Pig welfare in intensive systems: scientific basis for assessment and policy

[1,2]Ioan G. Oroian, [1]Cristian Iederan

[1] Department of Environmental Engineering and Protection, Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Cluj-Napoca, Romania; [2] Balkan Environmental Association (BENA), Thessaloniki, Greece. Corresponding author: C. Iederan, cristi.iederan@usamvcluj.ro

Abstract. Pig welfare in intensive production systems represents a multidimensional construct shaped by behavioral, physiological, environmental, and regulatory factors. This review synthesizes current scientific evidence on animal-based indicators used to assess welfare, emphasizing the integration of behavioral observations (e.g., aggression, tail biting, stereotypies) with physiological markers (e.g., cortisol, thermoregulation, immune responses). Particular attention is given to the limitations of single metrics and the growing importance of composite and technology-assisted approaches for real-time, non-invasive monitoring. The paper further evaluates the welfare implications of alternative production systems, such as organic and free-range models, highlighting their benefits in promoting natural behaviors alongside challenges related to biosecurity, health risks, and management complexity. Stocking density and environmental conditions are identified as critical determinants of welfare, with strong empirical evidence linking space allowance and microclimate to both animal well-being and productivity outcomes. Finally, the review examines the interplay between European legislative frameworks and on-farm practices, revealing persistent gaps between regulatory standards and practical implementation. The analysis underscores the need for policy approaches that integrate validated welfare indicators, incentivize best management practices, and align economic, societal, and ethical considerations within the pork production chain.
Keywords: pig welfare, intensive farming systems, animal-based indicators, stocking density, behavioral stress, physiological stress, environmental enrichment, European legislation, Welfare Quality®, alternative production systems.

Introduction. Pig welfare in intensive European-style systems is shaped by how animals cope with stressors such as confinement, social mixing, high density, and management routines, and by how these conditions are regulated and enforced (Maes et al., 2019; Fu et al., 2015). Research links animal-based indicators with housing design, stocking density, and evolving EU and national legislation, offering concrete levers for both on-farm optimization and public policy (Guevara et al., 2022; Nielsen et al., 2022; Wallenbeck et al., 2024).

The aim of this mini-review is to critically evaluate the scientific basis for assessing pig welfare in intensive production systems and to examine how this evidence informs and interacts with current policy frameworks. Specifically, the paper seeks to (i) identify and analyze the most reliable behavioral and physiological indicators of welfare, (ii) assess the comparative advantages and limitations of alternative versus conventional housing systems, (iii) investigate the role of stocking density and environmental conditions as primary determinants of welfare outcomes, and (iv) explore the extent to which European legislation is effectively translated into on-farm practices. Through this integrative approach, the study aims to highlight evidence-based pathways for improving both welfare assessment methodologies and policy implementation.

Behavioral and Physiological Indicators of Welfare. Stress in intensive systems alters behavior (aggression, tail biting, stereotypies) and physiology (cortisol, temperature, immune markers), affecting productivity and health (Smulders et al., 2006; Fu et al., 2015;

Guevara et al., 2022; Poroshynska et al., 2024). Aggressive behavior is the dominant indicator of social stress, while rectal temperature and skin temperature are central for thermal stress, and cytokines for immune-related stress (Guevara et al., 2022). Cortisol is widely used but should be interpreted cautiously; serum and oral-fluid cortisol often do not correlate well with integrated welfare scores such as the Welfare Quality® protocol, and are best treated as one indicator among many (Guevara et al., 2022; Plut et al., 2023). Validated behavioral tools integrating novel-object response, play, aggression, tail/ear lesions, coughing, and cleanliness reliably reflect stress physiology and growth, with salivary cortisol and catecholamines increasing in ear- and tail-bitten or dirty pigs (Smulders et al., 2006). Reviews emphasize that chronic stress in confined sows promotes stereotypies, impairs reproduction, and that social stress during mixing and feeding disrupts feeding and exploratory behavior, alters microbiota, and depresses immunity and growth (Poroshynska et al., 2024). Systematic frameworks now promote combined, preferably non-invasive and technology-assisted, indicators (e.g. vocalisation analysis, infrared thermography, machine vision) to capture "whole-animal" welfare in real time (Guevara et al., 2022; Poroshynska et al., 2024; Hasan et al., 2026) (Table 1).

Table 1

Principal indicators used to assess stress and welfare in pigs

Indicator / tool	*Main welfare dimension captured*	*Notes for policy and practice*	*Citations*
Aggression, lesions, tail/ear biting	Social stress, frustration, poor environment	Sensitive to density, mixing, enrichment; central for on-farm monitoring and enforcement thresholds	Guevara et al., 2022; Poroshynska et al., 2024; Fu et al., 2015; Smulders et al., 2006
Cortisol (serum, saliva, oral fluid)	Acute and chronic stress physiology	Useful only in combination with behavioral/clinical data; not a stand-alone welfare metric	Guevara et al., 2022; Poroshynska et al., 2024; Plut et al., 2023; Smulders et al., 2006
Body / ear temperature, respiratory rate	Thermal and general stress	Suited to remote sensing; links microclimate, density, transport, and lairage design to welfare	Guevara et al., 2022; Poroshynska et al., 2024; Song et al., 2024; Hasan et al., 2026
Composite protocols (Welfare Quality®, EFSA ABMs)	Integrated welfare assessment (health, behavior, affective state)	Provide structured, policy-ready animal-based measures for auditing farms and slaughterhouses	Nielsen et al., 2022; Guevara et al., 2022; Godyń et al., 2019; Plut et al., 2023

Alternative Systems: Free-Range and Organic. Alternative systems (organic, outdoor, free-range, enriched indoor) generally allow a broader behavioral repertoire and reduce abnormal behaviors compared with fully slatted, barren confinement (Millet et al., 2005; Godyń et al., 2019; Delsart et al., 2020; Pol et al., 2021). Access to litter or manipulable materials, as required by Council Directive 2008/120/EC and its 2016 Recommendation, and the use of optimal enrichments (edible, chewable, investigable, manipulable, e.g. straw) are central to preventing tail biting, aggression, and stereotypies across production stages (Godyń et al., 2019; Nielsen et al., 2022). Reviews show that outdoor or organic systems improve opportunities for exploration and social interaction but introduce challenges: more complex management of temperature, feeding, predators, and biosecurity; greater risks of parasitism, piglet crushing, and some zoonoses; and frequent reproductive disorders and weak sanitary "locks" in organic clusters (Delsart et al., 2020; Pol et al., 2021). Performance and meat-quality outcomes are variable but can match or exceed conventional systems when management and genetics are adapted, meaning welfare gains in alternative systems need not compromise productivity (Millet et al., 2005; Delsart et al., 2020). However, comparative analyses emphasize that no system is uniformly superior: extensive conditions trade enhanced behavioral welfare against biosecurity and some health and safety risks, suggesting that policy should incentivize "best practice packages" rather than simply indoor versus outdoor labels (Millet et al., 2005; Maes et al., 2019; Delsart et al., 2020).

Stocking Density, Environment, and Aggression. Stocking density is a pivotal driver of stress, aggression, injuries, thermal load, and growth efficiency in intensive systems (Fu et al., 2015; Guevara et al., 2022; Nielsen et al., 2022; Song et al., 2024; Vanlalhmangaihsanga et al., 2024; Ferrari et al., 2025; Hasan et al., 2026). Experimental manipulations of floor space in growing pigs consistently show that higher densities increase aggression, tail biting, skin lesions, dirtiness, abnormal body temperatures, and negative social behavior, while reducing positive social interactions and resting time (Fu et al., 2015; Song et al., 2024; Vanlalhmangaihsanga et al., 2024; Hasan et al., 2026). Moderate increases in space allowance (e.g. from 0.57 to around 1.0 m^2 per pig) improve average daily gain, feed conversion, lesion scores, cortisol, and ear temperature, demonstrating direct productivity benefits of welfare-oriented density standards (Hasan et al., 2026). Work in Indian and Chinese conditions similarly show that compressing space elevates aggression and tail biting without clear growth advantages, while intermediate densities can balance housing cost with better welfare indicators (Fu et al., 2015; Vanlalhmangaihsanga et al., 2024). Lairage studies add that the "optimal" density is temperature-dependent: at high ambient temperatures, very high densities (> 0.5 m^2 per 100 kg) worsen behavior, cortisol, and meat quality, whereas at very low temperatures, overly low densities can also be detrimental, probably via cold stress and agitation (Song et al., 2024). Broad reviews confirm that chronic social and environmental stressors (crowding, poor microclimate, barren floors) increase cortisol, disturb thermoregulation, reduce feed intake quality, and impair reproductive and immune functions, underlining that space and environmental quality should be treated together in regulation and design (Fu et al., 2015; Maes et al., 2019; Guevara et al., 2022; Poroshynska et al., 2024; Hasan et al., 2026). EU-level scientific opinions therefore link quantified relationships between space allowance, growth rate, lying behavior, and tail biting with recommendations for minimum space per category and for structured environmental enrichment and air quality management as primary tools to prevent damaging behaviors instead of routine mutilations (Godyń et al., 2019; Maes et al., 2019; Nielsen et al., 2022).

European Legislation Versus On-Farm Practices and Policy Implications. European pig welfare is formally anchored in Directive 2008/120/EC and subsequent instruments such as Commission Recommendation (EU) 2016/336, which define minimum standards for housing, enrichment, and painful procedures and encourage measures to reduce tail docking and to provide manipulable materials (Godyń et al., 2019; Maes et al., 2019; De Castro Lippi et al., 2022; Nielsen et al., 2022). Historical analyses of 13 EU member states show that pig welfare legislation has generally become more stringent from 1991 to 2020, with several countries adopting national rules that exceed EU minima in key areas affecting cost and competitiveness (e.g. space, sow housing, enrichment, mutilations) (Wallenbeck et al., 2024). Comparative work on the implementation of pig-welfare directives in Denmark, Germany, France, and Spain reveals marked variation: Denmark and Germany tend to "over-implement" via denser and more restrictive national regulations, whereas France and Spain remain closer to EU minima, reflecting differences in public opinion and party politics (Kuenzler & Vogeler, 2025). At the same time, socio-legal studies of the French sector show how industry actors perform "legal repair": they technically comply with new EU housing rules by adapting equipment and specifications in ways that stabilize existing intensive systems, often without substantial welfare gains, for example by fitting crate-compatible solutions that meet formal metrics while preserving behavioral restrictions (Billows & Déplaude, 2024). Parallel qualitative research on Brazilian intensive pig farmers highlights that producers often acknowledge welfare in terms of health and environment, but perceive their room for maneuver as limited by economic constraints, industry demands, and advisory structures, leading to routine reliance on antibiotics and to a failure to treat abnormal behaviors as welfare problems (Albernaz-Gonçalves et al., 2021). A global review of guidelines documents how the EU, OIE and other regions have increasingly restricted sow cages, early weaning, and painful procedures without analgesia, and have embedded environmental enrichment in normative frameworks, which in turn pressures exporting countries to upgrade standards (Godyń et al., 2019; Maes et al., 2019; De Castro Lippi et al., 2022). National-level instruments, such as Brazil's 2020 normative instruction mandating enriched environments and nesting material, explicitly connect welfare improvements to productivity, disease reduction, and meat quality, aligning farmer incentives with animal-centered goals (De Castro Lippi et al., 2022; Poroshynska et al., 2024). Scientific authorities in the EU now recommend suites of animal-based measures (e.g. tail lesions, lameness, live-born mortality, body dirtiness, behavioral tests) to be applied at farm and slaughterhouse level to monitor and enforce compliance and to evaluate initiatives such as the "End the Cage Age" (Godyń et al., 2019; Nielsen et al., 2022). Overall, the research indicates that bridging the gap between ambitious legal texts and on-farm outcomes requires: integrating validated behavioral and physiological indicators into inspection and certification schemes; revising space, enrichment, and mutilation rules in line with quantitative welfare–productivity relationships; supporting farmers through targeted incentives, advisory services, and technology (e.g. AI-based behavioral monitoring) (Smulders et al., 2006; Maes et al., 2019; Guevara et al., 2022; Plut et al., 2023; Hasan et al., 2026); and recognizing that effective pig welfare policy must align consumer expectations, public opinion, and political and economic realities within the production chain (Albernaz-Gonçalves et al., 2021; De Castro Lippi et al., 2022; Billows & Déplaude, 2024; Wallenbeck et al., 2024; Kuenzler & Vogeler, 2025).

Conclusions. The evidence reviewed confirms that pig welfare in intensive systems cannot be adequately assessed using isolated indicators but requires integrated, multidimensional frameworks combining behavioral, physiological, and environmental data. Advances in technology, including automated behavioral analysis and remote sensing, offer promising tools for more accurate and continuous welfare monitoring.

Alternative production systems generally enhance behavioral welfare by enabling natural activities; however, they introduce trade-offs related to health risks, biosecurity, and management complexity. Consequently, no single production model can be considered universally optimal, reinforcing the need for context-specific, evidence-based management strategies.

Stocking density and environmental quality emerge as central, interdependent drivers of welfare, with clear quantitative relationships to both animal well-being and productive performance. These findings support the revision of regulatory standards to reflect scientifically validated thresholds rather than minimal compliance criteria.

Despite increasingly stringent European legislation, a significant gap persists between regulatory intent and practical implementation. This discrepancy is influenced by economic constraints, industry structures, and adaptive compliance strategies that may satisfy legal requirements without delivering substantive welfare improvements.

Overall, effective advancement of pig welfare requires a systemic approach that integrates robust scientific indicators into policy frameworks, supports farmers through incentives and advisory systems, and aligns regulatory measures with economic and societal realities.

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Authors:
Ioan Gheorghe Oroian (IGO), Department of Environmental Engineering and Protection, Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Mănăştur Street, 400372 Cluj-Napoca, Romania, e-mail: ioan.g.oroian@gmail.com
Cristian Iederan (CI), Department of Environmental Engineering and Protection, Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Mănăştur Street, 400372 Cluj-Napoca, Romania, e-mail: cristi.iederan@usamvcluj.ro

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