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Nutrition, Housing, Handling, Environmental Enrichment, and Social Conditions as Interacting Determinants of Farm-Animal Welfare: An Umbrella Review of Review-Level Evidence and Welfare Outcomes, 2017–2025

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ABSTRACT

Farm-animal welfare is determined by interacting biological, environmental, management, and social conditions, yet these determinants are commonly evaluated in separate evidence streams. This umbrella review synthesizes review-level evidence concerning nutrition, housing, handling and human interaction, environmental enrichment, social conditions, and painful management procedures, with emphasis on how domain interactions alter welfare interpretation. Eligible evidence comprised peer-reviewed review-level publications relevant to farm-animal welfare and methodological sources required for transparent umbrella-review conduct. Review selection, extraction, methodological appraisal, primary-study overlap assessment, and narrative synthesis were designed to preserve species, production-system, developmental-stage, outcome, and measurement boundaries. Numerical retrieval and selection totals are not reported because reproducible export-level counts were unavailable; no counts were reconstructed retrospectively. The review-level evidence indicates that welfare cannot be inferred reliably from a single resource or management characteristic. Nutritional adequacy may coexist with hunger-related behaviour or difficult transitions; housing effects depend on design and management; social contact can alter behavioural development and stress responses; enrichment requires biological relevance and sustained engagement; human-animal relationships can modify fear and interaction; and painful procedures remain procedure-, time-, and analgesia-dependent. The synthesis therefore treats welfare as a conditional configuration of interacting determinants rather than an additive checklist. A proposed cross-domain interpretation architecture emphasizes animal-based outcomes, temporal change, biological constraints, determinant interactions, and uncertainty. Major limitations include uneven species coverage, methodological heterogeneity, overlapping primary evidence, inconsistent outcome definitions, and incomplete reproducibility of selection counts. The findings support multidomain welfare assessment while cautioning against universal prescriptions or causal interpretations unsupported by the underlying reviews.

Keywords: Farm-animal welfare, Environmental enrichment, Livestock housing, Social housing, Nutrition, Human-animal interaction

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Introduction

Farm-animal welfare cannot be reduced to whether feed, housing, or management meets an isolated resource standard. Physiological capacity, environmental opportunities, health, and production-system conditions can

interact in ways that make similar husbandry environments differentially tolerable or beneficial across animals and life stages [1–3]. Human contact adds another determinant because stockperson behaviour, familiarity, and animal responses can modify fear and other welfare-relevant outcomes [4]. Consequently, evaluating nutrition, housing, handling, enrichment, and social conditions as independent checklist items risks obscuring interaction, compensation, and constraint. This umbrella review addresses that fragmentation by integrating review-level evidence across these domains while preserving species, developmental-stage, production-system, temporal, and measurement boundaries. Its central contribution is a proposed configuration-based interpretation: welfare evidence should be read according to how determinants combine around the animal, not according to the nominal presence of individually desirable management features.

Rationale for review-level evidence synthesis

The relevant literature is distributed across determinant-specific reviews that frequently use different species, comparators, welfare constructs, follow-up periods, and definitions of acceptable management. Environmental enrichment, for example, has been linked conceptually with functional capacity and resilience, but those relationships depend on the nature and timing of environmental opportunities rather than enrichment as a simple binary exposure [2]. Review-level synthesis is therefore useful not because reviews automatically resolve uncertainty, but because it permits comparison of where evidence converges, where apparently similar conclusions arise from different underlying conditions, and where repeated primary studies may exaggerate apparent breadth. An umbrella design also creates an explicit separation between review findings and the integrative interpretation proposed here, reducing pressure to treat cross-domain patterns as direct causal evidence.

Objectives

The primary objective was to synthesize review-level evidence on nutritional conditions, housing, handling and human interaction, environmental enrichment, social environment, and painful management procedures as determinants of farm-animal welfare. Secondary objectives were to identify species and production-system boundaries; distinguish resource conditions from observable animal-based welfare outcomes; examine areas of agreement, contradiction, and uncertainty among reviews; identify where conclusions may be influenced by overlapping primary studies; and assess how methodological limitations constrain inference. The review further sought to determine whether these evidence streams justify interpretation as interacting domains rather than independent management variables. Where integration extended beyond relationships directly established in the underlying reviews, the resulting classification or relationship was treated explicitly as proposed synthesis rather than as a validated welfare mechanism or decision rule.

Materials and Methods

The review was organized as an umbrella review of review-level farm-animal welfare evidence. Reporting logic was aligned with PRISMA principles for transparent systematic-review reporting [5] and with PRIOR considerations specific to overviews of reviews [6]. Particular attention was given to duplicated evidence, discordant review findings, and the risk of interpreting repeated primary studies as independent confirmation, problems documented in methodological research on overviews [7]. Evidence verification incorporated bibliographic records, publisher or DOI metadata, review-design classification, publication year, journal eligibility, species or production population, determinant domain, reported welfare outcomes, methodological limitations, and claim-level relevance. The review did not generate new pooled effect estimates. Where reproducible database-export counts were unavailable, retrieval, deduplication, screening, exclusion, and inclusion totals were not reconstructed. Synthesis therefore emphasizes evidence relationships, methodological boundaries, and review-level findings rather than an unsupported numerical representation of search volume.

Eligibility criteria for reviews

Eligible welfare evidence comprised peer-reviewed review-level publications published within the prespecified period and directly addressing farm animals, production settings, or management conditions relevant to the review domains. Systematic reviews, meta-analyses, and other eligible review designs were distinguished according to their reported methods rather than treated as interchangeable evidence units. A publication had to provide sufficiently identifiable species or population, exposure or management condition, welfare-related outcome or

construct, and interpretive context to support a bounded manuscript claim. Topic-adjacent papers were not considered equivalent merely because they discussed livestock management. Duplicate article versions, sources outside the temporal scope, records without verifiable article identity, and evidence materially incompatible with the intended species, exposure, outcome, or review-level unit were excluded from substantive synthesis. Methodological publications were retained only for review conduct and interpretation rather than counted as welfare-evidence units.

Information sources

Evidence identification used targeted bibliographic discovery of PubMed-indexed material supplemented by publisher and DOI-based verification of candidate publications. Bibliographic metadata were cross-checked at article level before sources were assigned to manuscript claims. The information-source process was used to distinguish substantive farm-animal welfare reviews from methodological literature required for reporting, appraisal, search design, and overlap assessment. General web discovery was not treated as equivalent to a reproducible bibliographic-database export. Because an auditable source-by-source export chain was not available, no numerical database retrieval totals are presented. Search-date precision was likewise not reconstructed retrospectively. These constraints were carried forward into selection reporting so that absence of reproducible search accounting was not converted into an apparently complete selection history.

Search strategy

The search architecture combined four concept blocks: farm-animal populations; welfare and welfare-related outcomes; determinant terms covering nutrition, housing, handling, enrichment, social environment, and painful procedures; and review-design terminology. Database complementarity was treated as important because different bibliographic sources can retrieve non-identical evidence sets [8]. Search construction also followed guidance favouring explicit, reproducible definitions of the literature-search process rather than undocumented iterative searching [9]. Reporting principles from PRISMA-S informed the level of search detail considered necessary for reproducibility [10]. Because availability of complete search strategies materially affects whether another investigator can evaluate or reproduce a review search, search transparency was treated as a methodological requirement rather than an optional supplement [11]. Candidate articles were subsequently checked for date eligibility, article type, DOI identity, journal eligibility, species or setting compatibility, and claim-level relevance.

Review selection

Selection was conducted at the level required by the intended evidential role of each publication. A candidate welfare review had to satisfy article-level eligibility and contribute extractable evidence to at least one prespecified determinant or cross-domain question. Methodological publications could inform review conduct without becoming welfare-evidence units. When a candidate mixed relevant and peripheral content, eligibility depended on whether the farm-animal welfare component could be bounded without transferring conclusions from incompatible populations or outcomes. Apparent duplication was assessed by article identity and, conceptually, by likely overlap in underlying primary evidence. Topic similarity alone was insufficient for retention. No numerical selection totals are reported because exact export-derived transition counts were not available. This avoids treating bibliography size as a surrogate for records identified, screened, excluded, or ultimately represented in the substantive review-level evidence.

Table 1 presents evidential roles and dispositions of records screened for the farm-animal welfare umbrella review.

Table 1. Evidential roles and dispositions of records screened for the farm-animal welfare umbrella review

Record class	Role in the umbrella review	Animal or system filter	Extractable basis	Disposition	Independence or scope check
Direct determinant review	Review-level welfare evidence is extractable	Species, life stage, production system	Explicit determinant and welfare outcomes	Retain for domain synthesis	Bound conclusions to reported population and outcomes
Mixed-scope review	Only a bounded component is relevant	Relevant farm-animal subgroup identifiable	Welfare component separable from peripheral content	Retain only the compatible evidence	Reassess if subgroup inference cannot be isolated

Topic-adjacent review	Management relevance does not establish welfare fit	Exposure or outcome incompletely aligned	No claim-level match to a review question	Do not use for substantive inference	Reconsider only if an exact welfare claim becomes extractable
Duplicate or strongly overlapping synthesis	Apparent breadth may not represent independent evidence	Similar population, intervention, and primary-study period	Repeated article identity or overlapping study base	Preserve unique review role; flag dependence	Examine primary-study overlap before interpreting consistency
Methodological source	Supports review conduct, not animal-welfare findings	Not applicable	Reporting, appraisal, search, or overlap method	Retain outside welfare-evidence unit	Do not convert methodological literature into outcome evidence

The adjudication categories are proposed organizational distinctions used in this umbrella review; they are not a validated selection score.

A flow representation is necessary to make explicit where selection-accounting transparency ends rather than filling the missing transitions with inferred numbers (**Figure 1**).

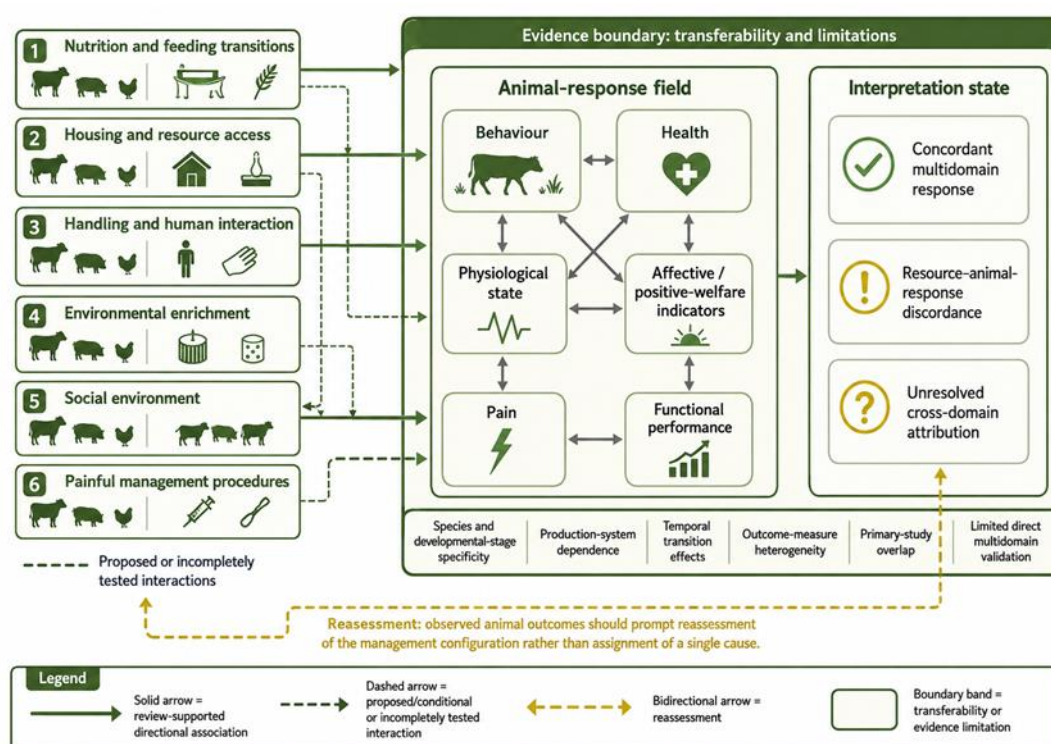


Figure 1. Auditable selection stages and the boundary of numerical reporting in the farm-animal welfare umbrella review

The review-selection architecture separates identification, duplicate assessment, screening, full-text eligibility, exclusion, and final review-level evidence assignment. Numerical nodes are intentionally absent because reproducible export-derived counts were not available and were not retrospectively reconstructed. Exclusion logic is restricted to prespecified article type, date, journal, DOI, species or setting compatibility, determinant relevance, outcome relevance, and duplicate/version criteria. Methodological sources remain distinct from substantive welfare reviews.

Top-to-bottom review-selection flow beginning with targeted bibliographic identification, followed by duplicate/version assessment, record-level relevance screening, full-text review-level eligibility, explicit exclusion pathways, and assignment of eligible welfare reviews to nutrition, housing, handling, enrichment, social-environment, painful-procedure, or cross-domain synthesis. A boundary band marks unavailable numerical accounting; no node displays an inferred count.

Data extraction

Extraction was organized around the smallest review-level unit required to support a specific manuscript claim. Recorded fields included review purpose and design, species or production population, setting, intervention or exposure, comparator where reported, welfare construct, measurement source, direction of reported findings, methodological approach, relevant modifiers, contradictory or null findings, authors' limitations, and transferability boundaries. Missing characteristics were treated as not reported rather than inferred. Particular attention was paid to whether apparently similar outcomes represented behaviour, physiology, health, productivity, affective state, pain, or composite welfare assessment. Extraction also separated direct review findings from interpretation added by the present synthesis. This distinction was necessary because review-level aggregation can otherwise obscure the different inferential roles of measured outcomes, author interpretation, and cross-review reconstruction [7].

Methodological-quality appraisal

Methodological quality was considered using AMSTAR 2 as a domain-based appraisal framework [12]. Attention centred on protocol specification, search adequacy, study-selection and extraction procedures, transparency of exclusions, risk-of-bias assessment, appropriateness of synthesis methods, incorporation of primary-study limitations into interpretation, publication-bias considerations where applicable, and conflicts or funding. AMSTAR 2 was not converted into a numerical score because such scoring can mask critical-domain weaknesses. Where available information was insufficient to support a complete domain judgement, no unsupported confidence classification was assigned. Quality appraisal therefore functioned as an interpretive boundary: conclusions from a methodologically limited review could still identify a relevant welfare question, but apparent consistency was not treated as equivalent to high-certainty evidence merely because similar conclusions appeared in multiple publications.

Primary-study overlap assessment

Primary-study overlap was treated as a separate source of dependence across reviews. Corrected covered area methodology provides one approach for quantifying repeated inclusion of the same primary studies across review matrices [13]. More recent methodological work emphasizes that pairwise overlap may reveal relationships obscured by a single overall overlap estimate [14]. Evidence also indicates that overall and pairwise approaches can yield materially different impressions when review sizes and study distributions vary [15]. Potential high-overlap clusters were therefore identified conceptually where reviews addressed closely related populations, management exposures, and evidence periods. However, no numerical corrected-covered-area value was calculated because complete primary-study membership matrices were not available for every relevant review. Accordingly, repeated review conclusions were interpreted cautiously and were not automatically counted as independent corroboration.

Evidence-synthesis strategy

Given heterogeneity in species, production systems, review design, management exposures, comparators, outcome definitions, and measurement timing, synthesis was primarily structured and narrative. Evidence was organized first by determinant domain and then examined for cross-domain interaction, concordance, contradiction, and boundary conditions. No new umbrella-level pooled effect estimate was generated. Greater interpretive weight was given to conclusions that remained coherent after considering directness, methodological quality, outcome relevance, population comparability, and likely primary-study overlap. Where reviews addressed different manifestations of welfare, apparent disagreement was not automatically classified as contradiction; behavioural, physiological, health, affective, and productivity outcomes were kept analytically distinct. The final integrative argument distinguishes review-supported relationships from proposed cross-domain synthesis and avoids interpreting management associations as validated causal mechanisms.

Results and Discussion

The verified substantive evidence demonstrated substantial heterogeneity in both management exposure and welfare outcome. In dairy calves, milk-feeding practices influenced hunger-related behaviour, feeding behaviour, intake, growth, and other outcomes, with effects dependent on feeding quantity and method rather than a single “adequate feeding” category [16]. Weaning evidence similarly indicated that timing and method can alter

behavioural and performance responses, making transition design integral to nutritional-welfare interpretation [17]. A broader systematic review of calf feeding management reinforced the need to distinguish biological functioning, opportunities for more natural behaviour, and affective consequences rather than treating feeding solely as nutrient provision [18]. Painful management procedures represented a different evidence structure: review and meta-analytic evidence on cattle castration supported benefits of some analgesic strategies for acute pain-related outcomes while retaining heterogeneity by procedure, outcome, treatment, and assessment time [19]. No numerical review-selection totals are presented.

Included-review landscape

The early evidence landscape demonstrates why determinant labels alone are insufficient units of interpretation. The calf literature illustrates dense review-level attention to feeding quantity, delivery method, weaning, and broader feeding management, but these reviews differ in outcomes, comparisons, and developmental timing [16]. Weaning is especially dependent on transition conditions and cannot be treated as a simple age-defined event [17]. Broader calf-management synthesis spans biological functioning, behavioural opportunities, and affective interpretation, demonstrating that even one determinant domain can contain multiple welfare constructs [18]. Pain-management evidence introduces a contrasting structure in which procedure, analgesic approach, assessment interval, and outcome type determine interpretation [19]. The landscape therefore supports domain-by-domain synthesis followed by cautious cross-domain integration rather than aggregation of nominally similar “welfare effects.”

Nutritional determinants

Review-level evidence indicates that nutritional welfare cannot be reduced to nutrient adequacy alone. In dairy calves, milk allowance and delivery method influence hunger-related behaviours, sucking motivation, intake, growth, and feeding patterns, making access conditions part of welfare interpretation [16]. Weaning adds a temporal transition in which timing, nutritional dependence, and method can alter behavioural and performance responses [17]. Broader feeding-management synthesis similarly separates biological functioning from opportunities for species-relevant behaviour and affective experience [18]. The evidence therefore supports interpreting nutrition as a dynamic state involving provision, access, motivation, transition, and animal response rather than a binary adequate/inadequate exposure. **Table 2** presents calf feeding and weaning configurations viewed through provision, motivation, transition, and animal response.

Table 2. Calf feeding and weaning configurations viewed through provision, motivation, transition, and animal response

Feeding or weaning configuration	Welfare dimension exposed	Animal and management conditions	Animal-based readout	Management meaning	Next developmental checkpoint
Nutritionally sufficient but motivationally constrained	Intake may meet biological requirements while hunger- or sucking-related motivation remains	Milk allowance, feeding frequency, delivery method, age	Feeding-directed behaviour, non-nutritive sucking, intake pattern	Do not infer satisfactory welfare from growth alone	Limit: Behavioural meaning depends on feeding context Recheck: Reassess behavioural and intake responses together
High-provision feeding	Greater provision may reduce hunger while changing solid-feed transition	Allowance, starter access, individual development	Intake, growth, feeding behaviour	Balance immediate satiety with transition readiness	Limit: Effects vary across feeding systems Recheck: Reassess as solid-feed dependence develops
Abrupt nutritional transition	Weaning can produce short-term behavioural or performance disruption	Weaning age, body development, method	Vocalisation, feeding change, growth response	Treat weaning as a transition rather than a calendar event	Limit: Outcomes differ by preweaning management Recheck: Reassess before, during, and after transition
Gradual or intake-linked transition	Transition may better match individual nutritional development	Starter intake, milk reduction schedule	Solid-feed intake, behavioural adjustment	Align transition with observable readiness where feasible	Limit: No single method is universally optimal Recheck: Reassess if intake or behaviour indicates poor adaptation

Proposed cross-domain state	Nutritional response may be modified by housing, social access, and handling	Competition, feeder access, social environment	Discordance between provision and individual response	Investigate interacting determinants before changing diet alone	Limit: Cross-domain causality is not established Recheck: Reassess the surrounding management configuration
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Housing determinants

Housing effects were conditional rather than directionally uniform. Review-level dairy evidence shows that year-round loose housing, grazing access, and other housing systems cannot be ranked reliably without considering management, climate, health, behaviour, resource design, and comparator conditions [20–22]. Sow housing similarly illustrates trade-offs among movement opportunities, injury risk, piglet outcomes, environmental requirements, and management feasibility [23]. Historical poultry synthesis also shows that cage and cage-free labels encompass different welfare advantages and hazards rather than representing singular welfare states [24]. Housing should therefore be interpreted as an enabling or constraining environment whose welfare meaning emerges through resource access, behavioural opportunity, injury exposure, social configuration, and management quality. A nominal system label is consequently weaker evidence than animal-based outcomes observed within that system.

Handling and human interaction

Human-animal interaction is both an exposure and a context through which other husbandry practices are delivered. Positive, predictable contact can reduce fear and support more favourable animal responses, whereas aversive or inconsistent interaction may compromise welfare [25]. The relationship is not determined solely by isolated handling events: stockperson attitudes, routines, familiarity, and the practical organization of work influence how interactions occur [26]. Evidence from sow and piglet systems further illustrates that housing and human contact may operate together rather than as separable determinants [27]. These findings justify retaining handling as an independent analytical domain while avoiding the assumption that “positive contact” has a uniform magnitude or effect across farms. Interpretation requires species, prior experience, frequency of contact, production stage, housing design, and the particular welfare outcome being measured.

Environmental enrichment

Environmental enrichment has welfare relevance when it provides biologically meaningful opportunities rather than merely adding objects to an enclosure. Review-level synthesis conceptualizes enrichment as potentially supporting information acquisition, behavioural competence, and adaptive capacity [28]. Practical evidence in pigs and broiler chickens similarly emphasizes manipulability, accessibility, novelty, and species-specific motivation in determining whether enrichment is actually used [29]. Earlier pig-focused synthesis documents effects on behaviour and welfare while also showing substantial variation among materials, housing circumstances, and outcome measures [30]. Consequently, enrichment presence should not be treated as equivalent to enrichment effectiveness. Interpretation should examine what opportunity is created, whether animals engage with it, whether access is socially constrained, how engagement changes over time, and whether animal-based outcomes improve. These requirements distinguish functional enrichment from nominal environmental complexity.

Social environment

Social conditions influence welfare through companionship, competition, learning, behavioural development, and access to resources. Systematic review evidence in calves indicates that pair or group management can alter social behaviour and responses to novelty without supporting a simple claim that every social arrangement is superior under every management condition [31]. Pair-housing evidence similarly suggests behavioural advantages while emphasizing variation in health, feeding access, age at grouping, and management [22]. Social environment also interacts with human contact: animals housed differently may experience handlers, feeding routines, and stressful procedures differently [27]. Social contact therefore should not be interpreted as a binary housed-alone/housed-together variable. Group size, stability, age, resource distribution, competition, previous experience, and opportunity for withdrawal can alter whether social exposure functions as support, challenge, or both.

Painful management procedures

Painful procedures represent a welfare determinant whose interpretation depends strongly on procedure type, tissue injury, analgesic regimen, timing, and outcome measurement. Systematic review and meta-analytic evidence for cattle castration indicates that some analgesic approaches reduce acute pain-associated responses, but heterogeneity across methods and outcomes prevents a claim of complete pain elimination [19]. Broader farm-animal pain-management literature similarly identifies substantial variation in recognition, measurement, timing, and treatment across cattle, sheep, and pigs [32]. Pain-related welfare assessment should therefore distinguish prevention, mitigation, residual pain, and recovery rather than classify a procedure simply according to whether analgesia was administered. Observable behaviour, physiological responses, function, and time since intervention provide complementary but non-interchangeable information. Management convenience or procedural convention cannot establish that remaining pain is negligible.

Cross-domain welfare effects

The reviewed domains are analytically separable but biologically interconnected. Feeding access may depend on housing and competition; social housing may alter feeding behaviour and handling exposure; enrichment opportunities can be restricted by space or group dynamics; and painful procedures may modify activity, social interaction, and resource use. These relationships support a proposed configuration-based interpretation in which welfare is inferred from the animal's response to the current combination of determinants rather than by adding independent management features. The proposal does not establish a universal causal network. Instead, it identifies when single-domain interpretation is especially vulnerable to error: when resource provision and animal-based outcomes disagree, when one determinant constrains access to another, when welfare changes during transitions, or when apparently favourable management coincides with adverse behavioural, health, or affective evidence.

Consistency of review-level evidence

Consistency was strongest at the level of conditional principles rather than universal prescriptions. Enrichment reviews converge on the importance of biological relevance and engagement, yet specific materials and outcomes remain context dependent [28]. Poultry evidence illustrates another source of apparent inconsistency: extended laying cycles can involve interacting productivity, egg-quality, physiological, and welfare consequences rather than a single direction of effect [33]. Transport-related water deprivation likewise shows that duration and accompanying conditions shape welfare interpretation [34]. Repeated conclusions cannot automatically be considered independent because related reviews may contain overlapping primary studies. **Table 3** presents why agreement among farm-welfare reviews may represent replication, transfer, outcome divergence, or overlap.

Table 3. Why agreement among farm-welfare reviews may represent replication, transfer, outcome divergence, or overlap

Cross-review pattern	Source of agreement or disagreement	Meaning retained in synthesis	Dependence or transfer problem	Study-level check
Convergent, context-matched evidence	Conditions: Species, life stage, production system Observed pattern: Directionally compatible review findings	Interpretation: Similar conclusions arise under comparable populations and conditions Synthesis use: Greater interpretive confidence	Independence of primary evidence still matters	Recheck overlap and methodological quality
Convergent but context-divergent evidence	Conditions: Management configuration, outcome definition Observed pattern: Comparable qualitative pattern, different exposures	Interpretation: Similar principle appears across dissimilar systems Synthesis use: Supports a conditional principle, not one prescription	Transferability may be limited	Test the principle within each target system
Outcome-dependent discordance	Conditions: Behaviour, health, physiology, productivity, affect Observed pattern: Benefit in one outcome with neutral/adverse result in another	Interpretation: Reviews differ because they measure different welfare dimensions Synthesis use: Preserve multidimensional interpretation	Outcomes are not interchangeable	Reassess using multiple animal-based measures

Potentially overlap-driven agreement	Conditions: Publication period, population, intervention Observed pattern: Similar conclusions from closely related evidence bases	Interpretation: Several reviews may reuse the same primary evidence Synthesis use: Do not count agreement as independent replication	Exact dependence requires study-level mapping	Update overlap assessment when matrices are available
Proposed interaction uncertainty	Conditions: Combined nutrition, housing, social, handling, enrichment conditions Observed pattern: Sparse direct interaction evidence	Interpretation: Cross-domain relationship is plausible but insufficiently tested Synthesis use: Treat relationship as hypothesis-level synthesis	Causal direction and magnitude unresolved	Prioritize factorial or longitudinal validation

Quality and certainty of evidence

The evidence base contains useful convergence but not uniform certainty. Review quality depends on search completeness, transparent eligibility, risk-of-bias appraisal, synthesis appropriateness, and whether limitations of primary studies are incorporated into conclusions [12]. Confidence is further affected by primary-study overlap: similar conclusions across several reviews can create an impression of replication when they originate partly from the same experiments [14]. Heterogeneity in welfare constructs presents an additional boundary because behaviour, physiology, health, productivity, pain, and affective indicators capture related but non-identical dimensions. Accordingly, this umbrella review does not impose an unverified numerical certainty grade. Greater confidence is reserved for bounded conclusions supported by methodologically transparent reviews, directly relevant populations and outcomes, consistent interpretation across comparable conditions, and no obvious dependence on a narrow repeated evidence base.

The synthesis indicates that farm-animal welfare is better interpreted as a configuration of interacting conditions than as a collection of independently satisfactory resources. This conclusion is compatible with multidimensional welfare models emphasizing biological functioning and affective experience while recognizing that favourable provision does not guarantee favourable animal response [35]. A well-resourced environment may still produce poor welfare if access is constrained, transitions are poorly managed, painful procedures remain insufficiently mitigated, social conditions create competition, or enrichment lacks functional relevance. Conversely, one adverse indicator does not automatically identify its causal determinant. The proposed configuration-based architecture therefore begins with animal-based evidence and asks which combination of nutritional, physical, social, procedural, and human-interaction conditions can plausibly explain the observed state. It is an interpretive synthesis, not a validated diagnostic algorithm, and should not replace species-specific welfare protocols or direct clinical and behavioural assessment.

Implications for welfare assessment

Commercial welfare assessment increasingly requires indicators that are scientifically meaningful while remaining feasible under farm conditions. Reviews of farmed-species assessment systems emphasize that protocols vary in validity, practicality, coverage, and implementation context [36–38]. Dairy-cow evidence further demonstrates that animal-based indicators differ in evidential support and operational feasibility [37]. Decision-tree work for laying hens illustrates why protocol choice itself may need to respond to production system and assessment purpose rather than defaulting to one instrument [39]. Assessment should therefore combine resource information with animal-based measures and temporal context. A favourable housing, feeding, or enrichment provision should not override contradictory animal evidence, while an adverse animal outcome should trigger investigation across interacting determinants instead of immediate attribution to a single management feature.

Implications for farm management

The synthesis favours management responses that are conditional and reassessable. Feeding should be evaluated through both provision and animal response; housing through resource access, injury, behaviour, and system-specific constraints; social management through companionship and competition; enrichment through meaningful engagement; handling through predictability and animal response; and painful procedures through prevention, analgesia, residual pain, and recovery. This does not imply that every farm requires maximal intervention in every domain simultaneously. The more defensible principle is to identify welfare-relevant discordance and determine whether one domain is constraining another. Changes should therefore be judged against subsequent animal-based outcomes rather than assumed beneficial because they conform to a preferred husbandry label. Production

feasibility, climate, facility design, labour capacity, species, developmental stage, and individual variation remain legitimate boundaries on transferability.

Evidence gaps

The largest gap is not absence of determinant-specific research but scarcity of evidence testing interactions among determinants over time. Calf, pig, cattle, and poultry reviews frequently examine feeding, housing, social conditions, enrichment, handling, or procedures separately, leaving uncertain how combined exposures alter welfare trajectories. Positive welfare outcomes are also less consistently integrated with health, pain, or productivity measures. Primary-study overlap further obscures whether apparent review-level breadth represents independent replication. Needed research includes longitudinal designs across management transitions, direct comparisons of multidomain configurations, validated positive-welfare measures, better reporting of contextual modifiers, and explicit testing of whether resource changes produce concordant animal-based responses. These deficiencies motivate a manuscript-derived architecture that separates established determinant evidence from proposed cross-domain relationships.

A synthesis figure is useful here because the principal research gaps arise at intersections between evidence domains rather than within a single linear pathway (**Figure 2**).

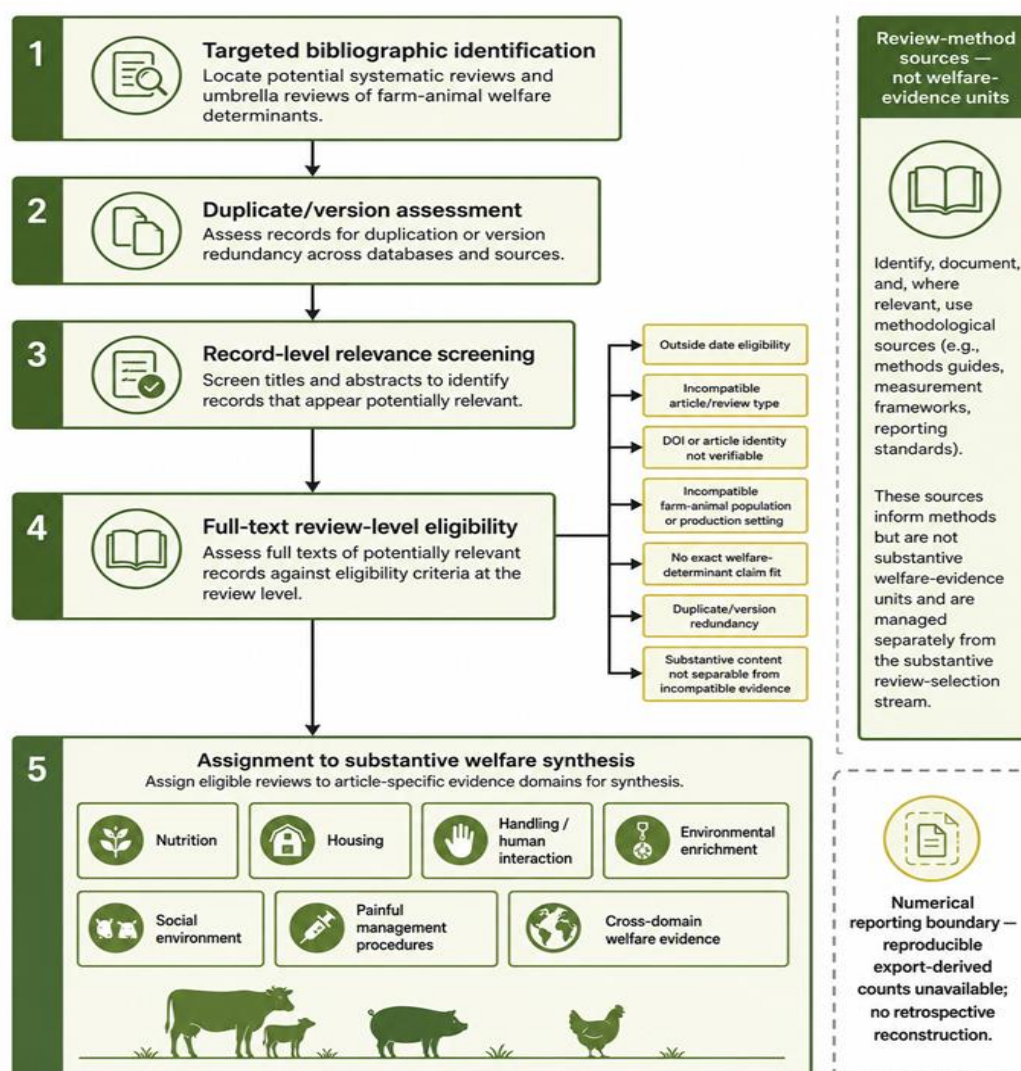


Figure 2. Evidence blind spots at the intersections of farm-animal welfare determinants

Separate evidence domains for nutrition, housing, handling/human interaction, environmental enrichment, social environment, and painful procedures feed into an animal-response field containing behavioural, health,

physiological, affective, pain, and functional outcomes. Solid connections denote relationships directly represented in review-level evidence; dashed cross-links denote proposed or incompletely tested interactions. An external evidence boundary highlights species and life-stage specificity, temporal transitions, measurement heterogeneity, primary-study overlap, and limited multidomain validation. Reassessment returns from observed animal response to the determinant configuration rather than assuming a single cause.

Layered left-to-right scientific architecture with six separate farm-management evidence domains surrounding a central animal-response region. Conditional dashed links connect domains where nutrition, housing, social conditions, handling, enrichment, and procedures may interact. A right-side interpretation region distinguishes concordant response, cross-domain discordance, and unresolved attribution. A surrounding boundary lists species, developmental stage, time, measurement, overlap, and validation limits, with a feedback arrow returning interpretation to reassessment of the management configuration.

Limitations

Several constraints delimit interpretation. Review-level evidence is uneven across species, life stages, production systems, and welfare domains, with dairy calves particularly prominent in some determinant areas. Enrichment evidence illustrates how intervention labels can conceal substantial variation in material, access, duration, and behavioural relevance [30]. Pain reviews likewise show heterogeneity in procedures, measurement, and treatment conditions [32]. Housing comparisons can be strongly system-specific, as illustrated by long-standing differences between cage and cage-free poultry evidence [24]. Primary-study overlap was recognized but could not be quantified comprehensively without complete study-membership matrices. Reproducible database-export counts were unavailable and therefore were not reconstructed. Finally, the proposed configuration-based interpretation organizes cross-domain reasoning but has not been prospectively validated against independent welfare outcomes.

Conclusion

Farm-animal welfare emerges from the configuration of nutritional, physical, social, procedural, environmental, and human-interaction conditions surrounding the animal. Review-level evidence supports evaluating these domains jointly while preserving species, production-system, developmental, temporal, and measurement boundaries. Resource provision alone cannot establish welfare, and concordant animal-based outcomes remain essential to interpretation. The proposed configuration-based synthesis identifies cross-domain discordance and reassessment needs without assigning universal causal weights. Direct multidomain and longitudinal validation is required before this architecture can support standardized predictive or management decisions.

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