction of cross-links between the proteins (cohesion). This process is not well understood but seems to be strongly related to the presence of DOPA.

This strong and water-insoluble adhesiveness is very attractive because it offers a wide range of biotechnological applications. Polyphenolic proteins are non-toxic, biodegradable and have low immunogenicity which makes them highly attractive for medical purposes. Mussel glue could be used as an adhesive to mend broken bones, tendons or tissues. It could also be used in dentistry as a sealant to fill cavities in teeth or to fix broken teeth. Surgeons could also make use of this particular glue while operating, to coat stitches so as to prevent infections.

Affinity of DOPA for Fe^{3+} and other metals enables polyphenolic proteins to interact strongly with these materials. Studies have shown that a multiple-layer coating confers resistance to corrosion in seawater.

Mussel shell, watercolour by Lucy Arnold

Courtesy of the artist

Besides its attractiveness in the field of biotechnology, mussel adhesiveness is a huge problem to the shipping industry. It causes what is known as « fouling », i.e. the encrustation of ships' hulls with various molluscs amongst which mussels. Anti-fouling compounds are highly toxic and polluting, so any biodegradable inhibitor of the mussel MAP would be a godsend to this important industrial sector.

Getting hold of products based on mussel adhesive proteins is a major problem. Several thousands of *Mytilus edulis* specimens are required to produce only one gram of protein! With the exception, however, of *Aulacomya ater* which produces 15 to 20 times more protein than others. One solution is genetic engineering. Attempts to use bacteria as an expression system have failed since the gene is recognised as a foreign body and eliminated. In 1993, Maugh et al. cloned and expressed the cDNA in yeast. And now McQueen-Mason and co-workers at the University of York are trying to make tobacco plants express the gene.

There are other examples of adhesive proteins. One is the freshwater mussel: *Dreissena polymorpha* or zebra mussel, which causes damage by clogging piping systems and canals in water-treatment plants. Their attachment is also mediated by DOPA proteins, though they differ from the MAP of other mussels. Barnacles also produce a proteinaceous secretion called the barnacle cement. However, it lacks DOPA suggesting that several strategies for adhesion have evolved.

Cross-references to Swiss-Prot

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Adhesive plaque matrix protein, *Mytilus edulis* (Blue mussel) : Q25460
Adhesive plaque matrix protein 1, *Mytilus galloprovincialis* (Mediterranean mussel) : Q27409
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