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Surface Architecture of the Skin of the Indian Catfish, *Bagarius bagarius* (Hamilton) (Sisoridae; Siluriformes)

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Abstract The skin surface of *Bagarius bagarius* was observed primarily by SEM. The epidermis was differentiated into polyhedral, epidermal plaques, separated by deep epidermal furrows. These structures showed significant modifications, associated with their physiological status, in their surface architecture, the epidermal plaques being keratinized and the furrows non-keratinized and mucogenic.

The epithelial cells of the keratinized plaques supported projections of fine bristles (unculi). Mucous cells and taste buds were absent. In the non-keratinized mucogenic furrows, the epithelial cells were characterized by intricate patterns of microridges, mucous cells being irregularly distributed and taste buds generally located on epidermal protuberances. The boundaries separating adjacent, keratinized epithelial cells appeared more distinct than those of the non-keratinized mucogenic epithelial cells. The structural peculiarities in the surface sculpture of the skin of *B. bagarius* apparently reflect functional adaptations.

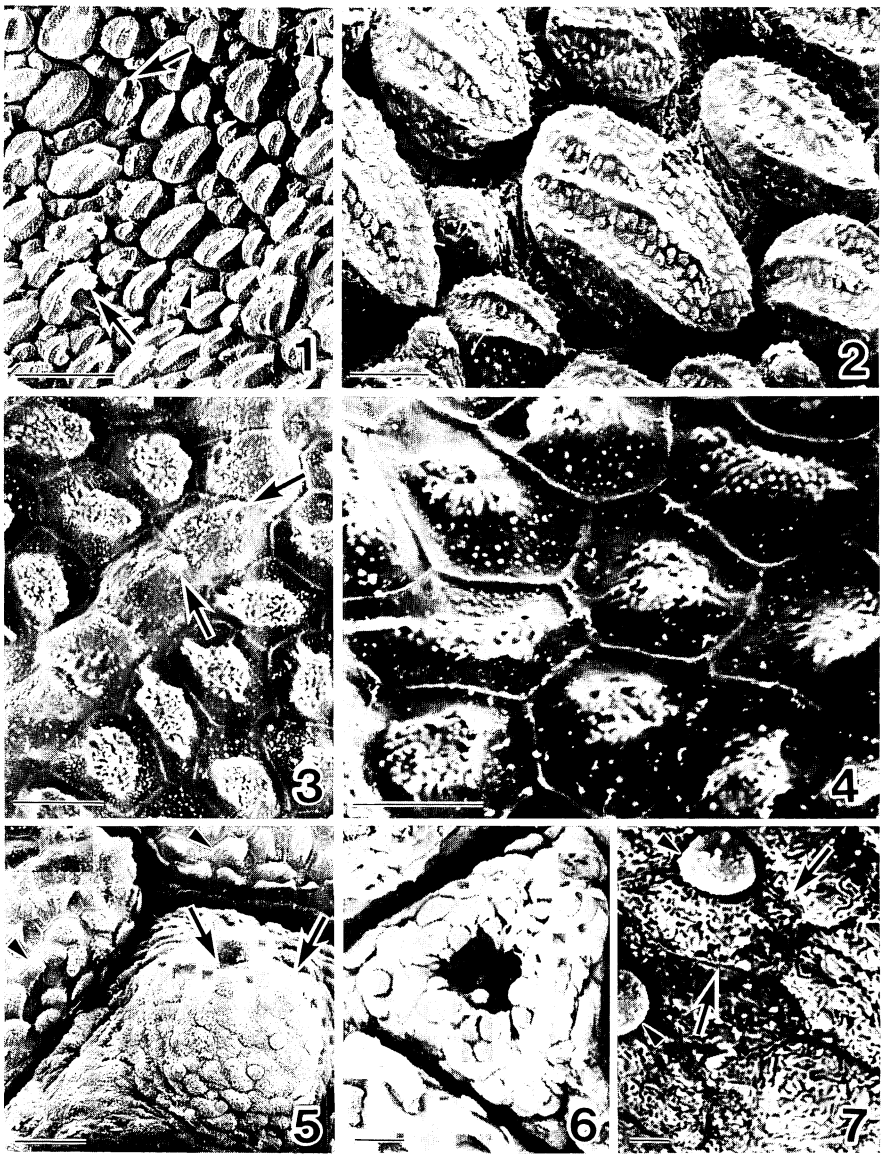
In vertebrates the epidermis has two developmental potentials, one related to keratinization and the other to mucogenesis. Generally, fish epidermis is mucogenic. There are, however, reports that keratinization occurs in the epidermis of some fishes (Collette, 1977; Mittal and Banerjee, 1980; Roberts, 1982; Whitear, 1986). In the epidermis of the Indian catfish, *Bagarius bagarius*, histological (Mittal and Munshi, 1970), histochemical (Mittal and Banerjee, 1974) and transmission electron microscopic (Mittal and Whitear, 1979) studies have shown that the general body surface has characteristic, keratinized areas separated by narrow mucogenic areas. Although relatively extensive studies have been made on the surface relief patterns of the mucogenic epidermis in fish (Whitear, 1990; Suzuki, 1992), studies on the surface architecture of keratinized fish epidermis are limited. Notwithstanding, Roberts (1982) described horny projections arising from single cells (unculi) in the epidermis of a number of ostariophysan fishes and gave a brief account of the surface organization of the keratinized areas of *B. bagarius*.

The present investigation compared the surface architecture of keratinized and mucogenic areas of the skin of *B. bagarius*.

Materials and Methods

Live specimens ($n=5$) of *Bagarius bagarius* (Hamilton) (body length 128±5 mm; weight 25±2 gm) were collected from the River Gangas at Varanasi, India. The fish were maintained in the laboratory at controlled room temperature (25±1°C), being fed minced goat liver on alternate days.

After acclimatization to the laboratory conditions for at least 15 days, the fish were cold anaesthetized (Mittal and Whitear, 1978). Pieces of the dorsal skin between the lateral line and the dorsal fin were excised, rinsed in physiological saline, cut into conveniently-sized pieces (approximately 4×4 mm) and fixed in 3% glutaraldehyde in 0.1 M cacodylate buffer (pH 7.4) for 4 h at 4°C. Fixed tissues were washed with 0.1 M cacodylate buffer (pH 7.4) and dehydrated in a cold (4°C) ethyl alcohol series of ascending concentrations, mixtures of ethyl alcohol and acetone in the ratios 3:1, 1:1 and 1:3, and anhydrous acetone. Tissues were critical point dried using a CPD 750 dryer (EMscope Laboratories Ltd., England) with liquid carbon dioxide as the transitional fluid. The pieces of skin with epidermis facing upwards were then attached on stubs, coated with



Figs. 1–7. Scanning electron micrographs showing surface architecture of the skin of *Bagarius bagarius.*

Fig. 1. Skin surface differentiated into polyhedral, epidermal plaques of variable dimensions with deep furrows between them. In places the surface cells are lifted up in the form of sheets (arrows). Apertures of pit organs occur on some protuberances of the furrows (arrow heads) (scale bar, 500 μm).

Fig. 2. Keratinized epidermal plaques separated by mucogenic furrows. Note characteristic ridges at the surface of the epidermal plaques (scale bar, 100 μm).

Fig. 3. Epithelial cells with a convex surface and with pointed crests (arrows), arranged in a row at the ridge of the epidermal plaque (scale bar, 10 μm).

Fig. 4. Region between the ridges of a plaque showing boundaries of the adjacent epithelial cells. Note the epithelial cells bearing fine projections (scale bar, 10 μm).

Fig. 5. Rounded, non-keratinized protuberance, developed in a furrow with taste buds (arrows) at the summit. Note fine projections on most epithelial cells of the adjacent keratinized plaques, collectively taking a cone-like form (arrow heads) in side view (scale bar, 20 μm).

Fig. 6. Raised triangular area of the epidermal furrow, including the aperture of a pit organ (scale bar, 10 μm).

gold using a SC500 sputter coater (EMscope Laboratories Ltd., England) and examined with a JSM-840A (JEOL, Japan) or 515 SEM (Philips, England) scanning electron microscope.

Observations

In *Bagarius bagarius*, the skin covering the body was scabrous, being studded with pebble-like epidermal elevations giving a grainy texture to the surface. These elevations, called plaques by Roberts (1982), generally ranged from $112 \times 90\,\mu m$ to $450 \times 222\,\mu m$ in size and were separated from each other by deep furrows (Fig.1). The surface architecture of the plaques differed considerably from that of the furrows.

Epidermal plaques.—The epidermal plaques were polyhedral, in dorsal view appearing oval or somewhat elongated in outline, although the smaller ones were often rounded (Fig. 2). Each plaque had, generally 3 or 4, although sometimes up to 6 or 7, prominent longitudinal ridges, some of which appeared to be bifurcated. Each ridge represented an edge along which the faces of the polyhedron met (Fig. 2), the regions between the ridges being somewhat depressed. The epithelial cells of the plaques were generally polygonal. The cells forming the ridges were characteristically arranged in a single or (sometimes) double row, their free surface being convex (Fig. 3). Most of the ridges comprised cells having a distinct, pointed crest (Fig. 3). Generally, the epithelial cells exhibited a surface relief of fine projections, such being usually prominent in the central part of the cell, their appearance closely approximating the bristles of a brush (Fig. 4). Viewed laterally the projections had an overall conical appearance (Fig. 5). The projections at the narrow, peripheral portions of the cells were relatively short, being more widely spaced and irregularly located. The boundaries of the epithelial cells were demarcated by prominent, continuous marginal elevations of adjacent cells, sometimes with an inconspicuous gap between them (Fig. 4).

Some epithelial cells were observed to be lifted up in sheets from the underlying tissues (Fig. 1). They were probably in the process of being sloughed.

Epidermal furrows.—In places the epidermis of the furrow region between the epidermal plaques formed rounded or triangular elevations (Figs. 1, 5 and 6). Some of these had a conspicuous pit (Figs. 1 and 6), being the aperture of a pit organ or ampullary organ. At intervals, the characteristically rounded protuberances reached the level of the epidermal plaques, bearing a variable number of taste buds, each distinguished by a cluster of gustatory processes protruding from the surface (Fig. 5). The epidermal surface of the furrows and protuberances was a mosaic of irregular, polygonal epithelial cells. The surface relief of each cell was characterized by discontinuous microridges, branching and interlocking to form intricate, maze-like patterns (Fig. 7). The boundary between adjacent epithelial cells was demarcated by a double row of narrowly separated, continuous microridges. Nevertheless, the boundaries of these cells, in contrast to those of the epidermal plaques, were relatively indistinct

Among the epithelial cells, irregularly distributed openings of goblet mucous cells occurred, often with a globular mass of mucus (Figs. 5 and 7).

Discussion

The epidermis of *Bagarius bagarius* is characterized by differentiation of epidermal plaques and furrows. Histological, histochemical and transmission electron microscopic studies have showed that the surface cells of the epidermal plaques are keratinized, while those in the furrows are mucogenic and non-keratinized (Mittal and Munshi, 1970; Mittal and Banerjee, 1974; Mittal and Whitear, 1979). The differences in surface architecture of the keratinized plaque and non-keratinized, mucogenic furrow regions are associated with the physiological status of the epithelial cells. In cross-section, the epithelial cells of the plaques are large and arranged in 7 to 14 tiers, while those in the furrows are flatter and arranged in 5 or more tiers (Mittal and Whitear, 1979). Thus, the development of individual keratinized plaques may be associated with a localized increase in the thickness of the epidermis due to hypertrophy and hyperplasia of the epithelial cells, and also with a demand for quicker turnover of epithelial

Fig. 7. Epithelial cells at the surface of a protuberance, as in Figure 5, bearing microridges in maze-like patterns. The boundaries of the epithelial cells are demarcated by a double row of microridges (arrows). Globular mucous deposits (arrow heads) mark mucous goblet cell openings between the epithelial cells (scale bar, $20\,\mu m$).

cells to replace sloughed, keratinized cells. Similar tubercle-like structures or plaques over the entire body surface have also been reported in the epidermis of *Acrochordonichthys melanogaster* (Akysidae), *Chiloglanis brevibarbis* and *Synodontis acanthomias* (Mochokidae) and *Balitoropsis bartschi* (Homalopteridae) (Whitehead, 1958; Willey and Collette, 1970; Roberts, 1982).

The keratinized plaques in the epidermis of *B. bagarius* are provided with characteristic ridges. Roberts (1982) reported that each ridge consisted of double or triple rows of elevated, epithelial cells. Most ridges observed in the present study comprised a single row of cells, each with a distinct, pointed crest, such having been documented previously (also in cross section) (Mittal and Munshi, 1970; Mittal and Banerjee, 1974; 1980). The development of a ridge may be associated with the enlargement of the underlying epithelial cells, the latter often appearing hypertrophied in cross-section, compared to the adjacent epithelial cells, and showing a gradual enlargement as they are displaced towards the free surface and transformed into a columnar arrangement (Mittal and Munshi, 1970; Mittal and Banerjee, 1974, 1980).

The presence of fine, bristle-like projections, called unculi by Roberts (1982), at the surface of the epithelial cells of the keratinized plaques in *B. bagarius* is interesting. TEM studies have already shown that the surface of the keratinized cells in *B. bagarius* is drawn up into small peaks or peg-like projections, especially at the slightly elevated, central portion of the cell (Mittal and Whitear, 1979). The development of the fine projections could be due to shrinkage of the epithelial cells during keratinization (Willey and Collette, 1970).

The rugose surface suggested that the skin of *B. bagarius* provides mechanical protection, e.g., against abrasion. Periodic sloughing of the superficial, keratinized layer of epithelial cells may remove in addition, silty deposits, organic debris and pathogens, thereby keeping the skin surface clean. A rough skin surface may induce laminar flow to reduce drag and may affect intra-specific behaviour (Roberts, 1982), but the keratinized plaques of *B. bagarius* are not regarded as breeding tubercles (Willey and Collette, 1970; Collette, 1977) because of their being distributed over the entire body surface in both adults and juveniles.

In *B. bagarius*, intricate patterns of microridges on the surface of the epithelial cells in the epidermal furrows are characteristic of non-keratinized, mucogenic epithelia. These structures are thought to be involved in the retention of mucus and to facilitate its spreading over the cell surface (Sperry and Wassersug, 1976). The microridge form is related to the process of secretion from the vesicles within the superficial epithelial layer cell (Whitear, 1990). Secretory activities of epithelial cells and goblet mucous cells in the non-keratinized epidermal furrows may provide protection to the fish against various harmful factors in the environment (Mittal et al., 1994).

In *B. bagarius* conspicuous pits located in the furrow region corresponded with the apertures of specialized sensory structures—the pit organs or ampullary organs, as observed in sections by Mittal and Munshi (1970). Among teleosts, these organs occur in weakly electric fishes (mormyrids and gymnotids), as well as in some catfishes (Srivastava and Seal, 1981; Andres et al., 1988; Garg and Mittal, 1990). These sensory structures are considered to be electroreceptors (Bullock, 1974; Szabo and Fessard, 1974) and are thought to detect enemies (for subsequent avoidance), and to complement the taste buds in the location of food (Srivastava and Seal, 1981; Agrawal and Mittal, 1992).

The epidermis in the furrow region, where the taste buds are located, is partially elevated in the form of epidermal protuberances, which enable the taste buds to come close to the body surface of the fish. This may therefore be regarded as an important adaptation increasing the efficiency of their gustatory function, since taste buds deep in the furrrows may be of lesser value.

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インド産ナマズ *Bagarius bagarius* 皮膚の表面構造

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Bagarius bagarius の皮膚表皮は，多面体の表皮小板とこれらの間に存在する深い上皮性の溝とに分化している．これら二つの表面構造は，最表層の上皮細胞の生理的対応の結果，表皮小板が角化するか，または，上皮溝が非角化性で粘液産生を果たすかにより，著しい変更を遂げたものである．角化性表皮小板においては，上皮細胞が微細な剛毛ないし角質突起 (unculi) を備えているが，粘液細胞や味蕾を欠く．一方，非角化性の粘液産生溝では，上皮細胞に複雑な紋様を呈した微小堤が顕著に見られ，粘液細胞は不規則に分布し，味蕾は表皮の隆起部に位置していることが多い．隣接する角化上皮細胞間の境界は，非角化性粘液産生上皮細胞間の境界よりも明瞭である．本種の皮膚表面の彫刻構造の特異性は，多分機能的な適応を反映しているのであろう．