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An integrative review of pre-slaughter stress: Physiological mechanisms, meat quality impacts and mitigation strategies

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Abstract
The time leading up to slaughter represents a crucial phase where animal welfare and economic value intersect. This review consolidates scientific findings on how pre-slaughter stress affects meat quality in livestock and poultry. It explains the physiological basis of stress especially the rapid Sympathetic-Adrenal-Medullary (SAM) axis and the slower Hypothalamic-Pituitary-Adrenal (HPA) axis and their roles in muscle metabolism. Acute stress causes a sharp post-mortem pH fall, resulting in Pale, Soft, Exudative (PSE) meat, while chronic stress leads to glycogen depletion and Dark, Firm, Dry (DFD) meat. The review also considers psychological stressors like fear and novelty, discusses cortisol-induced ante-mortem proteolysis, and compares the regulatory frameworks of the United Kingdom, the United States, and India. It concludes that mitigating pre-slaughter stress is both an ethical duty and a cornerstone of meat quality assurance, advocating for science-based strategies to integrate animal welfare into meat production. (AHDB, N.D.; Research Gate, N.D.; PubMed Central, N.D.) [1, 6, 7, 23, 24].

Keywords: N.D., Earthworm Express, N.D, pre-slaughter stress, meat quality, livestock, poultry, animal welfare, stress physiology, muscle biochemistry, well-being international studies repository

1. Introduction
The final moments before slaughter are among the most physiologically demanding for production animals. During this period, various stressors can affect both welfare and meat quality. The interaction between the neuroendocrine system and muscle metabolism plays a central role in these outcomes. Understanding the mechanisms behind these processes is critical for developing humane and quality-focused meat production practices.

2. Physiological mechanisms of stress
The stress response in animals involves two interconnected pathways: The Sympathetic-Adrenal-Medullary (SAM) axis, responsible for immediate reactions, and the Hypothalamic-Pituitary-Adrenal (HPA) axis, which regulates long-term stress.

2.1 SAM Axis
When exposed to acute stressors such as rough handling or loud noises, the sympathetic nervous system triggers the adrenal medulla to release catecholamines (adrenaline and noradrenaline). These hormones accelerate glycogen breakdown and lactic acid production, which, if occurring before slaughter, can cause the rapid pH decline associated with PSE meat. (PubMed Central, N.D.; ResearchGate, N.D.) [1, 5].

2.2 HPA Axis
Prolonged stress activates the hypothalamus to secrete CRH, leading to ACTH release from the pituitary and cortisol secretion from the adrenal cortex. Cortisol maintains energy balance by promoting gluconeogenesis and lipid mobilization but simultaneously depletes muscle glycogen. The resulting high ultimate pH produces DFD meat with dark color and reduced shelf life (PubMed Central, N.D.; ResearchGate, N.D.) [1, 6, 7, 23, 24].

3. Impact of chronic stress and cortisol

Cortisol's prolonged elevation induces ante-mortem proteolysis, degrading structural proteins like actin and myosin before death. This weakens muscle structure, leading to softer texture and higher drip loss. Such subtle damage may not be detected by pH measurements but significantly impacts processing yield and product quality. Consequently, managing chronic stress is essential to avoid hidden economic losses. (PubMed Central, N.D.; ResearchGate, N.D.) [4, 13].

4. Meat Quality Defects

4.1 DFD Meat

Chronic stress causes glycogen depletion, leading to insufficient lactic acid production post-mortem. The muscle pH remains above 6.0, resulting in dark, firm meat with high water retention and increased microbial risk. (AHDB, N.D.; ResearchGate, N.D.; PubMed Central, N.D.) [1, 6, 7, 23, 24].

4.2 PSE Meat

Acute pre-slaughter stress results in rapid glycolysis and heat-induced protein denaturation. This creates pale, soft, and exudative meat with low water-holding capacity and poor cooking properties. (AHDB, N.D.; ResearchGate, N.D.; PubMed Central, N.D.) [1, 6, 7, 23, 24].

4.3 Stress Continuum

PSE and DFD represent two extremes of a stress spectrum, influenced by the duration and type of stress. Effective management must target both chronic and acute stressors. (AHDB, N.D.; ResearchGate, N.D.; PubMed Central, N.D.) [1, 6, 7, 23, 24].

5. Psychological Stressors (Cambridge University Press, N.D.; Grandin, N.D.)

Psychological challenges, such as fear, novelty, and witnessing slaughter, profoundly influence stress physiology. Environmental cues like noise, unfamiliar smells, and social isolation activate the HPA axis. Legal frameworks, such as India's Slaughter House Rules (2001), recognize these as welfare concerns by prohibiting slaughter in the presence of other animals. (PubMed Central, N.D.; ResearchGate, N.D.) [1, 2, 3].

6. Comparative Regulations

- **United Kingdom:** Governed by the Animal Welfare Act (2006) and WATOK Regulations, requiring stunning and CCTV monitoring in slaughter areas.
- **United States:** Regulated by the Humane Methods of Slaughter Act (1958), mandating stunning for livestock but excluding poultry.
- **India:** Under the Prevention of Cruelty to Animals Act (1960) and Slaughter House Rules (2001), which mandate licensed slaughterhouses, veterinary inspection, and prohibit slaughter in view of other animals. (Animal Welfare Board of India, N.D.) [12].

These frameworks differ in enforcement and scope but share a common goal of reducing suffering.

7. Mitigation Strategies

7.1 Humane Handling

Handlers should use behavioral principles respecting flight zones, minimizing noise, and avoiding electric prods to reduce fear responses [11, 26].

7.2 Facility Design

Curved races with solid walls, adequate ventilation, and non-slip flooring help maintain calm movement. Lairage areas must offer clean bedding, water, and rest before slaughter. (AHDB, N.D.; MDPI, N.D.).

7.3 Technological Advances

Controlled Atmosphere Stunning (CAS) is preferred for poultry and pigs, inducing unconsciousness without manual restraint. Such technology improves welfare and consistency in meat quality. (MDPI, N.D.; WOAH, 2018) [19, 20, 27].

8. Conclusion

Pre-slaughter stress significantly influences meat quality through biochemical and physiological mechanisms. Both acute and chronic stress alter muscle metabolism, producing PSE and DFD conditions. Effective control requires integrating welfare principles, modern technology, and international regulatory harmonization. Future research should focus on non-invasive biomarkers and the molecular mechanisms of cortisol-induced proteolysis to enhance quality assurance. (AHDB, N.D.; ResearchGate, N.D.; PubMed Central, N.D.) [1, 6, 7, 23, 24].

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