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Frog foams and natural protein surfactants

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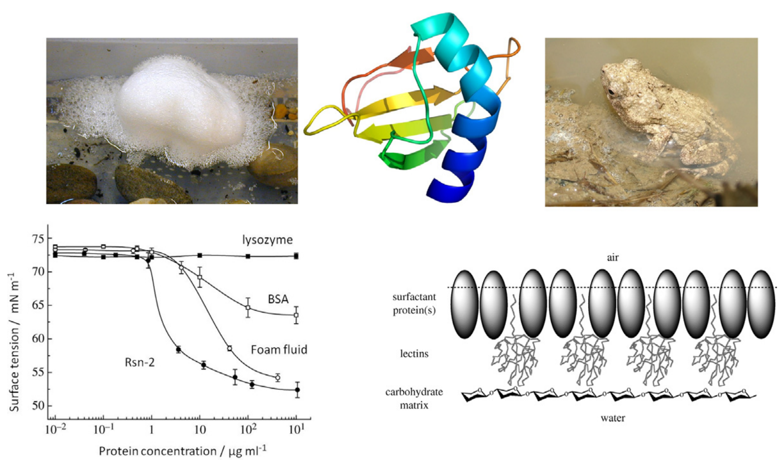
HIGHLIGHTS

- Biological foams contain a cocktail of unusual proteins with diverse properties.
- Natural foam proteins have surfactant properties equal to or better than conventional detergents.
- They reveal new physical principles based on conformational change at interfaces.
- They illustrate alternative surfactant mechanisms not available to conventional detergents.
- Can act synergistically to form and stabilize bio-compatible, hydrated foam structures.

GRAPHICAL ABSTRACT



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ABSTRACT

Foams and surfactants are relatively rare in biology because of their potential to harm cell membranes and other delicate tissues. However, in recent work we have identified and characterized a number of natural surfactant proteins found in the foam nests of tropical frogs and other unusual sources. These proteins, and their associated foams, are relatively stable and bio-compatible, but with intriguing molecular structures that reveal a new class of surfactant activity. Here we review the structures and functional mechanisms of some of these proteins as revealed by experiments involving a range of biophysical and biochemical techniques, with additional mechanistic support coming from more recent site-directed mutagenesis studies.

1. Introduction

The mechanical agitation and surfactant activities normally required to create aqueous foams and emulsions are generally damaging to biological systems. Strong shearing forces and interactions at surfaces and other interfaces can disrupt delicate cells and tissues, and can also denature proteins and other biological macromolecules. Conventional ionic/non-ionic detergents and surfactants will disrupt the phospholipid bilayers of cell membranes and can denature proteins. Indeed, various combinations of mechanical disruption and detergent extraction have long been used in laboratory procedures for the homogenization of biological

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tissues and the extraction and analysis of their various components for biochemical research and other purposes. Consequently, it is perhaps not surprising that natural foams and surfactants are relatively rare in biology. However, there are a few instances where natural biological foams and surfactants have evolved for apparently quite specific purposes, presenting us with an opportunity to explore potentially interesting new physics and physical chemistry of foams in an unusual context. Here we review some of our recent work in Glasgow, focussing mainly on the structure and function of some of the proteins that we have identified and characterized as a result of fieldwork and collaborations with colleagues worldwide [1–7]. Work on other surfactant proteins has been reviewed elsewhere [1,8].

It is a pleasing historical coincidence that some of the early work on foam physics was initiated in Glasgow by William Thomson (Lord Kelvin). It was here that he devised the classic polyhedral structural model for foams as efficient space-filling entities [9] that has only more recently been superseded by the work of the Dublin group in the form of the Weaire-Phelan model [10,11]. Our own interest in biological foams arises out of a natural curiosity for some of the natural foams, in particular frog foam nests, which had not been previously investigated.

Foam nesting is one of the strategies that have evolved to allow some species of frogs to provide an appropriate environment for their eggs and embryos in regions of the world where standing water is otherwise rare or transient (Fig. 1). These nests are typically found in temporary pools or puddles (Fig. 1A), on tree branches or other structures overhanging water (Fig. 1B and D), or buried underground (Fig. 1C). As we have shown in earlier work [1–4], these water-based foams are made from dilute solutions of proteins and carbohydrates that are very stable under tropical conditions. They resist dehydration, predation, and microbial degradation, and

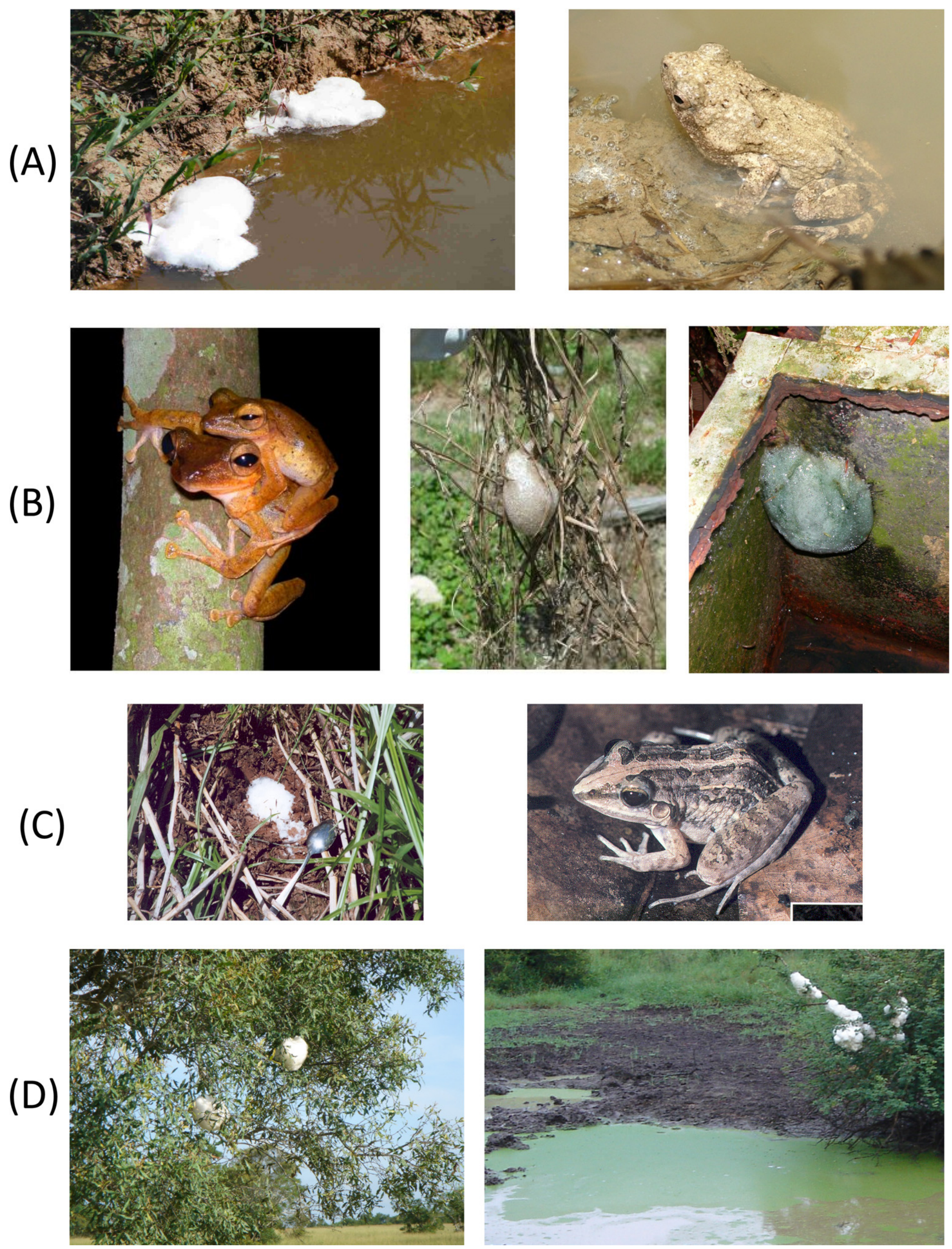

Fig. 1. Frog foam nests from different continents. (A) Trinidad: *Engystomops pustulosus* ("túngara" or "mud puddle frog"). (B) Malaysia: *Polypedates leucomystax* (Java whipping frog). (C) Trinidad: *Leptodactylus fuscus* (whistling frog). (D) South Africa: *Chiromantis xerampelina* (grey foam-nest tree frog).