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Formation, architecture and functionality of microbial biofilms in the food industry

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Recent publications on biofilm formation, architecture and function were reviewed. Biofilm formation begins with organic material, then cell conditioning of a surface. Environmental conditions and microorganisms then influence the establishment of the biofilm architecture. This in turn supports the function of the biofilm which enhances microbial survival, reproduction and contamination of new areas. In the food industry, 'true' biofilms are usually found on closed surfaces such as pipe works where liquid flows over a solid surface. On open surfaces, fouling will affect microbial retention, survival and transfer potential but is less likely to support the development of a true biofilm. Each aspect of biofilm formation is complex with a myriad of influencing factors, which we are only just beginning to elucidate. Much more research needs to be carried out in all aspects of these areas to understand these elegant biofilm and fouling systems if they are ever to be controlled.

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Introduction

The preparation and processing of food is considered an important route for cross contamination of pathogenic bacteria in food products [1–4]. Within nature, as well as in food processing, cells living freely in bulk solution usually become attached to a surface, and if retained, can then form a biofilm. The formation, architecture and function of biofilms are complex phenomena influenced by surface properties, microbiological and environmental factors which will be related to the specific industrial setting in which they are found (Figure 1).

Biofilms are defined as matrix-enclosed bacterial populations that are attached to a surface, an interface and/or to each other [5]. It not surprising that more than 99% of all the planets bacteria live in a biofilm since microorganisms gain considerable advantages from being part of a community [6]. Microorganisms are living organisms with a vast range of physiologically and metabolically varied species that enables them to colonise, adapt and utilise almost any situation they encounter. Thus, a biofilm may be a small or large-scale entity and in the food processing environment these may be a few micrometres or several millimetres in thickness [7]. In the food industry, large-scale biofilms or fouling may occur on such items as heat exchangers or may form on enclosed surfaces when they are in contact with a wet product; an example of this is in pipework. Closed or 'true' biofilms usually occur under conditions of continuous or intermittent flow and are considered to have well developed stacked structures with pore channels. Under static conditions, it has been shown that biofilms with different architecture and functionalities occur [8,9••].

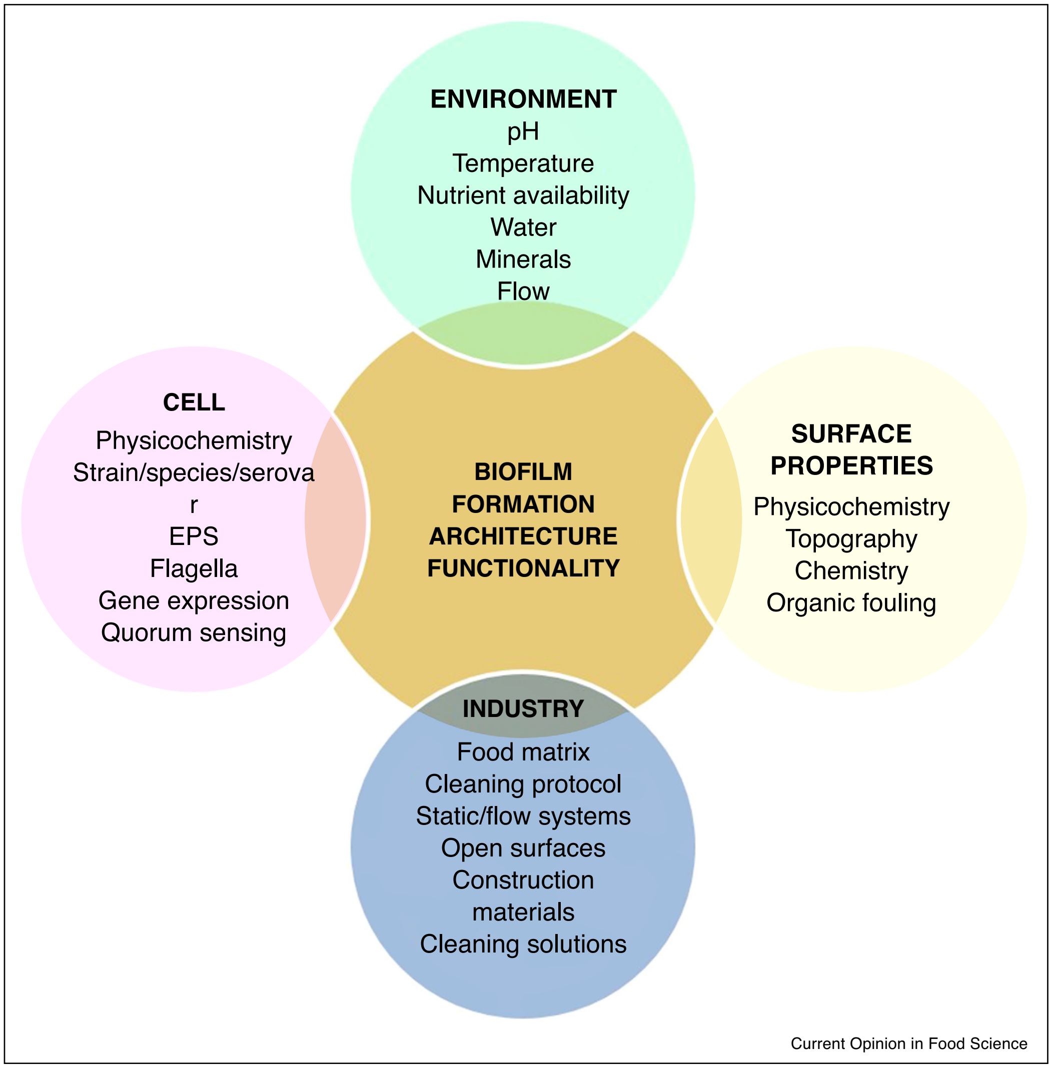
Smaller scale biofilms or biofouling may also occur in the food industry on open surfaces. Open surfaces are exposed, with food being handled or prepared on them and in these situations flow is absent. On an open surface, organic soiling, which may also compromise microorganisms along with the food material, is a major issue in the food processing industries, causing a range of biofouling and microbiological problems [10–12]. The term biofilm is often used to describe cells and organic material retained on a surface; these do not have the characteristic, classic biofilm 'mushroom' type morphology. This type of biofouling is common to a regularly cleaned surface, where material may accumulate, but not possess the morphology of a traditional biofilm.

Biofilm formation, architecture and function is dependent on a wide range and combination of surface morphologies (chemistry, topography, physicochemistry), environmental conditions (pH, nutrient availability, temperature, host proteins/adhesins, fluid dynamics) and microbiological factors (Gram negative/positive, microbial shape, structure, molecular composition, species, physicochemistry, growth phase, age, presence of flagella, pili, capsules or exopolymeric substances) [13]. However, to cover all these factors is beyond the scope of this review. This article will give a brief summary of recent work on three aspects of the biofilm: formation, architecture and function.

Biofilm formation

Biofilm formation is a complex process regulated by the diverse characteristics of the surroundings. Perhaps one of

Figure 1



A complex interplay of factors results in biofilm formation, architecture and hence functionality which are related to the specific industrial food setting in which they are found.

the most important factors that influence biofilm formation are the surface properties and deposition organic material. Before the onset of biofilm formation, initial cell attachment, adhesion, retention and proliferation must occur. However, before a cell can bind to a surface, the surface is conditioned by adsorbing molecules from the surrounding environment.

The chemical, topographical and physicochemical properties of the surface affect initial organic material adsorption and distribution [14–17]. The type and amount of organic material adsorbed onto the surface will then, in turn alter the surface properties [18••]. Indeed, it has been demonstrated that a pristine surface only remains as such for one exposure, being subsequently irreversibly altered by organic material [18••]. When stainless steel surfaces where repeatedly cleaned thirty times without soiling, organic material was still found to become built up on the surfaces [18••]. Further, the biochemical structure, adsorption and distribution of the conditioning film or organic material is dependent on the type of food processing being carried out [19,20], adding an additional level of complexity to the surface (Figure 2). The composition of organic material that might be found in the fish industry (muscle proteins troponin, tropomyosin, and myosin, and the lipid binding protein apolipoprotein) [21••], will vary from that deposited on surfaces in the dairy industry (α-casein, β-casein, κ-casein, and α-lactalbumin) [22]. This in turn will affect cell retention [9••,10] and thus subsequent biofilm architecture, function [23••],