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Research

Ion and Molecule Transport Mechanisms Across Animal Fascia and Skin for Biomedical Applications

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Abstract:
The present study compared the properties of the skin and fascia of Broiler and Gavran (desi) chickens to explore their relationship with transdermal transport processes and meat quality. Electrical conductivity, ion transport properties, pH, moisture, fat, free fatty acids, saponification value, and lipid composition were determined using conductometric measurements and GC-MS. Broiler chicken tissues exhibited higher electrical conductivity in distilled water, ethanol, diethyl ether, and polyethylene glycol than Gavran chickens, suggesting greater membrane permeability and ion transfer. Gavran chicken tissues showed reduced conductivity, indicating stronger ion-retention capacity. Physicochemical analysis revealed that Broiler skin contains higher moisture and slightly higher free fatty acids, while Gavran skin has higher fat content and saponification value; lipid composition did not differ significantly between the breeds. These findings indicate that Broiler chickens are better suited to rapid ion transport and quick cooking, while Gavran chickens, owing to higher fat content and superior ion retention, are more suitable for traditional cooking methods and for modelling controlled transdermal transport.

Keywords: Ion Transport, Animal Fascia, Chicken Skin, Broiler, Gavran, Saponification, Fat Content, Moisture Content, Nutritional Profile, GC-MS Analysis.

I. INTRODUCTION

The permeability of ions and molecules across membranes governs homeostasis, nutrition, and waste excretion. Skin and fascia act as biological barriers preventing uncontrolled migration of water, electrolytes, metabolites, and drugs, making them central to research in physiology, pharmacology, and material science (Prausnitz & Langer, 2008; Guy et al., 2015). The skin, the body's largest organ, is a semi-permeable membrane whose stratum corneum regulates transcellular, trans-appendageal, and intracellular transport routes (Elias, 2005; Prausnitz, Mitragotri & Langer, 2004). Fascia, a connective-tissue network rich in collagen, elastin, and glycosaminoglycans, similarly influences fluid and ion transportation and is of growing interest in regenerative medicine and biomaterials (Stecco et al., 2018; Schleip et al., 2012).

Transport across these membranes occurs via passive diffusion (energy-independent, driven by concentration gradients) and active or facilitated transport (requiring ATP hydrolysis to move ions such as Na+, K+, and Ca2+ against gradients through ion channels and pumps) (Alberts et al., 2022; Guyton & Hall, 2021; Hille, 2001). Conductometric measurement of these ion movements is a fast, reliable proxy for membrane permeability, which is further shaped by hydration level, lipid organisation, and structural integrity (Grimnes & Martinsen, 2015). Moisture content, lipid composition, free fatty acid levels, and saponification value are standard physicochemical

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indicators of membrane integrity and are widely used in food science, meat processing, and pharmacology (AOAC, 2019; Codex Alimentarius Commission, 2019), with GC-MS commonly used to resolve lipid fractions influencing transport.

Broiler and Gavran (desi) chickens differ markedly in muscle mass, water content, connective/fat tissue proportion, and growth rate (Petracci & Cavani, 2012; FAO, 2010), making them a useful comparative model for membrane transport studies. Because the physicochemical properties of biological membranes directly inform the design of biocompatible materials and transdermal drug delivery systems (TDDS) (Benson & Watkinson, 2012), characterising the transport differences between these two breeds' skin and fascia can guide applications in pharmacology, material science, and food technology.

1.1 Ionic and Molecular Transport Mechanisms

Transport of ions and molecules across the skin and fascia is governed by tissue structure, the physicochemical properties of the transported biomolecules, electrochemical gradients, and the presence of specific transporters (Alberts et al., 2022; Guyton & Hall, 2021). Broadly, these processes are classed as passive or active, depending on the molecule involved and whether energy input is required.

Passive diffusion is the simplest transport mode, occurring along a concentration gradient without energy expenditure; small non-polar molecules such as CO2, O2, and lipophilic substances cross the membrane freely by this route (Lodish et al., 2021). Hydrophilic and ionic species, unable to cross the hydrophobic lipid bilayer directly, instead rely on facilitated diffusion through integral membrane proteins and ion-specific channels — the route by which Na+, K+, Cl-, and Ca2+ are exchanged (Alberts et al., 2022; Hille, 2001). Although facilitated diffusion requires no direct energy input, channel availability can depend on ATP status. These passive routes are essential for maintaining osmotic pressure, electrolyte balance, membrane potential, and hydration in skin and fascia (Guyton & Hall, 2021).

Active transport, by contrast, uses ATP hydrolysis to move ions against their concentration gradient, maintaining ionic balance, cell volume, and pH, and supporting protein synthesis (Alberts et al., 2022; Lodish et al., 2021). The Na+/K+-ATPase pump is the principal example, while calcium ATPases and proton pumps regulate calcium concentration and acid-base balance. Larger molecules such as proteins, hormones, and growth factors are moved by active endocytosis and exocytosis, mechanisms important for intercellular communication and extracellular-matrix homeostasis in skin and fascia (Cooper & Hausman, 2019). Collectively, these passive and active mechanisms determine how pharmaceutical preparations are delivered across the skin, underpinning applications in transdermal drug delivery, iontophoresis, and tissue engineering (Prausnitz & Langer, 2008; Benson & Watkinson, 2012).

II. MATERIALS AND METHODS

This comparative study evaluated ion and molecule transport mechanisms in Broiler and Gavran chicken skin and fascia using conductometric measurements in distilled water, ethanol, diethyl ether, and polyethylene glycol (PEG 400). Physicochemical properties — pH, moisture, total fat, free fatty acid, and saponification value — were determined by standard methods (AOAC, 2019), and GC-MS was used to correlate lipid/compound profiles with membrane permeability.

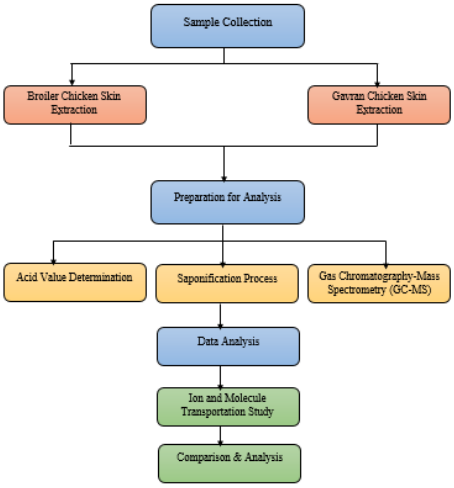

Fig. 1. Research methodology flowchart

2.1 Sample Collection and Skin Extraction

Fresh Broiler and Gavran skin and fascia were obtained from healthy adult birds at the moment of slaughter (Broiler from a local abattoir; free-range Gavran from local farms), following standard animal-welfare and hygiene procedures. Tissues were transported to the laboratory in sterile, chilled containers and processed within 24 hours. The skin was separated from underlying muscle with sterile surgical instruments, and adherent fat, connective tissue, and fascia were removed. Samples were rinsed extensively with sterile normal saline (0.9% NaCl) and phosphate-buffered saline (PBS, pH 7.4) to remove blood and debris (Bronaugh & Maibach, 2005). For epidermis-only assays, the epidermis was separated from the dermis by digestion in 0.25% trypsin (37 °C) followed by PBS washing. Samples for short-term use were stored at 4 ± 1 °C (24–48 h); samples for later use were stored at –20 °C

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in sterile polyethylene bags (OECD, 2004; OECD, 2019). Prior to testing, refrigerated/frozen samples were equilibrated to room temperature and rewashed with PBS. Prepared skin and epidermal membranes were used for conductometric ion-transport experiments, permeability testing, histology, scanning electron microscopy, and GC-MS chemical identification. Gavran birds, raised under free-range/extensive management, are expected to differ from intensively raised Broilers in skin thickness, collagen percentage, and lipid content, all of which shape barrier function (Bronaugh & Maibach, 2005; Williams, 2003).

Fig. 1a. Broiler chicken skin extraction

Fig. 1b. Gavran (desi) chicken skin extraction

III. EXPERIMENTAL WORK

3.1 Skin Extraction and Standardisation

Chicken skin was chosen as a transdermal transport model owing to its structural and functional similarity to human skin (Bronaugh & Maibach, 2005; OECD, 2004). Skin was cut into standardised ~1 cm² pieces to ensure consistent, comparable conductometric and permeability results. Standardised pieces were either used within 24–48 h (stored at 4 °C) or preserved at –20 °C for later trials (OECD, 2004; OECD, 2019), and were subsequently used for conductometric ion-transport study, permeability testing, electrolyte transport, histology, SEM, and GC-MS.

3.2 Ion Transport Solutions and Franz Diffusion Cell Assay

Transport solutions were prepared by dissolving Na+, K+, and Ca2+ salts in 10 mL of distilled water (control), absolute ethanol, diethyl ether, or PEG 400 — solvents selected respectively as a chemical penetration enhancer, a lipid-disrupting agent, and a hydrophilic high-molecular-weight comparator (Benson & Watkinson, 2012). Ion transport was measured using a vertical Franz diffusion cell: skin was mounted between donor and receptor chambers with the epidermis facing the donor side; the receptor chamber (PBS, pH 7.4) was stirred continuously and maintained at 37 ± 0.5 °C. Samples (1 mL) were withdrawn from the receptor chamber at 1, 2, 4, and 8 h and replaced with fresh PBS. Ca2+ was quantified by atomic absorption spectrometry, and Na+/K+ by ion-selective electrode, against standard calibration curves (Williams, 2003; Benson & Watkinson, 2012).

3.3 Sample Preparation for Physicochemical Analysis

Skin was separated into epidermis and dermis, and fascia was separated from muscle, then sectioned into uniform pieces, blotted dry, and weighed. For assays requiring homogeneity (acid value, saponification value, GC-MS), tissue was homogenised at reduced speed under chilled conditions to prevent heat-induced alteration of physical properties (AOAC, 2019; OECD, 2004).

IV. RESULTS AND DISCUSSION

Conductometric analysis showed a consistent, time-dependent rise in ion transfer (µS/cm) across all skin types over 1–120 minutes, with Broiler chicken skin showing the highest conductivity and Gavran the lowest among the chicken breeds tested (Table 1), indicating greater membrane permeability in Broiler skin.

Tissue	Conductivity at 1 min (µS/cm)	Conductivity at 120 min (µS/cm)
Kadaknath chicken skin	1.5	15.0
Gavran chicken skin	1.2	14.5
Broiler chicken skin	2.0	15.5
Goat skin	1.7	15.2

Table 1. Ion transfer in distilled water across animal skin types over time (Fig. 7)

Increasing KCl and NaCl concentration (0.1–0.5 N) produced a proportional rise in conductivity for every skin type tested (Kadaknath, Gavran, Broiler, goat), confirming that ionic strength of the bathing solution, alongside exposure time, is a primary determinant of measured membrane conductivity (Table 2).

Tissue	0.1 N (120 min, µS/cm)	0.5 N (120 min, µS/cm)
Kadaknath (KCl)	7.8	10.8
Gavran (KCl)	7.7	10.5

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Tissue	0.1 N (120 min, µS/cm)	0.5 N (120 min, µS/cm)
Broiler (KCl)	7.9	10.9
Kadaknath (NaCl)	7.1	8.6
Gavran (NaCl)	7.6	8.1*
Broiler (NaCl)	7.7	9.2
Goat (NaCl)	7.3	8.8

*Table 2. Effect of electrolyte concentration on skin conductivity at 120 min (Figs. 8–16; *value at 0.1 N shown where 0.5 N not reported)*

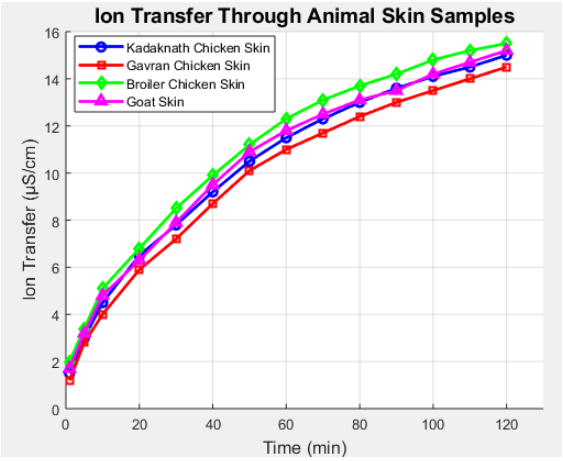

Fig. 2. Representative ion-transfer profile of animal skin samples over time

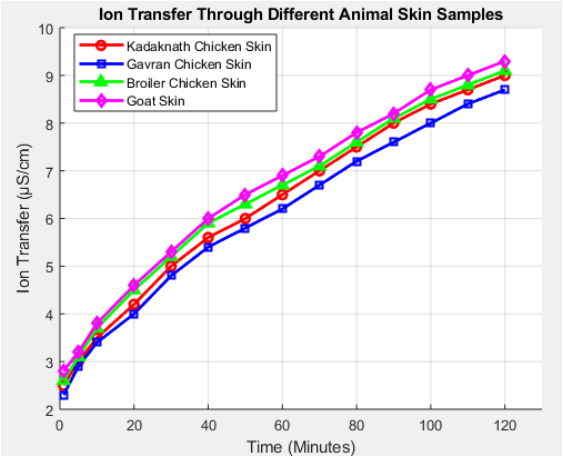

Fig. 3. Ion transfer comparison across animal skin samples in NaCl solution (goat > Broiler > Gavran > Kadaknath at 120 min)

Broiler tissue consistently showed higher conductivity than Gavran tissue across all four transport solvents, with the highest conductivity recorded in PEG (200 µS/cm for Broiler vs. 190 µS/cm for Gavran) and the lowest in diethyl ether; pH remained close to neutral in all solvents. Acid values followed the same pattern, with Broiler skin exceeding Gavran skin in distilled water (10 vs. 9 mg KOH/g), ethanol (12 vs. 11 mg KOH/g), and PEG (14 vs. 13 mg KOH/g), consistent with titration results using NaOH/KOH. Ion transport rates mirrored the conductivity trend: Broiler skin transported ions faster than Gavran in distilled water (5 vs. 4.5 mm/min) and PEG (6 vs. 5.5 mm/min), while both solvents' rates fell below the diffusion standard in diethyl ether (Broiler 1.5, Gavran 1.0 mm/min).

In contrast, Gavran skin retained ions more effectively than Broiler skin over a 30-minute period (Table 3), consistent with a denser extracellular matrix that impedes ion efflux. Measured KCl concentrations after saponification (Broiler 8.5 mM, Gavran 8.0 mM) were both below the theoretical 10 mM, suggesting incomplete potassium absorption in both breeds; across replicate trials potassium showed the least deviation (0–6%), calcium and magnesium showed moderate deviation (2–8% and 2–10% respectively), and sodium showed the greatest variability (10–14%), indicating potassium is transported most consistently during saponification while sodium is most sensitive to experimental conditions.

Ion	Broiler retention (%)	Gavran retention (%)	Chithade retention (%)
Sodium	80	85	78
Potassium	82	88	79
Calcium	75	80	76
Magnesium	78	82	77

Table 3. Ion retention (30 min) in Broiler, Gavran, and Chithade chicken epidermis (Fig. 24)

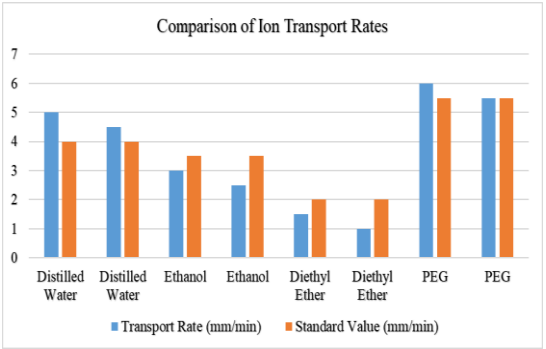

Fig. 4. GC-MS peak-area comparison of Broiler and Gavran skin/fascia extracts across solvents

GC-MS analysis of skin and fascia extracts showed the largest peak areas in PEG (Gavran epidermis 132,000 AU; fascia 130,000 AU), with Gavran samples consistently

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marginally higher than Broiler across all solvents; distilled water produced the second-highest peak areas (Gavran epidermis 102,000 AU; fascia 97,500 AU), while ethanol produced the lowest. Key spectral peaks at 3000–3500 cm^{-1} (O–H/N–H stretching), 2800–3000 cm^{-1} (C–H stretching), and 1500–1700 cm^{-1} (C=O stretching) indicated greater lipid and protein content in Broiler tissue than in Gavran tissue. Scanning electron microscopy further showed that chrome-tanned Gavran skin retained a compact, tightly woven collagen fibre structure at 100–500× magnification, consistent with denser, more mechanically robust tissue, whereas semi-chrome-tanned Broiler skin showed a looser, more disorganised fibre arrangement, consistent with its higher permeability and lower retention capacity.

Comparative ion-concentration analysis (sodium, potassium, and calcium) across the four transport solvents showed that solvent identity had only a marginal effect on ionic solubility: sodium concentration was 43 mg/mL in diethyl ether versus 49 mg/mL in PEG; potassium was highest in ethyl alcohol (50 mg/mL) and lowest in PEG (45 mg/mL); and calcium was highest in ethyl alcohol (49 mg/mL) and lowest in diethyl ether and PEG (46 mg/mL). Taken together with the saponification data — where Gavran fat required more KOH than Broiler fat across all four solvents, peaking in distilled water (195 vs. 190 mg KOH/g) — these results reinforce that the two breeds' lipid fractions differ modestly in composition but consistently enough to influence membrane conductivity and retention behaviour.

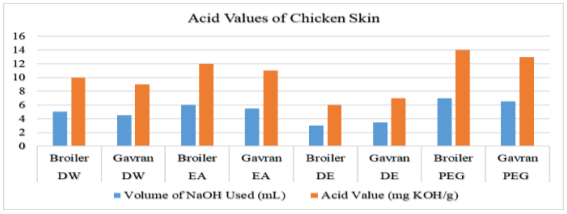

Fig. 5. Comparative microscopy of Gavran (dense, compact) and Broiler (looser, irregular) collagen fibre structure

Taken together, the conductometric, physicochemical, and spectroscopic results converge on a consistent picture: Broiler chicken skin is the more permeable, faster-conducting membrane, while Gavran chicken skin is the more retentive, structurally denser membrane. This distinction has practical implications beyond meat science. As a fast-transport, high-moisture membrane, Broiler skin may better approximate conditions favouring rapid transdermal drug release, whereas Gavran skin, with its denser collagen network and higher lipid/saponification profile, may serve as a more representative model for sustained-release or barrier-limited delivery systems (Benson & Watkinson, 2012; Bronaugh & Maibach, 2005). These complementary properties suggest that both breeds' tissues can serve distinct, deliberately chosen roles in future *in vitro* permeability and biomaterials research, rather than one being a universally superior model.

V. CONCLUSION

This study compared the physicochemical and ion-transport properties of Broiler and Gavran chicken skin as models for membrane permeability and transdermal transport. Broiler skin consistently showed greater ion-transport capacity — conductivity of 150 µS/cm in distilled water and 200 µS/cm in PEG, versus 140 and 190 µS/cm for Gavran — attributable to differences in skin thickness, collagen arrangement, lipid content, and hydration (Bronaugh & Maibach, 2005; Williams, 2003). Conversely, Gavran skin retained ions more effectively (85% Na^+, 88% K^+ vs. 80% and 82% for Broiler), consistent with its denser extracellular matrix (Benson & Watkinson, 2012).

Broiler skin also showed a slightly higher acid value (12 vs. 11) and higher moisture content (60% vs. 55%), while Gavran skin had higher lipid content (25% vs. 20%) and saponification value, indicating differing fatty-acid chain composition and hydrolytic stability between the breeds. A higher acid value signifies a greater proportion of unsaturated fatty acids, whereas a higher saponification value points to a larger fraction of short-chain fatty acids — together suggesting that, despite broadly similar lipid profiles on GC-MS, the two breeds' fat fractions are not chemically identical. The higher moisture content of Broiler skin likely underlies its greater ion conductivity, whereas Gavran's higher lipid content reduces extracellular-matrix conductivity (OECD, 2004). Overall, Broiler chicken skin is better suited as a model for high-permeability, rapid transdermal ion transport (and for quick-cooking applications), while Gavran chicken skin — with superior ion retention and lipid content — is more appropriate for modelling controlled/limited transport and traditional cooking methods. These findings offer practical guidance for meat-quality assessment and for selecting biological membrane models in transdermal drug delivery and biomaterials research.

Future work extending this comparison to additional indigenous breeds (e.g., Kadaknath, Chithade) and to non-avian membranes such as goat skin — both of which were included in the conductometric survey here — would help establish whether the Broiler/Gavran contrast reflects a

general pattern of intensive- versus extensive-rearing effects on membrane transport, or is specific to these two chicken genotypes.

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