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Review: A systematic review of dairy cow health, welfare, and behaviour in year-round loose range housing

W.J. Harvey [a,b,*], L. Petrokofsky [a], M.W. Jordon [c], G. Arnott [d], L.W. von Walter [e], A. Malik [a], T. Carter [a], L.S. Wade [a], G. Petrokofsky [a,f]

[a] Oxford Systematic Reviews, 266 Banbury Road, Oxford, OX2 7DL, UK
[b] School of Archaeology, University of Oxford, 36 Beaumont Street, Oxford OX1 2PG, UK
[c] Oxford Martin School, University of Oxford, 34 Broad Street, Oxford, OX1 3BD, UK
[d] Institute for Global Food Security, School of Biological Sciences, Queen's University Belfast, BT9 5DL, UK
[e] Department of Anatomy, Physiology and Biochemistry, Faculty of Veterinary Medicine and Animal Science, Swedish University of Agricultural Sciences, SE-750 07 Uppsala, Sweden
[f] Department of Biology, University of Oxford, Mansfield Road, Oxford, OX1 3SZ, UK

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ABSTRACT

This systematic review compares the health, welfare, and behaviour of dairy cows in year-round loose housing systems against those kept in other housing systems in temperate regions. Year-round loose housing systems comprised housing where dairy cows had no access to the outdoors or only had access to a yard, pen or run. The comparator housing systems also comprised housing with and without outdoor access (including grazing). To contribute to evidence-informed policy, a systematic evidence evaluation was undertaken to assess the scientific evidence base for this question, and determine whether the evidence base is robust enough to determine any association between housing systems and health, welfare and natural behaviour in dairy cows. We assessed 11 181 references and reviewed 53 articles in detail following best practice guidance for systematic review. Seven different types of housing systems were compared and a total of 120 different Health, Welfare and Behaviour (**HWB**) outcomes were assessed, comprising 839 measurements for HWB. Results indicate both advantages and disadvantages of year-round loose-housing systems. These differences were not just between studies; there were also differences within-studies for individual HWB indicators. There was substantial heterogeneity in methods of collecting and measuring HWB outcomes across the studies; therefore, a robust statistical test (such as meta-analysis) of correlation between potential explanatory variables and HWB outcomes was not possible for any housing comparison or any individual HWB measurement. Assessing the evidence base systematically as a whole, there is only weak evidence that year-round loose-housing is either better or worse than housing systems with grazing for the health and welfare of dairy cows. There is also only weak evidence that year-round loose-housing is either better or worse than housing systems with any outdoor access, including but not limited to grazing, for the health and welfare of dairy cows. Variation in data reporting across studies is too great to allow robust statistical analysis of the direct effects of loose-housing systems and/or grazing on the health and welfare of dairy cows. Data are also often presented in an aggregated form that limits meaningful comparisons. For future research, data collected should be made freely available in a disaggregated form to enable robust meta-analysis to be conducted. In order to change policies and practices, based on evidence, more standardised primary research studies, measuring welfare indicators, including behaviour, are necessary.

Implications

This research explores whether dairy cows fare better in year-round loose housing or with access to the outdoors and grazing. Our findings reveal no definitive advantage or disadvantage of either system on cow health, welfare, or behaviour. This insight is crucial for dairy farmers and industry policymakers, guiding

* Corresponding author.
E-mail address: william.j.harvey@oxsrev.org (W.J. Harvey).

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them towards more informed decisions about cattle housing practices. This work highlights the need for more targeted studies to refine housing strategies, ultimately benefiting the dairy industry by promoting animal health and welfare.

Background

The motivation for this review arises from a question that has emerged in the global agricultural context: Does the practice of summer grazing for dairy cows genuinely enhance animal welfare when compared to year-round confinement? This enquiry lies at the crossroads of the escalating demands for intensified livestock production to meet the global food requirements (Steinfeld et al., 2006) and the ongoing concerns for animal welfare, which have significantly influenced contemporary agricultural legislation. These concerns trace their origins to Harrison (1964), which shed light on the consequences of the increasing industrialisation of agriculture. Harrison's work triggered a comprehensive investigation in the United Kingdom into the lives of animals raised under intensive, confined conditions. The subsequent Brambell report defined animal welfare as "a broad term encompassing both the physical and psychological well-being of the animal. Therefore, any attempt to assess welfare must consider the scientific evidence available regarding the emotions of animals, which can be deduced from their anatomy, physiology, and behaviour" (HMSO, 1965). While the Brambell report did not possess regulatory authority in the United Kingdom, it laid the foundation for European Union legislation, including the Animal Health Law. This law, despite primarily addressing transmissible animal diseases, amended and repealed numerous animal health regulations (Reg. EU 2016/429) and played a crucial role in shaping the legislation of various European countries. One noteworthy example is the 1988 Swedish law, which imposed stringent restrictions on the confinement of farm animals. The development of this law was greatly influenced by Astrid Lindgren, in collaboration with Swedish farm animal veterinarian Christina Forslund. In honour of her advocacy for improved animal welfare, the law was named 'Lex Lindgren'.

The concept of Five Freedoms was implicit in the Brambell report and formed the basis of later guidance and legislation worldwide relating to the welfare of farm animals in confinement (FAWC, 2009). The Five Domains developed as a reformulation and elaboration of the Five Freedoms (Mellor et al., 2020). Table 1 summarises these two models. The five freedoms framework can be used to analyse welfare within any livestock system and continues to be critiqued (see, for example, Fraser, 2008), and developed, for example, the concept of Positive Animal Welfare and a live worth living has emerged, which goes beyond the "absence of sufferings" and "absence of negatives" (Lawrence et al., 2019).

There has been steadily increasing pressure on animal agriculture in many countries to regulate production practices to assure or improve animal welfare. Many factors have driven this increased interest, not least the increasing awareness by the general public of the intensification of the dairy industry, although research shows that public opposition to intensive ('factory farm') systems are not directly related to animal welfare (Clark et al., 2016). In addition, Robbins et al. (2016) reported in their literature review of 150 papers that there was no relationship between animal welfare and size of farm (mostly dairy farms), despite the fact that many smaller farms rear cows outdoors in extensive systems and tend to use more workers per animal.

Regulation can be voluntary (compliance by individuals or organisations without legal mandates), involuntary (compliance enforced by laws, regulations, and legal instruments) or a combination of both (Knierim and Pajor, 2018, Vapnek and Chapman, 2010). Involuntary regulations are the main approach in the European Union, with bans on some production systems and animal welfare standards for rearing, transport and slaughter. In non-European Union countries, including the United States of America, Canada, Australia, and New Zealand, voluntary regulation is the main regulatory system (Whiting, 2013, Mench, 2008). These can take the form of standards developed by commodity groups and audited by independent bodies to ensure continued compliance, or standards set by food retailers.

It is likely that the trend towards greater pressure to address animal welfare concerns in farming will continue along the lines developed from the Five Freedoms, and more recently the Five Domains Model (Mellor et al., 2020), as set out in the General Principles by the World Organisation for Animal Health (Fraser et al., 2013). These concerns will be influenced by three, interrelated, factors — "the rise in demand for animal products in developing countries and the associated globalisation of production and trade in animal products; the importance of minimising the environmental impact of animal agriculture; and reconciling demands for animal products with the public's evolving expectations about the treatment of animals" (Mench, 2020).

Table 1
Five Freedoms and Five Domains Models used for the Systematic Review of Dairy Cow Health, Welfare, and Behaviour in Year-Round Loose Range Housing.

Aspect	Five Freedoms Model	Five Domains Model
Origin	Developed in the 1960 s, formalised in the 1970 s by the UK Farm Animal Welfare Council.	Developed by David Mellor and colleagues in the 1990 s, as an expansion and elaboration of the Five Freedoms.
Focus	Primarily concerned with minimising negative states of welfare.	Focuses on both negative and positive states of welfare, emphasising a balance.
Components	1. Freedom from hunger and thirst.	1. Nutrition – factors that involve the animal's access to sufficient, balanced, varied, and clean food and water.
	2. Freedom from discomfort.	2. Environment – factors that enable comfort through temperature, substrate, space, air, and others.
	3. Freedom from pain, injury, or disease.	3. Health – factors that cover disease prevention, diagnosis, and treatment.
	4. Freedom to express normal behaviour.	4. Behavioural interactions – factors that enable the expression of positive behaviours.
	5. Freedom from fear and distress.	5. Mental state – emphasis on the animal's psychological state, reflecting its overall welfare.
Approach	Negative-based approach; aims to avoid harm and suffering.	Positive-based approach; seeks to promote well-being and satisfaction of needs.
Application	Widely used as a basic standard for animal welfare in various sectors, including farming, zoos, and laboratory animals.	Increasingly adopted in recent years, especially for more comprehensive assessments of animal welfare.
Criticism	Criticised for being too simplistic and focusing mainly on avoiding negative experiences, rather than promoting positive states.	Can be more complex to implement due to the focus on both positive and negative aspects and the subjective nature of assessing mental states.
Impact on Policy	Influential in the development of animal welfare policies and legislation.	Being increasingly referenced in contemporary animal welfare policies and guidelines, advocating a more holistic view of animal welfare.

The public may have little knowledge about animal production practices, however, their opinions about what constitutes acceptable dairy farming, and in particular access to grazing and pasture, may not align with those of farmers (Smid et al., 2022, van den Pol-van Dasselaar et al., 2020). This lack of agricultural knowledge presents a problem in terms of reconciling producer vs consumer perceptions for evidence-informed policy in the future. Zero-grazing systems, where dairy cows are kept indoors permanently, are common in North America and, increasingly, in some parts of Europe (van Vuuren and van den Pol-van Dasselaar, 2006), but are often not popular with the public at large. Van den Pol-van Dasselaar et al. (2020) report that stakeholders considered grazing important, but the general public, as a group, considered it especially important (64% gave it the highest importance, compared with 31% in the farmer group and 46% in the scientist group).

There has been a trend towards less grazing and outdoor access in recent years, and in Europe, this trend differs markedly between regions, depending on a number of social, economic and geographical factors (van den Pol-van Dasselaar et al., 2020). Understanding the health and welfare implications of reduced exposure to the outdoors is a necessary precursor to proposing changes to legislation, in countries with mandatory grazing periods, and for responding to consumer demands for transparency in livestock production systems. Any change to guidance or legislation in respect of livestock farming is best discussed with as complete an evidence base as possible so that there is full transparency of the relative advantages and disadvantages of different production systems. The current review therefore follows the best practice guidelines of Cochrane (Higgins et al., 2023) and the Collaboration for Environmental Evidence (CEE, 2022).

For the purpose of this review, loose housing systems have been defined as animal houses where the animals are allowed to move freely and have free access over the whole area of the building or pen (a small enclosure for livestock). Unlike confined or tethered systems, loose-housing allows animals to move freely between sections for feeding, resting, and socialising. The design of the facility ensures protection from adverse weather conditions, maintains hygiene through manure management systems, and promotes animal welfare by facilitating natural behaviours. Year-round loose housing means either no outdoor access or outdoor access which is limited to pens, yards, or runs (i.e. no access to pasture).

Objective of the review

Primary question: Are the health and welfare of dairy cows kept in year-round loose housing systems better or worse than those kept in different housing systems (with or without outdoor access or grazing)? Secondary question(s): (i) Are all aspects of natural behaviour exhibited by dairy cows on pasture fully fulfilled by cows permanently in loose housing systems? (ii) Are there differences in health, welfare and behaviour of dairy cows housed in different systems of all-year loose housing? A Population Intervention Comparator Outcome (**PICO**) framework has been used to categorise the different aspects of both the primary and secondary questions (Table 2).

Table 2
Definitions of the question under the Population, Intervention, Comparator, Outcome (PICO) framework used for the Systematic Review of Dairy Cow Health, Welfare, and Behaviour in Year-Round Loose Range Housing.

PICO	Description
Population	Dairy cows in temperate countries
Intervention	All-year loose housing
Comparator	Combination of seasonal loose housing and grazing; different types of loose housing systems; before-and-after introduction of all-year loose-housing
Outcomes	Health and welfare of dairy cows; natural behaviours enabled

Methods

Stakeholder engagement and advisory group

Following good practice guidelines, the review involved stakeholders and advisors. An initial meeting organised by the Swedish Farmers' Foundation for Agricultural Research outlined the review objectives and solicited interest for participation amongst those attending the meeting. In addition to people who indicated interest from this meeting, potential stakeholders were found by emailing a list of people found through:

1. Authors of relevant academic papers
2. Contact persons from relevant farmer organisations and groups
3. Contact persons from relevant veterinary or dairy businesses or collectives
4. Contacts suggested by people from any of the groups (1–3 above)

A total of 54 people were invited to select times when they were available, if interested, in the first stakeholder meeting during the week commencing 24 January 2022. The email contained a brief description of the review aims and an Agenda.

The first stakeholder meeting was held on Friday 28th January between 1000–1200 h CET and attended by 14 people from a range of different organisations engaged in academia, policy-making, practice, and advocacy. The group discussed the focus of the review, developing a search strategy (suggesting keywords and phrases, sources of information, and compiling an exemplar set of publications to verify the search), what literature to include and exclude (including geographical extent and languages of articles to consider). The meeting also discussed the role of an Advisory Group (**AG**) formed from participants and others who had expressed interest in advising, but who could not attend the stakeholder meeting. Expressions of interest were collected after the meeting by a Google form, and an AG of 14 people from five countries was formed.

Inputs from the stakeholder meeting were used to draft the Protocol. The draft was circulated to the AG, amended and finalised. The first AG meeting was held in April 2022, and a second in October 2022. Email was used to communicate with AG members between meetings to seek guidance at different stages of the review.

Search strategy

Grey literature and organisational websites (e.g. institutional reports, government reports, non-governmental studies) were also searched to minimise biases arising from including only published, academic literature (Table 3). An additional call for grey literature was made to stakeholders, the advisory group, and relevant organisations (Table 3). The search strategy for bibliographic databases was designed to maximise the amount of relevant literature found by following best practice guidelines outlined in Livoreil et al. (2017). An iterative approach was applied to identify, improve, and optimise keywords and search terms (Supplementary Material 1: Tables S1, S2, S3, S4). The initial list of terms was collected in an online stakeholder workshop (28 January 2022) resulting in a list of 129 keywords or phrases. These terms were expanded upon through the identification of synonyms and preferred terms from relevant literature provided by stakeholders and the advisory group. This extensive list of keywords and terms was then opti-

Table 3
List of sources of literature searched: 10 February 2022 used for the Systematic Review of Dairy Cow Health, Welfare, and Behaviour in Year-Round Loose Range Housing.

Source of literature	Resource
Online Bibliographic Databases & Aggregators	Web of Science (Core collection) CAB Abstracts Scopus MEDLINE PubMed Organic eprints
Research Organisation's Websites	Swedish University of Agricultural Sciences Lund University Universitat Kassel Harper Adams University Queen's University Belfast University College Dublin Norwegian University of Life Sciences Natural Resources Institute Finland Wye College University of Copenhagen Aarhus University Wageningen, Netherlands INRA, France
Grey Literature	Swedish Board of Agriculture Swiss Federal Veterinary Office Sveriges Veterinärförbund Hushållningssällskapet Danish Dairy Board AHDB Dairy (UK) Statens veterinärmedicinska anstalt Svensk mjölk European Dairy Farmers Stiftelsen Lantbruksforskning Mjólkursamsalan TINE (Norway) Lantbrukarnas Riksförbund Växa Seges Denmark IDF International Dairy Farmers Association Teagasc, Ireland

mised against a test set of 20 relevant articles (Supplementary Material S1) to ensure the maximum return of relevant literature while reducing the overall quantity of irrelevant literature (Supplementary Material 1). The terms from the optimised search were then combined into a booleanBoolean string and used to search five online bibliographic databases on the 10 February 2022 (Table 4). Searches of the online bibliographic databases and aggregates were conducted in English only. Justification for this common limitation is provided in research by Ramírez-Castañeda (2020) that reports 98% of publications in science are written in English. The databases were chosen because they have high coverage rates of veterinary journals and others with significant veterinary content (Grindlay et al., 2012) and extensive coverage of dairy farming journals. The comprehensiveness of the search was assessed during the optimisation process by ensuring that test set articles present in Web of Science and CAB Abstracts were returned by combining key terms and keywords in Table 4. Optimisation of these combinations of terms was determined by achieving the lowest return rate while finding all test articles. (Supplementary Material 1). We also searched references cited in relevant literature reviews and in background sections of included papers - sometimes referred to as 'snowballing'- to identify other relevant articles to screen (CEE, 2022).

Table 4
Key words/terms used to search bibliographic databases used for the Systematic Review of Dairy Cow Health, Welfare, and Behaviour in Year-Round Loose Range Housing.

PICO Element	Key Term
Population 1	cow* | cattle
Population 2	dairy
Intervention/ Comparator	barn*|concrete floor|cubicle*|dry lot|dry-lot|earth floor|forced ventilation|free-stall|freestall*|hard core floor|house|housing|Indoor*|rubber mats|Shed|slat*| sloped system|Stall*|stanchion*|tether*|tiestall|zero graz*|sheds
Outcome	anti inflammatory|antibiotic use|body condition|feeding compet*|hoof quality|milk amount|milk qualit* & "milk composition"|milk yield*|social licking|activit*| behaviour*|behavior*|cleanliness|comfort*|discomfort*| diseas*|disorder*|distress*|fertility|health|infect*|lame*| lesions|locomotion|longevity|lunging|mastitis| oestrus|parasit*|nematod*|patho*|perching|pregnancy| rumination|stress*|welfare|wellbeing|well-being

Article screening and study inclusion criteria

Screening strategy

Following searching in each of the bibliographic databases and aggregators, articles were uploaded into EndNote20 (Gotschall, 2021), subscription reference management software published by Clarivate. Duplicate articles were removed and the resulting combined set of articles was uploaded into Rayyan (Ouzzani et al., 2016), a free natural-language processing tool that employs machine learning for screening articles for systematic evidence evaluation. Articles were screened for eligibility at two stages: (i) title and abstract assessment; and (ii) full-text assessment.

Consistency checking

Articles were single-screened by six screeners. In order to check the consistency of screening at title and abstract stage, sets of 100 articles were screened by all screeners, and inter-rater agreement was assessed using Cohen's kappa. Differences in screening were discussed amongst the screeners and the process was repeated with sets of 100 articles until a satisfactory level of agreement was reached (0.6). At full-text screening, sets of six articles were similarly assessed by all screeners until an inter-rater agreement was reached.

Inclusion criteria

In order to be included in the review, articles had to include information from all elements of the PICO framework. In the first assessment, screening was based on information in the title and abstracts in response to three questions: (i) Are the words in the title or abstract, or both, directly related to or included in the review questions? (ii) Does the title or abstract, or both, describe an original research study, as opposed to a literature review or opinion piece? (iii) Was measurement of an outcome of interest (e.g. disease or behaviour) an objective of the study? Only articles with a positive response to all three questions were eligible to proceed to the second stage - screening at full-text. Studies were included if they related to temperate countries or regions, with geographic exception noted in the exclusion criteria. There were no exclusion criteria on the basis of date of research.

Exclusion criteria

Studies were excluded if they related to work in: Africa, Central and South America, Asia and Russia. This limitation was agreed through discussions with the Stakeholder Group who advised dairy housing practices were significantly different in the above regions and therefore not comparable to loose housing practices in the rest of the world. The intention was to limit the language of the original

article to those languages that could be read by the review team and advisory group members willing to provide some translation: English, French, German, Spanish, Swedish, Greek, and Arabic. In practice, all of the academic journal articles were in English and a limited number of non-English articles were retrieved in the grey literature process, most of which did not satisfy inclusion criteria. Grey literature was only assessed where there was at least an English summary or English captions on tables and Figs, or where Google Translate provided a clear indication of the methods used in the article.

Risk of bias assessment

Full-text studies were evaluated for appropriateness of the study design for the research question, and an assessment of specific criteria related to the study design and the likelihood of internal and external biases, adapted from guidance in Pinchbeck and Archer (2020) and used checklists adapted from the Joanna Briggs Institute (JBI, 2021) and Arnott et al. (2012). The evaluation was conducted without consideration of the study results to avoid interpretation bias. Studies were scored according to how many of the nine questions were answered with "Yes". Scores therefore ranged from 0 to 9. The results of these assessments were not used for excluding studies from the evidence map, but are intended to enable filtering of studies at risk of bias from specific analyses. The following questions were posed for risk of bias assessment:

1. Is the sample size for each treatment group sufficiently large? (> 5)
2. Are missing data accounted for?
3. Are the criteria for inclusion in the sample clearly defined - including details of randomisation where appropriate?
4. Are the study subjects and the setting described in detail?
5. Are all of the intervention/exposure and control treatments described including details of treatment, timing, and duration of application?
6. Are the criteria for the measurement of all different interventions and their comparators (termed 'intervention arms') described in detail?
7. Are strategies to deal with confounding factors stated?
8. Is there a clear account of the statistical methods used to compare groups for all outcome(s)?
9. Are all raw data available?

Data coding and extraction strategy

Data from the included studies were extracted and summarised in a standardised evidence table. In addition to metadata about the article (authors, title, date of publication, source, abstract) taken directly from the bibliographic databases, and study design details, coded by the review team, information based on the PICO elements were extracted by the review team. In total, 266 data fields were completed; not all studies included data in all fields. The extracted information was used to assess the effects of all-year loose housing on health and welfare of dairy cows. Geographic location data (latitude/longitude expressed in decimal degrees) were either taken directly from the article or added using Google Maps to look up locations of place names in the article. Articles which provided data for multiple interventions were treated as separate 'studies' and all comparisons between housing systems were captured within each study separately. Consistency amongst coders and data extractors was assessed in the same way as full-text article screening, and differences were resolved by repeated discussion until an agreement was reached. Where data from articles were unclear or aggregated, authors were contacted by email for clarification. Disaggregated data or clarified data provided by authors were recorded and included where possible following the same inclusion criteria. Missing data were not imputed.

Potential effect modifiers/reasons for heterogeneity

Several potential effect modifiers that may have contributed to heterogeneity in the outcome were identified during the full-text screening and recorded for all the studies included in this review. These fell broadly into three categories:

1. Population-source variation: herd size, cattle breed, age of study animals,
2. Intervention-source variation: (i) house bedding type (straw, sawdust, rubber mats, slats), house space allowance (m^2 per cow); (ii) distance to walk to exercise area or pasture (if pastured control); (iii) surface of tracks to exercise or pasture (e.g. bark, gravel, earth, concrete); (iv) number of grazing days; (v) strategy (e.g. night-grazing, always open door, water and shadow at the pasture); (vi) Milking-system, milk yield and characteristics; (vii) other forms of environmental enrichment present (e.g. scratch brushes).
3. Location-source variation: i.e. location of farm.

Data synthesis and presentation

Studies were assessed for suitability for meta-analysis. To be deemed 'suitable', studies had to include data for the number of measurements, mean, and standard error or standard deviation. (The Results section explains that there were too few studies of sufficient comparability to facilitate meta-analyses, so these methods are not described further here). Data for date and source of publication, location of study, and study design (including cow breeds, farm/herd size, etc.) are summarised in a series of tables and Figures. Data showing numbers of different housing comparators for (i) year-round loose housing with zero grazing vs housing with grazing; and (ii) year-round loose housing without outdoor access vs housing with outdoor access are presented in tables. Health Welfare and Behaviour (**HWB**) data were assessed for positive, negative or no-difference (i.e. direction of effect, as reported by the authors) following Beaver et al. (2021) for each housing comparator. The number of independent studies from which the HWB measures were taken was assessed and used to filter results on the basis of strength of the evidence base for subsequent statistical and narrative analyses.

Canonical Correspondence Analysis (**CCA**) analysis and data visualisation were carried out in R (R. Core Team, 2012) using the package Vegan (Oksanen et al., 2015). The data were square-root converted in order to standardise the distribution and stabilise the variance (Harvey et al., 2019). A square root transform was chosen because it can be applied to data sets containing zero values. The HWB outcome data were subjected to Detrended Correspondence Analysis (**DCA**) to determine whether a linear or unimodal ordination method should be used (Ter Braak and Prentice, 1988). The CCA analysis was used to cluster the HWB data based on the direction of effect and housing comparator. These groups were used for narrative analyses of the studies.

Online interactive map

Using the geo-locations of all included studies, results are presented on an interactive map. The map is available at https://oxsrev.github.io/evidencemaps/loose_housing/. Brief operational details can be found on the website. The map was constructed using Open-Source software (Martin et al., 2017). Each circle on the map represents one location at which an evidence point was generated, or a regional cluster if more than one location occurred

nearby. Circle size represents the count of evidence points that occurred at the location. Pie segments represent a percentage of the evidence points at a location for each dairy cow housing type. Users can zoom in on the map to the point where individual circles indicate individual studies. Clicking the circle brings up a summary sheet of the associated studies. Users can also filter the map to show studies on one or a combination of attributes (e.g. type of housing, breed of dairy cows, etc.), and by dimension slices to show numerical filters (e.g. year, number of farms, etc.). Users can also filter the map to show studies on one or a combination of attributes (e.g. type of housing, breed of dairy cows, etc.), and by dimension slices to show numerical filters (e.g. year, number of farms, etc.).

Results

A total of 166 articles were retrieved and processed according to the methods described above. Fig. 1 shows the filtering process at each stage, which resulted in an evidence map of 53 Articles. Fig. 2 shows the location of studies and the number of studies at the country level. There are a total of 53 articles of literature that were included at full text of which the vast majority were made up of journal articles (n = 52) and one conference paper (Table 5). A total of 27 journals/resources were represented across the included articles of literature. The Journal of Dairy Science was the most prominent (n = 15), followed by Animal (n = 4), Livestock Science (n = 4), and Preventive Veterinary Medicine (n = 3) (Table 6). The earliest article included was published in 1997. The years with the highest number of publications include 2012, and 2017 with six publications in both years. The years 2006–2017 are best represented across the included articles of literature (Fig. 3). The total number of dairy cow breeds represented was 16 of which the dominant breeds examined in the included articles were Holstein cross (n = 30) and Holstein (n = 17) cattle (Fig. 4). Fig. 5 shows the scores for studies on the basis of the nine questions posed. Studies were scored according to how many of the nine questions were answered with "Yes". Scores therefore ranged from 0 to 9, where 9 is the lowest risk of bias and 0 is the greatest risk of bias. Only two studies scored the lowest risk of bias.

From the 53 articles of literature, a total of 120 separate HWB outcomes were coded from 86 studies, with 226 comparisons. These include diseases, welfare indicators, assessments of behaviour (including natural behaviours), and risk factors. Across these 120 HWB measures, 839 instances of HWB individual measurements were extracted. They fall into 13 broad categories (following Arnott et al., 2017; Beaver et al., 2021).

Meta-analysis was not possible from the collected data due to heterogeneity across collection methods and units for each of the health and welfare outcome measurements (in order to conduct meta-analysis the number of health, welfare or behaviour outcome measurements has to be greater than three).

Year-round loose housing vs other housing systems with grazing

Following the PICO framework adopted for the review (outlined in Methods), the intervention for all the following analyses was year-round loose housing with zero grazing. The comparators were different housing systems with grazing (Table 7). Table 8 shows the evidence base for HWB measures (outcomes) for year-round loose housing with zero grazing (**HTI**) vs housing with grazing (**HTC**). The data come from 25 articles containing 34 studies, with 75 housing comparisons, reporting 398 health, welfare and behaviour outcomes. The number of incidences is reported as positive (HTI+), negative (HTI−) or no-difference (HTI = HTC). These refer to, respectively: the health measure was better than, worse than, or the same as year-round loose-housing for zero-grazing compared with a housing system with grazing. HTI+ means a beneficial effect of the zero-grazed system whereas HTI− indicates a negative effect (i.e. worse in the zero grazed). Caution must be applied, however, in interpreting simple counts of data. Firstly, simple counts of data, based on incidences reported, cannot provide robust evidence that allows for a determination of association (correlation or causation), as outlined in the Method section. Secondly, even allowing for this limitation, a count can be useful to indicate trends within the evidence base, but it also needs to be interpreted with a consideration of the number of independent studies the measurements come from. Table 8, therefore, shows not only the raw directional counts but also the number of independent studies that contributed to each HWB count. The colour coding is a visual aid to the relative strength of the evidence, with darker purple indicating higher counts and a gradation of green to red showing high to low numbers of studies. As explained in the Method section, some articles yielded multiple independent studies.

Some HWB outcomes came from single studies, while the data for other HWB outcomes came from multiple studies. The data for the CCA were therefore filtered to include only HWB metrics drawn from more than one study (see Petrokofsky et al., 2024 for all studies and all HWB metrics).

A data set of 22 articles containing 33 studies, and 59 comparisons, reporting 192 health and welfare outcomes across four housing systems was included in the CCA which explained 3.5% of the data set across CCA1 (1.9%) and CCA2 (1.6%) (Fig. 6). CCA1 (horizontal axis) broadly represents positive (left), negative (middle), and no-difference (right) in HWB outcomes. This is due to how the groupings fall; CCA axes are not to be treated as representing a continuum. CCA2 (vertical axis) broadly indicates the split between tiestall and indoor (unspecified) (top), and loose housing (bottom). The detailed statistical interpretation of the CCA is described in the numbered points immediately below, followed by a summarised interpretation of these findings in the subsequent paragraphs.

1. Somatic Cell Count (**SCC**), Somatic Cell Score (**SCS**), sole lesion, and non-infectious claw disease are more closely aligned to CCA1 and are associated with more positive impacts for year-round loose housing with zero-grazing vs housing with grazing. Sole lesion and non-infectious claw disease outcomes are associated with the comparator loose housing with grazing; and SCC/SCS with loose-housing with grazing, and tiestall with grazing.
2. Heel horn erosion, digital dermatitis, clinical lameness and white line disease are aligned between CCA1 and CCA2 and are associated with more negative impacts for year-round loose housing with zero-grazing vs housing with grazing, and are most associated with the housing comparator loose housing with grazing.
3. Locomotion difficulties, sole ulcer, maximum axial wall deviation, white line lesion, dirty legs/flanks/udders, body condition, hygiene score and lesions and swellings are more closely aligned to CCA1 and are associated with no-difference impacts for year-round loose housing with zero-grazing vs housing with grazing and by the housing comparators loose-housing or mixed (loose and tiestall housing) with grazing.
4. Mastitis, severe hock lesions, and infectious claw disease are aligned between CCA1 and CCA2 and are associated with a combination of positive and negative impacts for year-round loose housing with zero-grazing vs housing with grazing. Mastitis is most explained by the housing comparator tiestall with grazing, while infectious claw disease and severe hock lesions are both explained by the housing comparator loose housing with grazing.

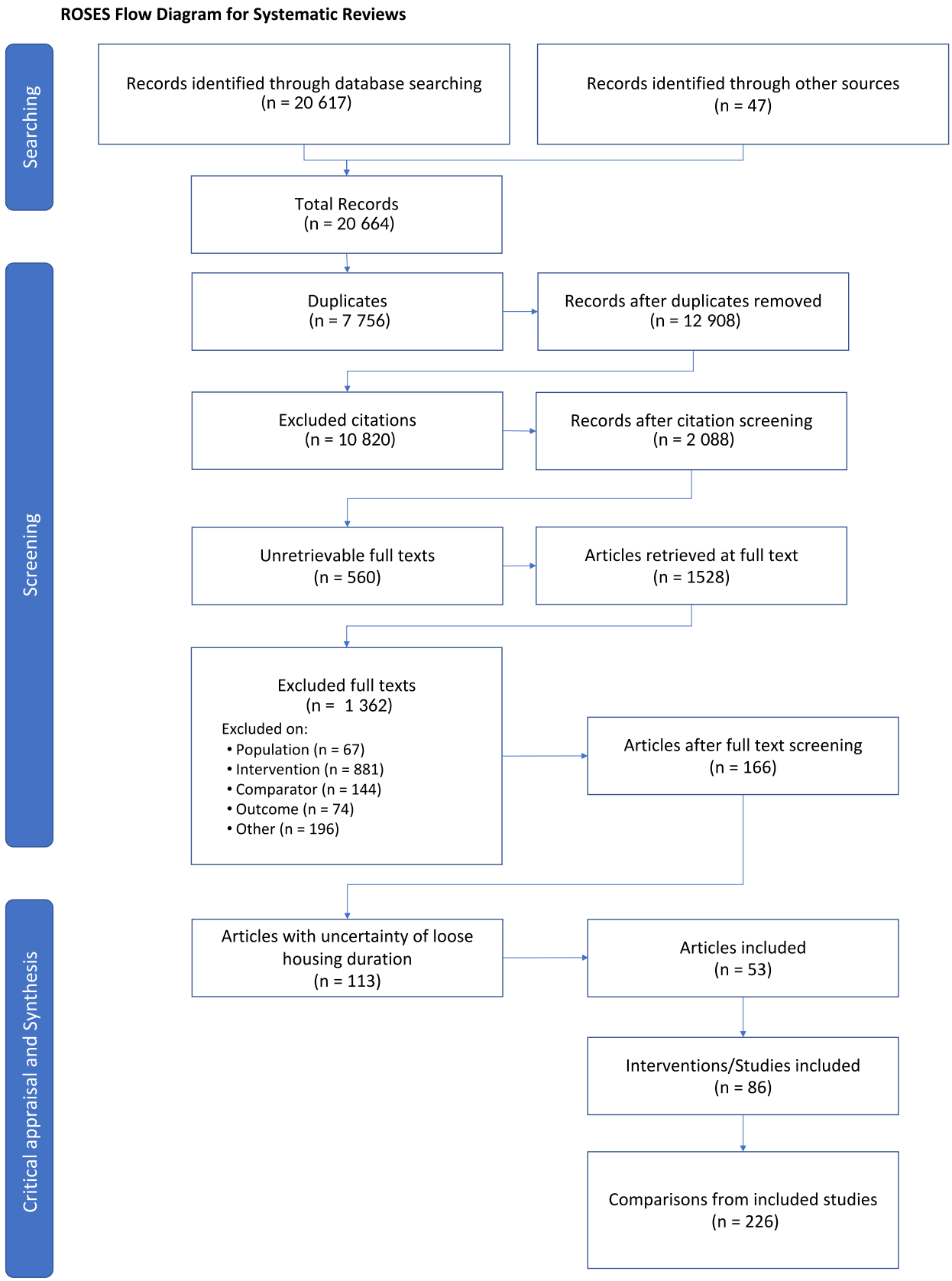

Fig. 1. Selection and screening of articles and studies reporting inclusion/exclusion used for the Systematic Review of Dairy Cow Health, Welfare, and Behaviour in Year-Round Loose Range Housing.

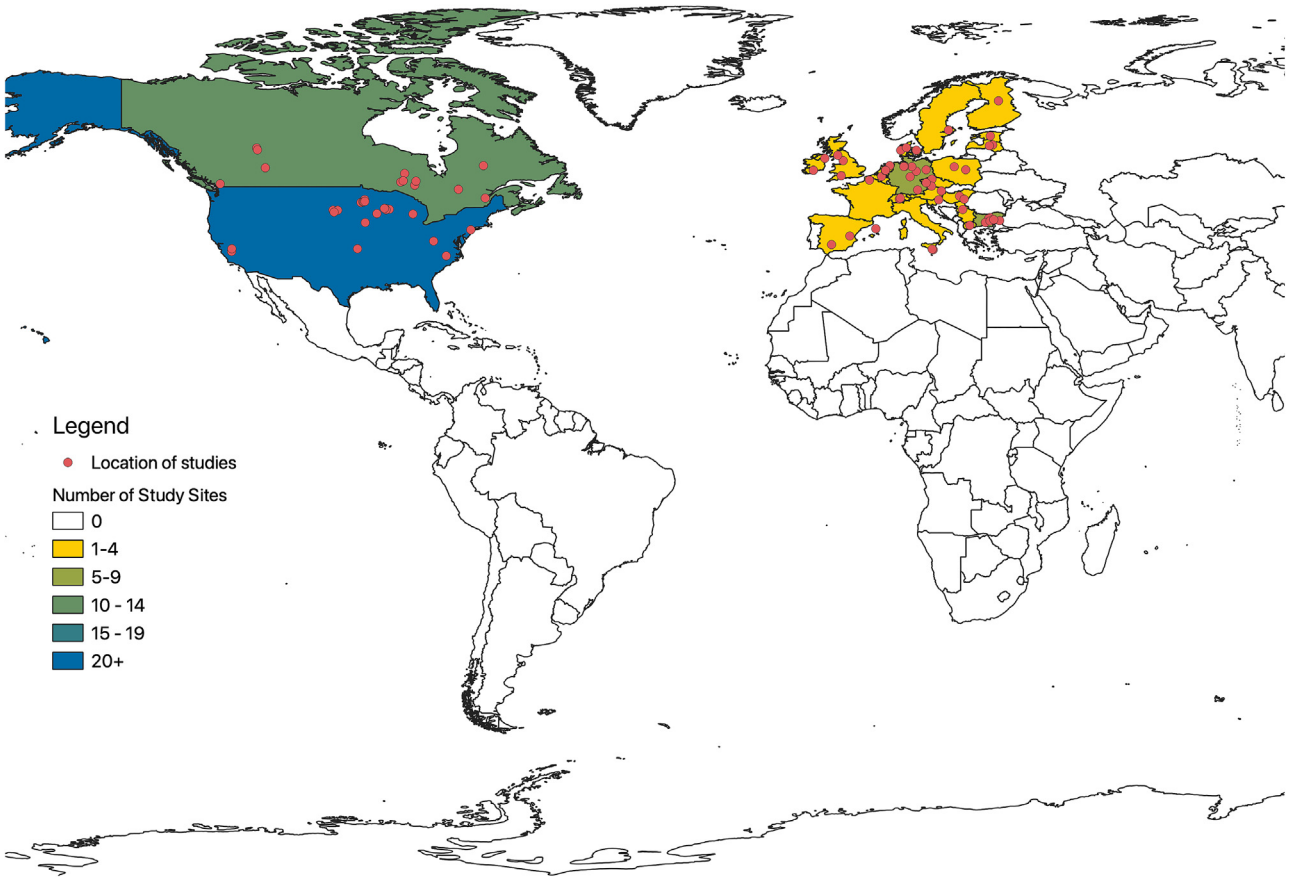

Fig. 2. Location of studies included in the evidence base created for the Systematic Review of Dairy Cow Health, Welfare, and Behaviour in Year-Round Loose Range Housing.

Table 5
Number of articles by publication type for the Systematic Review of Dairy Cow Health, Welfare, and Behaviour in Year-Round Loose Range Housing.

Publication Type	No.
Journal Article	52
Conference Paper/Proceedings	1
Total	53

Table 6
Journal/resources with two or more articles for the Systematic Review of Dairy Cow Health, Welfare, and Behaviour in Year-Round Loose Range Housing.

Journal/Resource Title	No.
Journal of Dairy Science	15
Livestock Science	4
Animal	4
Preventive Veterinary Medicine	3
Veterinary Record	2
Veterinary Journal	2
Animals	2
Agricultural Science and Technology	2

5. Severe lameness, dirty legs, double sole, interdigital dermatitis, interdigital hyperplasia, sole haemorrhages, and lameness (unspecified) are aligned between CCA1 and CCA2 and are associated with a combination of positive, negative, and no-difference impacts for year-round loose housing with zero-grazing vs housing with grazing. Mortality is more aligned with CCA2 and is also associated with a combination of positive and negative and no-difference impacts for year-round loose housing with zero-grazing vs housing with grazing. The impacts of mortality are most associated with the housing comparator tiestall housing with grazing, while severe lameness, dirty legs, double sole, interdigital dermatitis, interdigital hyperplasia, sole haemorrhages, and lameness (unspecified) are most associated with the housing comparator loose housing with grazing.

To summarise, five groups can be detected in the CCA (Fig. 6). Group 1 comprises three HWB outcomes where the evidence base indicates largely positive instances of year-round loose housing with zero grazing compared with housing systems with grazing (though it should be noted that individual studies within this grouping contain instances of the opposite effect or no difference). For SCC/SCS, Cielava and Lambertz reported only positive, Bradley reported positive and negative, Pavlenko reported no difference. For sole lesion, Baird reported positive. For non-infectious claw disease, Haggman reported positive and negative. Cielava and Pavlenko use a tiestall with an outdoor access comparator, all others use loose-housing. Bradley, Pavlenko, Baird, Lambertz and Haggman contained a grazing comparator of 91-180 days duration of grazing, Cielava used 181–270 days and Haggman also used 271–365 days (Table 9).

Group 2 comprises four HWB outcomes where the evidence base indicates largely negative instances of year-round loose housing with zero grazing compared with housing systems with grazing (though it should be noted that individual studies within this grouping contain instances of the reverse or no difference). For heel horn erosion, Baird, Olmos and Holzhauer report negative, Armbrecht reports positive, negative and no difference. For digital der-

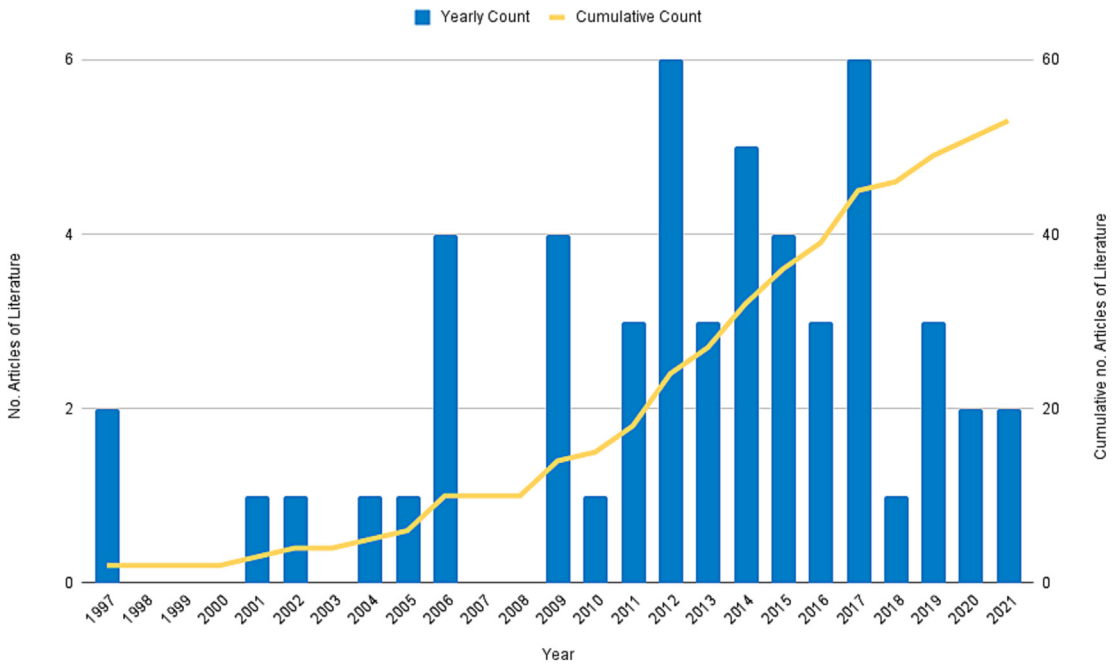

Fig. 3. Number of articles of literature by date of publication of articles included in the evidence map created for the Systematic Review of Dairy Cow Health, Welfare, and Behaviour in Year-Round Loose Range Housing by (i) individual year and (ii) cumulatively.

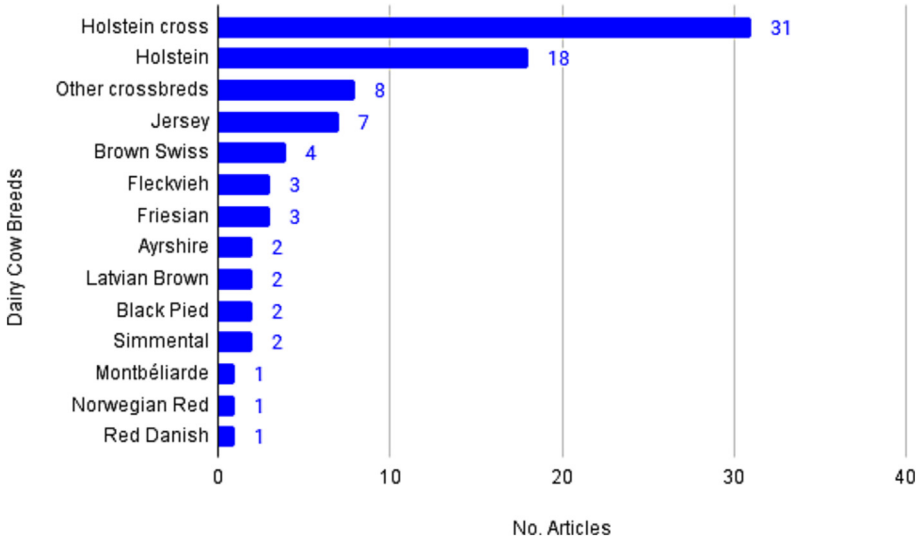

Fig. 4. Dairy cow breeds studied in Articles.

matitis, Olmos, Somers and Holzhauer report negative, Armbrecht reports negative and no difference. For white line disease, Olmos and Holzhauer report negative, Armbrecht reports positive, negative and no difference. For clinical lameness, Otten reports negative. N.B. All articles are for loose-housing systems only. Armbrecht, Baird and Holzhauer used a grazing comparator of 91-180 days duration of grazing, Olmos and Otten used 181–270 days (Table 10).

Group 3 comprises eight HWB outcomes where the evidence base indicates largely no-difference in instances of year-round loose housing with zero grazing compared with housing systems with grazing (though it should be noted that individual studies within this grouping contain instances of the reverse or no difference). For sole ulcer, Armbrecht and Holzhauer report no difference. For maximum axial wall deviation and white line lesion, Baird reports no difference. For locomotion difficulties, Olmos and Herlin report negative, Baird and Meul report no difference. For body condition, Meul reports no difference, Armbrecht reports positive and no difference. For dirty legs/flanks/udders, Gieseke and Meul report no difference, Armbrecht reports negative and no difference. For lesions and swellings, Gieseke and Meul report no difference, de Vries reports negative. For hygiene score, Salfer reports positive and no-difference. N.B. Herlin used tiestall as a comparator, Meul used a mix of tiestall and loose-housing as comparators, other authors used loose-housing, including one study by Herlin. Herlin and Meul used a grazing comparator of 91–180 days duration of grazing, Armbrecht, Baird, Gieseke, de Vries, Holzhauer used 91–180 days, Olmos and Salfer used 181–270 days (Table 11).

Group 4 comprises three HWB outcomes where the evidence base is a mix of positive, negative and no-difference instances of

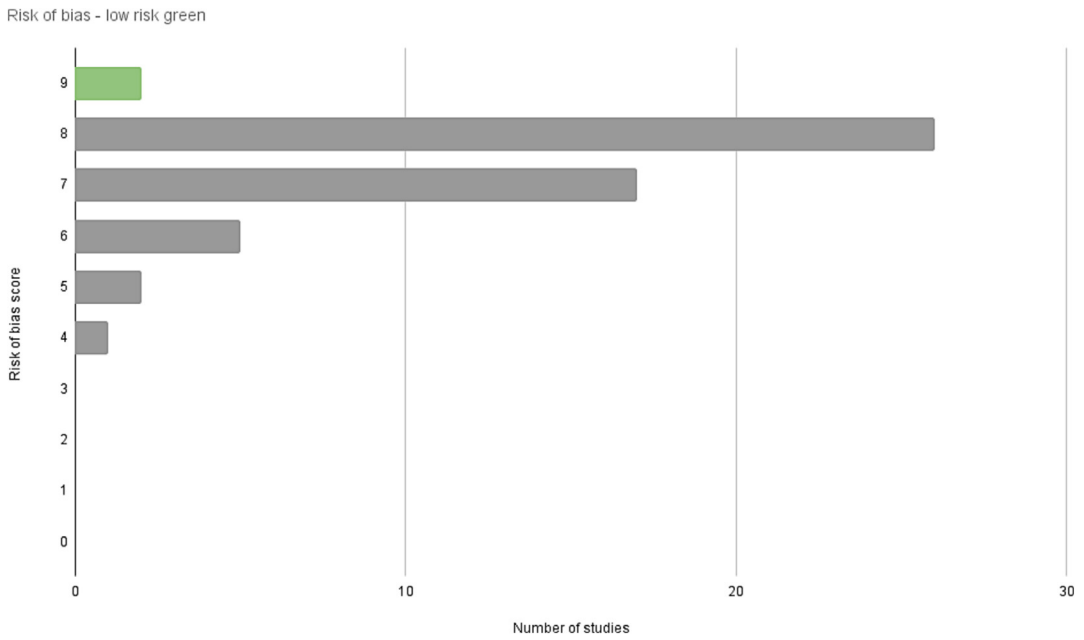

Fig. 5. Risk of bias scores for included articles for dairy cattle.

Table 7
Number of comparisons of "loose housing with zero grazing" vs "any other housing system (including loose housing) with grazing" for dairy cattle.

Item	Housing Type - with Grazing/Pasture Access (HTC)				
	Loose	Tiestall	Mixed	Indoor (Unspecified)	Total
Year-round Loose Housing - Zero Grazing (HTI)	50	18	2	5	75

year-round loose housing with zero grazing compared with housing systems with grazing, but with some instances of no difference. There is some influence in this group of the tiestall vs loose-housing comparator. For mastitis, Gieseke and Washburn report negative, Grabowski and Bradley report positive and negative, Olde-Riekerink reports positive and no-difference, Armbrecht reports positive, negative and no difference. For infectious claw disease, Haggman reports positive and negative. For severe hock lesions, Salfer reports positive and no-difference. N.B. Washburn used indoors (unspecified) as a comparator, Haggman, Grabowski, Olde-Riekerink, Bradley and Ambrecht used loose-housing as a comparator, Grabowski and Olde-Riekerink also used tiestall as a comparator. Grabowski, Bradley, Olde-Riekerink, Haggman and Armbrecht used a grazing comparator of 91-180 days duration of grazing, Salfer, used 181–270 days and Washburn, used 271–365 days (Table 12).

Group 5a comprises seven HWB outcomes where the evidence base is mainly negative and no-difference instances of year-round loose housing with zero grazing compared with housing systems with grazing, but with some instances of positive. There is some influence in this group of the tiestall vs loose-housing comparator. For sole haemorrhages, Olmos and Holzhauer report negative, Armbrecht reports negative and no difference. For interdigital hyperplasia, Armbrecht reports negative and no difference, Holzhauer reports no difference. For interdigital dermatitis, Armbrecht reports positive, negative and no difference. For double sole, Armbrecht reports negative and no difference. For lameness (unspecified), de Vries and Haskell report negative, Salfer reports positive, negative and no difference, Armbrecht reports negative and no difference. For severe lameness, Gieseke reports positive, Salfer reports positive, negative, and no difference, Armbrecht reports negative and no difference. For dirty legs, Gieseke reports no difference, Nielsen reports negative.

N.B. Grabowski and Cielava used tiestall as a comparator, Washburn used indoor (unspecified), and others used loose-housing as a comparator. Nielsen, Haskell, Cielava, Salfer and Olmos used a grazing comparator of 181–270 days duration of grazing, Washburn used 271–365 days, and all others used 91–180 days (Table 13). Group 5b comprises a single HWB measure, for which the evidence base is mainly negative or no difference, but in contrast to Group 4a, there is a tiestall effect. For mortality, Cielava and Washburn report negative, Armbrecht reports no difference, and Grabowski reports positive and negative (Table 14). In summary, only one HWB measurement (sole lesion) showed only positive and no-difference results (and the positives outweigh the no-difference) for zero–grazed year-round loose-housing. Whereas a total of three indicators (interdigital hyperplasia, sole haemorrhages, and clinical lameness) showed only negative and no-difference results (and the negatives outweigh the no-difference) for zero grazed year-round loose-housing.

Year-round loose housing without outdoor access vs housing systems with outdoor access (grazing or yards, runs, etc.)

Housing systems were compared against each other with the intervention being instances of year-round loose housing without outdoor access vs the comparator being housing with some outdoor access (Table 15). Table 16 shows the evidence base for health, welfare and behaviour measures (outcomes) for year-round loose housing without outdoor access vs housing with outdoor access. The data come from 17 articles containing 21 studies, with 85 comparisons, reporting 332 health, welfare and behaviour

Table 8
Total number of reported incidences for health, welfare, and behaviour (HWB) outcome measures in dairy cattle. Outcomes are categorised as positive for zero grazing (HTI+), negative for zero grazing (HTI−), or no difference between the systems (HTI = HTC), along with the number of studies these outcomes are derived from, as reported by the authors.

Category	HWB Measure	HTI+	HTI−	HTI = HTC	Studies n = 34
Udder Health	Mastitis	8	10	3	7
	Somatic Cell Count/Somatic Cell Score	12	2	1	5
	Yeast pathogens	3		2	1
	Bacterial pathogens – *Streptococcus uberis*	4	1		1
	Bacterial pathogens – *Streptococcus* species	5			1
	Bacterial pathogens – *Streptococcus faecalis*	3		2	1
	Bacterial pathogens – *Streptococcus dysgalactiae*		5		1
	Bacterial pathogens – *Serratia* species	3		2	1
	Bacterial pathogens – *Pseudomonas* species	2		3	1
	Bacterial pathogens – *Morganella* species	1		4	1
	Bacterial pathogens – *Klebsiella* species	2		3	1
	Bacterial pathogens – *Escherichia coli*	3	2		1
	Bacterial pathogens – *Enterobacter* species	1		4	1
	Bacterial pathogens – *Corynebacterium* species	1	4		1
	Bacterial pathogens – Coagulase positive staphylococci	5			1
	Bacterial pathogens – Coagulase negative staphylococci	2	3		1
	Bacterial pathogens – *Citrobacter* species	1		4	1
	Bacterial pathogens – *Bacillus* species	2	3		1
	Bacterial pathogens – *Arcanobacter pyogenes*		5		1
Foot and Leg Disorders	Heel Horn erosion	3	5	2	6
	Digital Dermatitis	1	8	1	5
	White Line disease	1	6	1	4
	Sole haemorrhages		5	3	4
	Sole ulcer			7	3
	Interdigital hyperplasia		5	2	3
	Interdigital Dermatitis	1	3	2	2
	Double Sole		3	3	2
	Severe Hock lesions	2		2	4
	Non-infectious claw disease	3	1		2
	Infectious claw disease	2	2		2
	Leg Diseases	2	1		1
	White line lesion			2	2
	Sole Lesion	2			2
	Maximum axial wall deviation			2	2
	Hock lesions (Unspecified)	2			1
	White Line haemorrhages		1		1
	Swelling		1		1
	Foot Infection			1	1
Uterine Health	Vaginal discharge			6	1
	Dystocia			6	1
	Reproductive tract diseases	3			1
	Retained foetal membranes			1	1
	Resumption of oestrus cyclicity			1	1
	Neospora caninum		1		1
	Metritis		1		1
	Endometritis		1		1
	Chlamydophila abortus			1	1
Maintenance	Dirty Legs/Flanks/Udders		1	8	4
	Hygiene Score	1		3	4
	Dirty legs		1	1	2
	Lying time		1		1
	Dirty udders			1	1
	Cows lying outside cubicles			1	1
	Collisions with cubicles		1		1
Nutrition	Body condition	1		7	3
	Absence of hunger			6	1
	β-Hydroxybutyric acid		1		1
	plasma concentrations of triglycerides	1			1
	Non-esterified fatty acids		1		1
	Cholesterol	1			1
Respiratory Health	Nasal discharge		3	3	1
	Hampered respiration			6	1
	Coughs			6	1
	Bovine herpesvirus specific antibodies (IBR-gE)		1		1
	Bovine herpesvirus specific antibodies (IBR-gB)		1		1
Gut and Intestinal Health	Diarrhoea		1	5	1
	Digestive tract diseases	2	1		1

(*continued on next page*)

Table 8 (*continued*)

Category	HWB Measure	HTI+	HTI−	HTI = HTC	Studies n = 34
	Rectal temperature		1		1
	Johne's disease		1		1
	Bovine viral diarrhoea (BVD)		1		1
Behaviour and Stress	Social Behaviour (Unspecified)			6	1
	Human–animal–relationship (Unspecified)			6	1
	Emotional State (Unspecified)			6	1
	Avoidance Distance		4	2	1
	Aggression			6	1
Lameness	Lameness (Unspecified)	2	6	4	7
	Severe Lameness	2	4	5	6
	Locomotion Difficulties		3	4	6
	Clinical lameness		2		2
Skin Health	Hairless Patches		4	2	1
	Lesions and swellings		1	3	4
Ocular Health	Ocular discharge	2		4	1
Mortality	Mortality	2	10	6	5
Metabolic Health	Metabolic disorders (Unspecified)	2	1		1

outcomes. The number of incidences is reported as positive (HTI+), negative (HTI−) or no-difference (HTI = HTC). These mean, respectively: the health measure was better than, worse than, or the same as year-round loose-housing without outdoor access compared with a housing system with outdoor access. HTI+ means a beneficial effect of loose housing system without outdoor access whereas HTI− indicates a negative effect (i.e. worse in loose housing system without outdoor access). Caution must be applied, how-

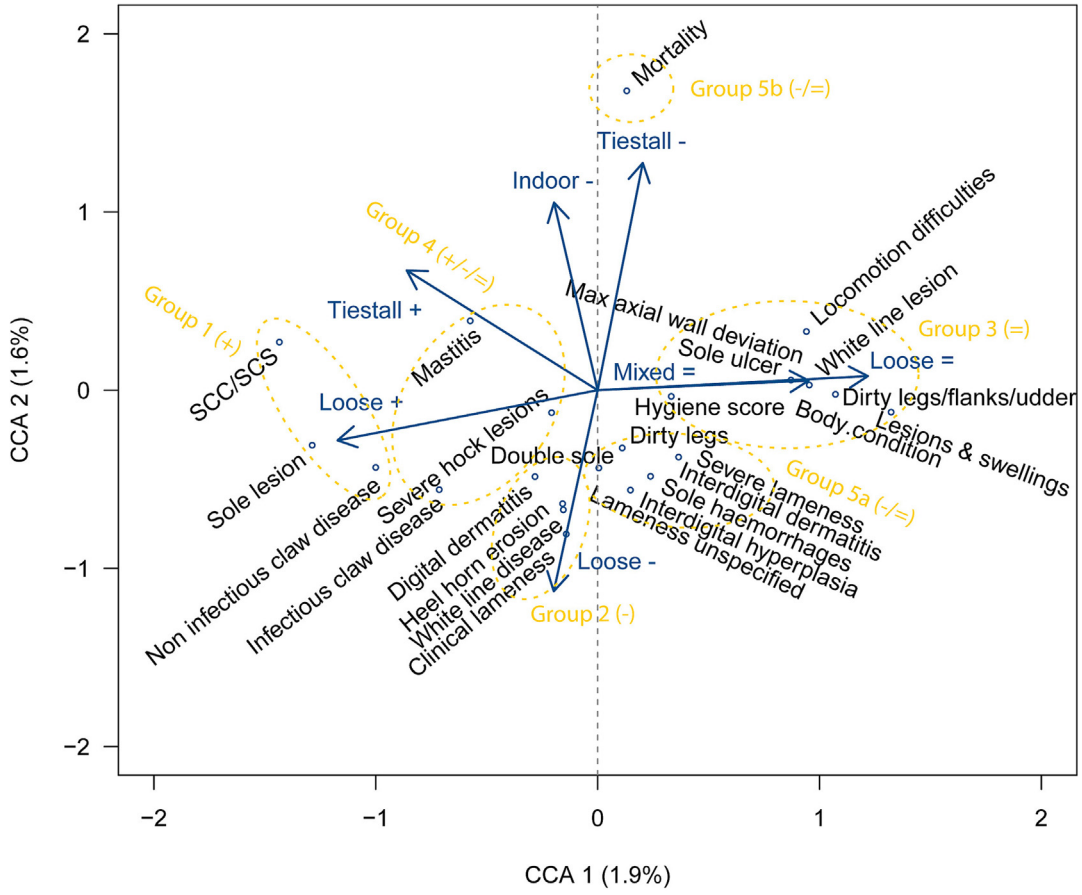

Fig. 6. Canonical correspondence analysis of year-round loose-housing with zero-grazing vs housing with grazing and impacts to health and welfare and behaviour (HWB) of dairy cattle. Abbreviations: CCA = Canonical correlation analysis, SCC = Somatic cell count, SCS = Somatic cell score, + = positive HWB measure with associated housing type, − = negative HWB measure with associated housing type, = = no difference in HWB measure with associated housing type.

Table 9
Group 1 health, welfare, and behaviour (HWB) outcomes for dairy cattle in year-round housing with zero grazing compared to systems with grazing/pasture access. Outcomes are categorised as positive for zero grazing (HTI+), negative for zero grazing (HTI−), or no difference between the systems (HTI = HTC), as reported by the authors.

Unique Identifier First Author Publication Date	Country of study	Housing Comparators	HWB Outcome Measurement	Effect Direction
1505_Baird_2009	UK	Loose housing	Sole lesion	+
1519_Haggman_2015	Finland	Loose housing	Non-infectious claw disease	+|−
2507_Cielava_2017	Latvia	Tiestall	Somatic Cell Count/Somatic Cell Score	+
294_Bradley_2001	UK	Loose housing	Somatic Cell Count/Somatic Cell Score	+| −
517_Pavlenko_2018	Estonia	Tiestall	Somatic Cell Count/Somatic Cell Score	=
738_Lambertz_2014	Germany	Loose housing	Somatic Cell Count/Somatic Cell Score	+

See Fig. 6 for the group identification.

Table 10
Group 2 health, welfare, and behaviour (HWB) outcomes for dairy cattle in year-round housing with zero grazing compared to systems with grazing/pasture access. Outcomes are categorised as positive for zero grazing (HTI+), negative for zero grazing (HTI−), or no difference between the systems (HTI = HTC), as reported by the authors.

Unique Identifier First Author Publication Date	Country of study	Housing Comparators	HWB Outcome Measurement	Effect Direction
1163_Armbrecht_2017	Germany	Loose-housing	Heel horn erosion	+|−|=
			Digital dermatitis	−|=
			White line disease	+|−|=
2074_Olmos_2009	Ireland	Loose-housing	Heel horn erosion	−
			Digital dermatitis	−
			White line disease	−
2539_Holzhauer_2012	Netherlands	Loose-housing	Heel horn erosion	−
			Digital dermatitis	−
			White line disease	−
3320_Somers_2005	Netherlands	Loose-housing	Digital dermatitis	−
1505_Baird_2009	UK	Loose-housing	Heel horn erosion	−
281_Otten_2013	Denmark	Loose-housing	Clinical lameness	−

See Fig. 6 for the group identification.

Table 11
Group 3 health, welfare, and behaviour (HWB) outcomes for dairy cattle in year-round housing with zero grazing compared to systems with grazing/pasture access. Outcomes are categorised as positive for zero grazing (HTI+), negative for zero grazing (HTI−), or no difference between the systems (HTI = HTC), as reported by the authors.

Unique Identifier First Author Publication Date	Country of study	Housing Comparators	HWB Outcome Measurement	Effect Direction
2061_Meul_2012	Belgium	Tiestall and Loose-housing	Locomotion difficulties	=
			Body condition	=
			Dirty legs, flanks, udders	=
			Lesions and swellings	=
439_Armbrecht_2019	Germany	Loose-housing	Body condition	+|=
			Dirty legs, flanks, udders	−|=
1521_Gieseke_2020	Germany	Loose-housing	Dirty legs, flanks, udders	=
			Lesions and swellings	=
2084_deVries_2015	Netherlands	Loose-housing	Lesions and swelling	−
1505_Baird_2009	UK	Loose housing	Maximum axial wall deviation	=
			White line lesion	=
			Locomotion difficulties	=
2074_Olmos_2009	Ireland	Loose housing	Locomotion difficulties	−
2392_Herlin_1997	Sweden	Tiestall and Loose housing	Locomotion difficulties	−
1163_Armbrecht_2017	Germany	Loose housing	Sole ulcer	=
2539_Holzhauer_2012	Netherlands	Loose housing	Sole ulcer	=
2119_Salfer_2018	USA	Loose housing	Hygiene score	+|=

See Fig. 6 for the group identification.

Table 12
Group 4 health, welfare, and behaviour (HWB) outcomes for dairy cattle in year-round housing with zero grazing compared to systems with grazing/pasture access. Outcomes are categorised as positive for zero grazing (HTI+), negative for zero grazing (HTI−), or no difference between the systems (HTI = HTC), as reported by the authors.

Unique Identifier First Author Publication Date	Country of study	Housing Comparators	HWB Outcome Measurement	Effect Direction
1519_Haggman_2015	Finland	Loose-housing	Infectious claw disease	+|−
2283_Grabowski_1997	Poland	Tiestall	Mastitis	+|−
1521_Gieseke_2020	Germany	Loose-housing	Mastitis	−
2214_Olde- Riekerink_2008	Canada	Tiestall	Mastitis	+|=
294_Bradley_2001	UK	Loose-housing	Mastitis	+|−
3245_Washburn_2002	USA	Indoor (unspecified)	Mastitis	−
439_Armbrecht_2019	Germany	Loose-housing	Mastitis	+|−|=
2119_Salfer_2018	USA	Loose-housing	Severe hock lesions	+|=

See Fig. 6 for the group identification.

Table 13
Group 5a health, welfare, and behaviour (HWB) outcomes for dairy cattle in year-round housing with zero grazing compared to systems with grazing/pasture access. Outcomes are categorised as positive for zero grazing (HTI+), negative for zero grazing (HTI−), or no difference between the systems (HTI = HTC), as reported by the authors.

Unique Identifier First Author Publication Date	Country of study	Housing Comparators	HWB Outcome Measurement	Effect Direction
1521_Gieseke_2020	Germany	Loose-housing	Severe lameness	+
			Dirty legs	=
2145_Nielsen_2011	Denmark	Loose-housing	Dirty Legs	−
1163_Armbrecht_2017	Germany	Loose-housing	Sole haemorrhages	−|=
			Interdigital hyperplasia	−|=
			Interdigital dermatitis	+|−|=
			Double sole	−|=
2539_Holzhauer_2012	Netherlands	Loose-housing	Sole haemorrhages	−|=
			Interdigital hyperplasia	=
2084_deVries_2015	Netherlands	Loose-housing	Lameness (unspecified)	−
2108_Haskell_2006	UK	Loose-housing	Lameness (unspecified)	−
2119_Salfer_2018	USA	Loose-housing	Lameness (unspecified)	+|−|=
			Severe lameness	+|−|=
439_Armbrecht_2019	Germany	Loose-housing	Lameness (unspecified)	−|=
			Severe lameness	−|=

See Fig. 6 for the group identification.

Table 14
Group 5b health, welfare, and behaviour (HWB) outcomes for dairy cattle in year-round housing with zero grazing compared to systems with grazing/pasture access. Outcomes are categorised as positive for zero grazing (HTI+), negative for zero grazing (HTI−), or no difference between the systems (HTI = HTC), as reported by the authors.

Unique Identifier First Author Publication Date	Country of study	Housing Comparators	HWB Outcome Measurement	Effect Direction
439_Armbrecht_2019	Germany	Loose-housing	Mortality	=
3245_Washburn_2002	USA	Indoor (unspecified)	Mortality	−
2074_Olmos_2009	Ireland	Loose-housing	Sole haemorrhages	−

See Fig. 6 for the group identification.

Table 15
Number of comparisons between loose housing systems without outdoor access and housing systems (including loose housing) with outdoor access (grazing or yards) for dairy cattle.

Item	Housing Type - with Outdoor Access (HTC)			
	Loose	Tiestall	Indoor (Unspecified)	Total
Year-round Loose Housing Without Outdoor Access (HTI)	51	33	1	85

ever, in interpreting simple counts of data. Firstly, simple counts of data, based on incidences reported, cannot provide robust evidence that allows for a determination of causation, or even correlation, as outlined in the Method section. Secondly, even allowing for this limitation, a count can be useful to indicate trends within the evidence base, but it also needs to be interpreted with a consideration of the number of independent studies the measurements come from. Table 16, therefore, shows not only the raw directional counts but also shows the number of independent studies that contributed to each HWB count. The colour coding is a visual aid to the relative strength of the evidence, with darker purple indicating higher counts and a gradation of green to red showing high to low numbers of studies. As explained in the Method section, some articles yielded multiple independent studies.

Some HWB outcomes came from single studies, while the data for other HWB outcomes came from multiple studies. The data for the CCA were therefore filtered to include only HWB metrics drawn from more than one study (see Petrokofsky et al., 2024 for all studies and all HWB metrics). A data set of 13 articles containing 18 studies, with 66 comparisons, reporting 206 health and welfare outcomes across 3 housing systems was included in the CCA which explained 4.3% of the data set across CCA1 (3.3%) and CCA2 (2.8%) (Fig. 7). CCA1 (horizontal axis) broadly represents no-difference (left), a mix of mainly negative or no-difference with some positive (middle) and either a more positive or a negative impact (right). CCA2 (vertical axis) broadly indicates a positive impact (top right) or a negative impact (bottom right). The detailed statistical interpretation of the CCA are described in the numbered points immediately below, and then summarise the interpretation of these findings in the subsequent paragraphs.

1. 'SCC and SCS', 'sole lesion', and 'mastitis' are aligned between CCA1 and CCA2 and are associated with more positive impacts for year-round loose housing without outdoor access vs housing with outdoor access. 'Sole lesion' is most associated with the housing comparator loose housing with outdoor access; and 'SCC/SCS' and 'mastitis' are associated between the comparators loose-housing and tiestall with outdoor access.
2. 'Locomotion', 'stockmanship', 'social interaction', and 'mortality' are aligned between CCA1 and CCA2 and are associated with more negative impacts for year-round loose housing without outdoor access vs housing with outdoor access. 'Social interaction' and 'mortality' are most associated with the housing comparator tiestall with outdoor access, while 'locomotion', 'stockmanship' are mostly associated with the housing comparator tiestall with outdoor access, and also with some loose housing with outdoor access.
3. 'Heel horn erosion', 'digital dermatitis', 'sole ulcer', 'white line disease', 'sole haemorrhages', 'interdigital hyperplasia', 'interdigital dermatitis', 'double sole', 'white line lesion', 'maximum axial wall deviation', and 'locomotion difficulties' are more closely aligned to CCA1 and are associated with no-difference or mixed (mainly negative or no-difference with some positive) impacts for year-round loose housing without outdoor access

Table 16
Total number of incidences for each health, welfare, and behaviour (HWB) outcome measure reported in the evidence base for year-round loose housing without outdoor access compared to housing with outdoor access (grazing or yards) for dairy cattle. Outcomes are categorised as positive for zero grazing (HTI+), negative for zero grazing (HTI−), or no difference between the systems (HTI = HTC), along with the number of studies these outcomes are derived from, as reported by the authors.

Category	HWB Measure	HTI+	HTI−	HTI = HTC	Studies n = 21
Udder Health	Somatic Cell Count/Somatic Cell Score	12	2	1	5
	Mastitis	6	2	0	2
	Yeast pathogens	3	0	2	1
	Bacterial pathogens – *Streptococcus uberis*	4	1	0	1
	Bacterial pathogens – *Streptococcus* spiecies	5	0	0	1
	Bacterial pathogens – *Streptococcus faecalis*	3	0	2	1
	Bacterial pathogens – *Streptococcus dysgalactiae*	0	5	0	1
	Bacterial pathogens – *Serratia* species	3	0	2	1
	Bacterial pathogens – *Pseudomonas* species	2	0	3	1
	Bacterial pathogens – *Morganella* species	1	0	4	1
	Bacterial pathogens – *Klebsiella* species	2	0	3	1
	Bacterial pathogens – *Escherichia coli*	3	2	0	1
	Bacterial pathogens – *Enterobacter* species	1	0	4	1
	Bacterial pathogens – *Corynebacterium* species	1	4	0	1
	Bacterial pathogens – Coagulase−positive staphylococci	5	0	0	1
	Bacterial pathogens – Coagulase−negative staphylococci	2	3	0	1
	Bacterial pathogens – *Citrobacter* species	1	0	4	1
	Bacterial pathogens – *Bacillus* species	2	3	0	1
	Bacterial pathogens – *Arcanobacter pyogenes*	0	5	0	1
Foot and Leg Disorders	Heel Horn erosion	3	5	2	6
	Digital Dermatitis	1	8	1	5
	Sole ulcer	0	1	8	4
	White Line disease	1	6	1	4
	Sole haemorrhages	0	5	3	4
	Interdigital hyperplasia	0	5	2	3
	Interdigital Dermatitis	1	3	2	2
	Double Sole	0	3	3	2
	Non-infectious claw disease	3	0	0	1
	Leg Diseases	2	1	0	1
	Infectious claw disease	2	1	0	1
	White line lesion	0	0	2	2
	Sole Lesion	2	0	0	2
	Maximum axial wall deviation	0	0	2	2
	Interdigital Fibroma	0	1	1	1
	White Line haemorrhages	0	1	0	1
	Foot Infection	0	0	1	1
Uterine Health	Reproductive tract diseases	3	0	0	1
	Retained foetal membranes	0	0	1	1
	Resumption of oestrus cyclicity	0	0	1	1
	Neospora caninum	0	1	0	1
	Metritis	0	1	0	1
	Endometritis	0	1	0	1
	Chlamydophila abortus	0	0	1	1
Nutrition	β-Hydroxybutyric acid	0	1	0	1
	Plasma concentrations of triglycerides	1	0	0	1
	Non-esterified fatty acids	0	1	0	1
	Cholesterol	1	0	0	1
Lameness	Locomotion	0	33	1	3
	Locomotion Difficulties	0	1	2	3
	Lameness (Unspecified)	0	1	0	1
	Clinical lameness	0	1	0	1
Gut and Intestinal Health	Digestive tract diseases	2	1	0	1
	Rectal temperature	0	1	0	1
	Johne's disease	0	1	0	1
	Bovine viral diarrhoea (BVD)	0	1	0	1
Respiratory Health	Bovine herpesvirus−specific antibodies (IBR-gE)	0	1	0	1
	Bovine herpesvirus−specific antibodies (IBR-gB)	0	1	0	1
Maintenance	Stockmanship	2	31	1	3
	Lying time	0	1	0	1
Skin Health	Lesions and swellings	0	1	0	1
Mortality	Mortality	2	6	0	2
Metabolic Health	Metabolic disorders (Unspecified)	2	1	0	1
Behaviour and Stress	Social Interaction	5	26	3	3

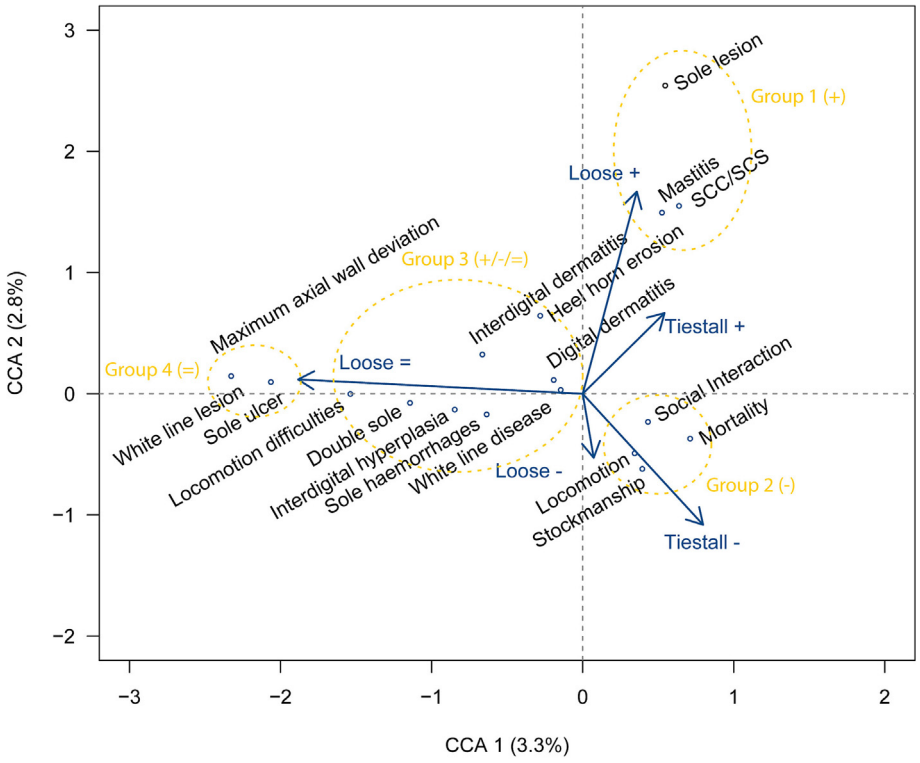

Fig. 7. Canonical correspondence analysis of year-round loose-housing without outdoor access vs housing with outdoor access and impacts to health and welfare and behaviour (HWB) of dairy cattle. Abbreviations: CCA = Canonical correlation analysis, SCC = Somatic cell count, SCS = Somatic cell score, + = positive HWB measure with associated housing type, – = negative HWB measure with associated housing type, = = no difference in HWB measure with associated housing type.

vs housing with outdoor access. 'Heel horn erosion', 'digital dermatitis', 'sole ulcer', 'white line disease', 'sole haemorrhages', 'interdigital hyperplasia', 'interdigital dermatitis', 'double sole', 'white line lesion', 'maximum axial wall deviation', and 'locomotion difficulties' are mostly associated with the housing comparator loose housing with some loose housing with outdoor access.

Based on the CCA (Fig. 7), four groups emerge from the data from the evidence base.

Group 1 comprises three HWB outcomes where the evidence base indicates largely positive instances of year-round loose housing with zero outdoor access compared with housing systems with some outdoor access (though it should be noted that individual studies within this grouping contain instances of the reverse or no difference). These derive from six articles. For SCC/SCS, Lambertz and Cielava report only positive outcomes; Bradley reports a mix of positive and negative, and Pavlenko reports no difference. For mastitis, Bradley reports only positive, and Grabowski reports positive if a tiestall comparator is used, but negative for a loose-housing comparator. For sole lesion, Baird reports positive. N.B. Cielava and Pavlenko use a tiestall with outdoor access comparator, whereas Bradley, Baird and Lambertz use a loose housing with outdoor access comparator. Grabowski uses both in separate studies. All articles used 91–270 days duration of outdoor access as a component of the comparator (Table 17).

Group 2 comprises four HWB outcomes where the evidence base indicates largely negative instances of year-round loose housing with zero outdoor access compared with housing systems with some outdoor access. Again, it should be noted that individual studies within this grouping contain instances of the reverse or no difference. These derive from four articles. Locomotion and social interaction are reported only as negative outcomes (Ornik, Hristov); stockmanship is either negative (Ornik), or no difference (Hristov). Mortality is negative (Cielava) or negative (Grabowski if in loose-housing), or positive if the comparator is tiestall. N.B. Cielava also uses a tiestall comparator, whereas Hristov and Ornik use a loose-housing with outdoor access comparator. Two articles (Ornik and Hristov) contain an outdoor comparator of 271–365 days outdoors. One article uses 91–180 days as the outdoor comparator (Grabowski), and one article (Cielava) uses 181–270 days as a component of the comparator (Table 18).

Group 3 comprises eight HWB outcomes where the evidence base indicates a mix of positive, negative and no difference for year-round loose housing with zero outdoor access compared with housing systems with some outdoor access. Again, it should be noted that individual studies within this grouping contain instances of positive or negative. These derive from six articles. For heel horn erosion, Baird, Olmos and Holzhauer report negative, Armbrecht reports positive, negative and no difference. For digital dermatitis, Olmos and Holzhauer report negative, Somers reports negative and positive, and Armbrecht reports negative and no difference. For interdigital dermatitis, Armbrecht reports positive, negative and no difference. For white line disease, Olmos and Holzhauer report negative, Armbrecht reports positive, negative and no difference. For sole haemorrhages, Olmos and Holzhauer report negative, Armbrecht reports negative and no difference. For interdigital hyperplasia, Holzhauer reports no difference, Armbrecht reports negative and no difference. For double sole, Armbrecht reports negative and no difference. For locomotion difficulties, Baird reports no difference, Olmos reports negative. One article (Cramer) contains an outdoor comparator of 271–365 days outdoors. Four articles use 91–180 days as the outdoor comparator (Armbrecht, Baird, Cramer and Holzhauer), one article (Olmos)

Table 17
Group 1 health, welfare, and behaviour (HWB) outcomes for dairy cattle in housing systems with outdoor access compared to housing systems without outdoor access. Outcomes are categorised as positive for housing without outdoor access (HTI+), negative for housing without outdoor access (HTI−), or no difference between the systems (HTI = HTC), as reported by the authors.

Unique Identifier First Author Publication Date	Country of study	Housing Comparators	HWB Outcome Measurement	Effect Direction
1505_Baird_2009	UK	Loose-housing	Sole lesion	+
2283_Grabowski_1997	Poland	Tiestall	Mastitis	+
		Loose-housing	Mastitis	−
2507_Cielava_2017	Latvia	Tiestall	Somatic Cell Count/Somatic Cell Score	+
294_Bradley_2001	UK	Loose-housing	Mastitis	+
			Somatic Cell Count/Somatic Cell Score	+|−|=
517_Pavlenko_2018	Estonia	Tiestall	Somatic Cell Count/Somatic Cell Score	=
738_Lambertz_2014	Germany	Loose-housing	Somatic Cell Count/Somatic Cell Score	+

See Fig. 7 for the group identification.

Table 18
Group 2 health, welfare, and behaviour (HWB) outcomes for dairy cattle in housing systems with outdoor access compared to housing systems without outdoor access. Outcomes are categorised as positive for housing without outdoor access (HTI+), negative for housing without outdoor access (HTI−), or no difference between the systems (HTI = HTC), as reported by the authors.

Unique Identifier First Author Publication Date	Country of study	Housing Comparators	HWB Outcome Measurement	Effect Direction
2283_Grabowski_1997	Poland	Tiestall	Mortality	+
		Loose-housing	Mortality	−
2507_Cielava_2017	Latvia	Loose-housing	Mortality	−
3201_Hristov_2014	Serbia	Loose-housing	Locomotion	−
			Social interaction	−
			Stockmanship	=
843_Ornik_2010	Slovenia	Loose-housing	Locomotion	−
			Social interaction	−
			Stockmanship	−

See Fig. 7 for the group identification.

uses 181–270 days and one article (Somers) uses 1–90 days duration of outdoor access as a component of the comparator (Table 19).

Group 4 comprises three HWB outcomes, where the evidence base shows largely no difference for year-round loose housing with zero outdoor access compared with housing systems with some outdoor access. Again, it should be noted that individual studies within this grouping contain instances of positive or negative. For white line lesion and maximum axial wall deviation, Baird reports no difference. For sole ulcer, Armbrecht and Holzhauer report no difference (Table 20). In summary, only one HWB measurement (sole lesion) showed only positive and no-difference results (and the positives outweigh the no-difference) for year-round loose-housing without outdoor access, whereas a total of three indicators (interdigital hyperplasia, sole haemorrhages, and locomotion) showed only negative and no-difference results (and the negatives outweigh the no-difference) for year-round loose-housing without outdoor access.

Housing design factors

The evidence base contains even less data that allows for comparisons between different design features of loose-housing systems. Therefore, meaningful comparisons cannot be made (see Petrokofsky et al., 2024 for all the data extracted for this component of the review). Further, given the lack of evidence overall for the benefits or disadvantages of loose-housing over housing systems with grazing or even some outdoor access, it is meaningless in the light of the overarching review question to analyse the data for design features.

Limitations of the evidence base

All literature reviews have limitations, and while systematic reviews aim to minimise biases in study selection and synthesis, reviewer bias can also affect the interpretation of results. The first limitation is often the review's scope, which is established by the

Table 19
Group 3 health, welfare, and behaviour (HWB) outcomes for dairy cattle in housing systems with outdoor access compared to housing systems without outdoor access. Outcomes are categorised as positive for housing without outdoor access (HTI+), negative for housing without outdoor access (HTI−), or no difference between the systems (HTI = HTC), as reported by the authors.

Unique Identifier First Author Publication Date	Country of study	Housing Comparators	HWB Outcome Measurement	Effect Direction
1163_Armbrecht_2017	Germany	Loose housing	Digital dermatitis	−|=
			Heel horn erosion	+|−|=
			Interdigital dermatitis	+|−|=
			Sole haemorrhages	−
			White line disease	+|−|=
2074_Olmos_2009	Ireland	Loose housing	Heel horn erosion	−
			Digital dermatitis	−
2539_Holzhauer_2012	Netherlands	Loose housing	Heel horn erosion	−
			Digital dermatitis	−
3320_Somers_2005	Netherlands	Loose housing	Digital dermatitis	−|+
1505_Baird_2009	UK	Loose housing	Heel horn erosion	−

See Fig. 7 for the group identification.

Table 20
Group 4 health, welfare, and behaviour (HWB) outcomes for dairy cattle in housing systems with outdoor access compared to housing systems without outdoor access. Outcomes are categorised as positive for housing without outdoor access (HTI+), negative for housing without outdoor access (HTI−), or no difference between the systems (HTI = HTC), as reported by the authors.

Unique Identifier First Author Publication Date	Country of study	Housing Comparators	HWB Outcome Measurement	Effect Direction
1163_Armbrecht	Germany	Loose housing	Sole ulcer	=
2539_Holzhauer_2012	Netherlands	Loose housing	Sole ulcer	=
1505_Baird_2009	UK	Loose housing	White line lesion	=
			Maximum axial wall deviation	=

See Fig. 7 for the group identification.

research topic and the consensus on its components. By including stakeholders in developing the research topic and agreeing with a predefined methodology (the Protocol) for the review, the systematic method partially overcomes this problem. The Protocol also helped reduce bias in the selection of articles for consideration. Terms and phrases were suggested collaboratively, and the sources for published articles were agreed; however, it is acknowledged that in any systematic review, there may be a small number of papers that have used highly specific terms and therefore may have been missed despite the use of extensive expert input for terminology and a set of representative test articles. The extensive search for grey literature helped to some extent to reduce bias caused by citing only academic publications (where a known bias is for positive results to be prioritised over negative or null results). However, it is recognised that the grey literature came largely from organisations known to stakeholders and was thus potentially a limitation.

In common with many other systematic evidence syntheses, despite the large number of articles assessed at full-text for inclusion in the current review, a substantial proportion lacked details of the intervention (year-round loose-housing with zero grazing or no outdoor access), comparator, or disaggregated HWB measures, and were therefore excluded from the review. It is likely that some or many of these excluded articles could be of relevance to the review question, and it is to be hoped that future updates may be able to utilise more disaggregated data.

The lack of comparable data across different studies to allow for meta-analysis is a serious limitation in that no robust statistical analysis of correlation can be made between year-round loose-housing and health, welfare or natural behaviours. Therefore, it is not possible to establish an effect between year-round loose-housing on any health, welfare or behaviour measure. Searching for more studies will not change this: there needs to be more consistency in data measuring and data presentation in the primary research. Raw data should be made available to the scientific community to facilitate secondary synthesis.

Discussion

Are the health and welfare of dairy cows kept in all-year-round loose housing systems better or worse than those kept in different housing systems (with or without outdoor access or grazing)?

Assessing the evidence base systematically as a whole, there is no strong evidence of the benefits of keeping dairy cows in year-round loose housing systems as well as no clear evidence of disadvantages of keeping dairy cows in year-round loose housing systems compared with dairy cows with access to pasture and/or outdoor access. There is too much variation across studies in terms of what is measured and how it is measured to allow robust statistical assessment of the direct effects of loose-housing systems and/or grazing on the health, and welfare of dairy cows. Individual studies report detrimental effects for some HWB outcomes, some report beneficial effects for some HWB outcomes, and others report no difference between year-round loose housing compared with other systems with outdoor access and/or grazing. It is also important to note that there is no systematic evidence of no-difference in HWB outcomes as a whole between year-round loose-housing and housing systems that allow outdoor access and/or grazing. However, policy and practice changes are best made on the basis of an evaluation of all available evidence, and not individual studies where there is no consensus in the evidence base.

Only one HWB measurement (sole lesion) showed a positive trend (meaning the majority of results were positive and there were no negative results) in year-round loose housing with zero grazing and year-round loose housing systems without outdoor access compared with housing systems with outdoor access and/or grazing, whereas two indicators (interdigital hyperplasia and sole haemorrhages) showed negative trends (meaning the majority of results were negative and there were no positive results) in both year-round loose housing with zero grazing and year-round loose housing systems without outdoor access compared with housing systems with outdoor access or grazing. An additional negative trend for clinical lameness was found for year-round loose housing systems with zero grazing only, and locomotion for year-round loose housing systems without outdoor access. However, it must be noted that sole haemorrhages can be seen as a form of sole lesion but opposing trends have been found for these two outcomes, indicating the extent to which data available are limited.

The evidence base does not therefore fully support the overarching findings from Alvåsen's (2015) review, which reported overall positive effects on HWB of giving cows access to pasture during the summer, nor does the evidence base fully align with the review by Arnott et al. (2017) which concluded that cows on pasture-based systems had lower levels of lameness, hoof pathologies, hock lesions, mastitis, uterine disease and mortality compared with cows on continuously housed systems. It is noted, however, that these reviews had different study objectives and methodologies and are not therefore wholly comparable with the current systematic review.

A previous European Food Safety Authority synthesis (EFSA, 2009) assembled a number of studies indicating that dairy cattle kept on pasture are healthier, including reduced incidence of mastitis, lameness, hoof problems, trampled teats, and disease incidence, concluding that zero-grazing would increase the likelihood of these health problems. However, the author group (EFSA, 2009) notes that: (i) it is difficult to identify the causes of these differences, due to large variation between and within housing and grazing conditions across studies making it challenging to identify the factors responsible for differing health and welfare outcomes, (ii) there are risks to welfare in poor grazing conditions and currently little information on the welfare problems associated with pasture-based systems, (iii) there is a possibility that some modifications to housing systems would increase the health and welfare of cows in zero-grazing systems to that equal to or above pasture-based systems. However, the evidence base assembled here has demonstrated that studies are available that show both

positive and negative effects of all-year-round loose housing compared to pasture, indicating the importance of systematic review methodologies to ensure all available evidence is considered to prevent conclusions being drawn that are not fully supported by all the available evidence.

Are all aspects of natural behaviour exhibited by dairy cows on pasture fully fulfilled by cows permanently in loose housing systems?

There is even less evidence for behavioural indicators and there were none that showed only positive or only negative for year-round loose-housing without outdoor access or zero grazing. This supports the findings of Arnott et al. (2017) that there are knowledge gaps, particularly with respect to behaviour and cow preference for grazing over continuous indoor housing. Clearly, given that one of the five freedoms is freedom to express natural behaviour, also emphasised in the five domains model under behavioural interactions, grazing is a natural behaviour, with access to pasture giving cows the opportunity to behave naturally (Alvåsen, 2015; Arnott et al., 2017). By definition, this opportunity is denied to cows in year-round loose housing and the welfare implications of this remain to be better understood. While outside the scope of the current systematic review, there is useful research using preference tests that offer dairy cows a choice between being indoors or at pasture (reviewed by Arnott et al., 2017; Charlton and Rutter, 2017). Put together, those studies demonstrate that cows have an overall partial preference for pasture. However, this was influenced and modified by a number of factors. For example, during the day, a number of studies showed that cows had a partial preference for indoor housing, with others showing they spent similar amounts of time indoors and on pasture. This was likely the result of an interaction with nutritional welfare, with fresh TMR feed available indoors enabling cows to meet their nutritional demands following milking. However, at night, the studies demonstrated that cows had a preference for pasture. The preference for pasture at night is most likely the result of an interaction with the environmental domain of welfare, whereby pasture offers a comfortable lying area, supported by findings of time spent lying while at pasture (Arnott et al., 2017). However, the preferences were also modified by a range of other factors. For example, unsurprisingly, climatic variables influenced preference, with pasture use decreasing with increasing rainfall, and being influenced by season and the temperature-humidity index. In addition, cow–level factors also influenced preference, including milk yield and lameness score, with indications that high–yielding cows spent more time indoors, as did those with a lower mobility score. Put together, in line with the overall findings of this systematic review, the preference test studies indicate that there are desirable aspects of both pasture and indoor housing that benefit welfare. Going forward, there is a need to use experimental designs that enable causal factors influencing welfare to be better understood so that both the housed and pasture environment can be optimised to support dairy cow welfare. This should include the further development of environmental enrichment, of which there has been a minimal study in relation to dairy cows (for a useful review see, Mandel et al., 2016).

Regarding welfare, it can be argued that for the individual animal, the key domain is mental state and well–being. However, this is also the most challenging to objectively measure and the current systematic review did not uncover any studies measuring this aspect within the scope of the review. That said, animal welfare science is developing useful approaches to assess affective state, including cognitive bias (reviewed by Lagisz et al., 2020) and Qualitative Behaviour Assessment (Wemelsfelder et al., 2001). It is important that approaches can also measure positive emotions as modern animal welfare frameworks rightly emphasise that welfare is not just about avoiding negative states but also requiring positive states so that an animal can experience a life worth living. Using a spatial judgement task, Crump et al. (2021) report evidence of a more positive affective state in cows that had access to pasture, compared to those housed indoors. However, results were not in line with predictions and there is a need for more research exploring the influence of the housed environment on mental state.

Are there differences in health, welfare and behaviour of dairy cows housed in different types of all-year loose housing?

There were insufficient studies reporting comparable data on housing designs for loose-housing systems to determine which features conferred better HWB outcomes. The current review therefore supports the conclusion by Emmoth (2020) that more controlled studies are needed comparing different housing systems and how they can be developed in order to improve the welfare of dairy cattle.

Implications for future research, policy, and practice

- More controlled studies are needed of different loose housing systems using health, and welfare measures that can be directly compared.
- There is a need for more primary research comparing the natural behaviours of dairy cows in loose housing systems and behaviours on pasture.
- Future research: data collected should be made accessible in a disaggregated form to allow for meaningful further analysis to be conducted, beyond the studies they are collected for.
- The current review provides a framework that can incorporate new comparative primary research.

Supplementary material

Supplementary Material for this article (https://doi.org/10.1016/j.animal.2024.101411) can be found at the foot of the online page, in the Appendix section.

Ethics approval

Not applicable.

Data and model availability statement

All data presented in this review can be found in: Petrokofsky et al. (2024). Review: A Systematic Review of Dairy Cow Health, Welfare, and Behaviour in Year-round Loose Range Housing - Data File [Data set]. Zenodo. https://doi.org/10.5281/zenodo.10666118. Information can be made available from the authors upon request.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use any AI and AI-assisted technologies.

Author ORCIDs

William J. Harvey: https://orcid.org/0000-0002-7386-6564.
Leo Petrokofsky: https://orcid.org/0000-0002-8198-654X.
Matthew W. Jordon: https://orcid.org/0000-0002-4547-0941.
Gareth Arnott: N/A.
Louise Winblad von Walter: https://orcid.org/0000-0002-7966-1842.

Ali Malik: N/A.
Thomas Carter: N/A.
Luke S. Wade: N/A.
Gillian Petrokofsky: https://orcid.org/0000-0001-6748-3869.

CRediT authorship contribution statement

W.J. Harvey: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **L. Petrokofsky:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **M.W. Jordon:** Writing – review & editing, Writing – original draft, Methodology. **G. Arnott:** Writing – review & editing, Methodology. **L.W. von Walter:** Writing – review & editing, Methodology. **A. Malik:** Writing – original draft, Methodology, Investigation. **T. Carter:** Writing – original draft, Methodology, Investigation. **L.S. Wade:** Writing – original draft, Methodology, Investigation. **G. Petrokofsky:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of interest

The authors declare that there are no conflicts of interest.

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