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A scoping review and systematic map of primary studies assessing heat stress on reproductive, physiological, and productive parameters of farm animals

Daniel, Diaz[1]
0000-0003-2302-1982
Ana M. Lopez-Orrantia[2]
Asly N. Camacho[2]
Rene J. Rosiles[3]
0000-0001-8130-7722
Miguel A. Rodriguez-Gaxiola[2]
0000-0002-6488-797X
Javier A. Romo-Rubio[2]
0000-0002-2364-2554
Jesus J. Portillo-Loera[2]
0000-0002-5990-7841
Soila M. Gaxiola[2]
0000-0002-5078-7636
Arnulfo Montero-Pardo[2]*
0000-0002-8836-4591

[1] Universidad Nacional Autónoma de México, Centro de Ciencias de la Complejidad (C3), Ciudad Universitaria, Ciudad de México 04510, México

[2] Universidad Autónoma de Sinaloa, Facultad de Medicina Veterinaria y Zootecnia, Culiacán Rosales 80246, Sinaloa, México

[3] Universidad Nacional Autónoma de México, Facultad de Medicina Veterinaria y Zootecnia/ Departamento de Nutrición Animal y Bioquímica, Ciudad Universitaria, Ciudad de México 04510, México

***Corresponding author:**
Email address:
arnulfo.montero@uas.edu.mx

Abstract

Heat stress induces failures in the physiological mechanisms that regulate the body temperature of farm animals and causes a loss in their productive and reproductive potential. Thus, we performed a scoping review to systematically map, describe, and classify primary research that assessed the effect of heat stress on the reproductive, physiological, and productive parameters of livestock. Electronic databases were searched to retrieve full text, peer-reviewed experimental or cohort studies published from 1980 to August 2018. We included *in vivo* and *in vitro* studies exposing animals or cells to heat stress conditions and used a control group. Studies were evaluated based on title and abstract and then selected for final inclusion based on full text. We performed data charting to describe and visualize the evidence. In total, we included 466 studies, among which bovines and pigs were the most frequent species studied. Reproductive and physiological parameters were the main groups of outcomes assessed, and studies using adult females predominated. Seventy percent of the studies were experimental, and almost half of the studies used natural environmental conditions to assess the effect of heat stress in animals. Most of the studies were performed in the Americas and Asia, and three journals provided one-third of the publications. The systematic evidence synthesis presented herein outlines the trends of research performed to assess the effect of heat stress on livestock and allowed us to define future secondary studies to extend our knowledge about the negative impact of heat stress on the productivity of farm animals..

Keywords: Evidence synthesis; Livestock; Physiological response; Productive parameters; Thermal stress.

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Study contribution

Heat stress is a condition that compromise the physiological response of livestock in several regions of the world and thus negatively affects the productive and reproductive parameters of farms animals. Thus, we performed a scoping review which represents a systematic approach to identify the body of evidence published in this relevant topic. Our summary of evidence showed that bovines and pigs were the most studied farm animals, and that females are most frequently included in the research. American continent and Asia provided most of the publications and reproductive and physiological parameters were frequently assessed in the studies. Our summary of evidence highlights the trends in the research topic and found research gaps where further studies are needed, as well as identify robust evidence where future systematic reviews and meta-analysis are warranted to further summarize the body of evidence.

Introduction

In each kind of farm animal, there is a thermal comfort zone in which the energy expenditure required to maintain their body temperature is minimal, constant, and independent of environmental factors.[1] However, in conditions such as heat stress, animals outside their thermal comfort zone may not only experience difficulties in coping with their surroundings but also require extra energy to thermoregulate and maintain homeothermy.[2,3] In heat-stressed animals, there are disruptions of several physiological functions related to thermoregulation.[4] Although, it is expected that many productive and reproductive processes will also be altered in livestock, there exist differences in the tolerances of farm animals to heat stress, which might be determined by the specific kind and breed of livestock, the genetic background, or the purpose of the animal husbandry (meat or milk). For instance, dairy cattle are more sensitive to heat stress due to a higher production of metabolic heat.[5]

The exposure of sheep and goats to elevated ambient temperatures negatively affects their biological functions, which are reflected as an impairment of their productive and reproductive traits.[6] Likewise, heat stress negatively influences the global pork industry by causing poor sow performance, reduced and inconsistent growth, decreased carcass quality, and higher mortality.[7-9] Therefore, the seasonal declines in the reproductive efficiency of swine due to heat stress during warm months is a global source of economic loss.[8] Furthermore, heat stress not only impairs the productive and reproductive parameters of females but also of males. In dairy bulls, low fertility has frequently been reported during the summer season, especially in tropical or subtropical conditions. Typically, spermatozoa at postmeiotic stages of development are more susceptible to heat stress.[10] Excessive heat leads to a decline in overall boar fertility that manifest as changes in semen quality, such as a reduction in sperm concentration, volume, and motility and affects sperm morphology and head shape.[8,11]

Given the aforementioned series of results, it is not surprising that heat stress is considered one of the main stressors that affect livestock productivity and thus has become a global economic burden.[12] Besides, in the present context of climate change and the expected increase of temperatures worldwide, the potential negative impact of heat stress on the animal food production chain has attracted

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attention.[13,14] Therefore, there is an extensive body of evidence based on primary studies that evaluate the deleterious effects of heat stress on livestock, as well as secondary studies that include reviews, systematic reviews, and meta-analysis that cover several isolated aspects related with this stressor. [10,15,17] However, due the extensive nature of the physiological and productive processes affected by heat stress, to date, no effort has been made to systematically map, classify, and synthesize the trends of research of all the available evidence on this fundamental topic for the most important species of farm animals.

In the present study, we conducted a scoping review with a systematic map of primary research to classify and summarize available evidence from studies that exposed cattle, sheep, goats or pigs or their cells to high temperatures to induce heat stress. Both scoping reviews[18] and systematic maps[19] are novel and reliable tools used to describe, summarize, and catalog a huge amount of literature on a broad study subject in an objective and systematic fashion. Additionally, these secondary studies follow a systematic approach with a transparent and strict methodology that allows researchers to: 1) answer a set of general questions instead of a single specific or particular question, 2) collate heterogeneous evidence for a broad topic and present it with integrated visual maps, 3) identify subtopics in which the number of primary studies is robust enough to develop systematic reviews or a meta-analysis, and finally 4) find gaps in knowledge where primary research might be necessary.[20]

We sought to provide an updated inventory of scientific research to elucidate publication trends classified according to the productive species, the type of assessed outcomes, the type of study, the frequency of publication, the main journals in which studies were published, and the geographical distribution of the studies.

Materials and methods

Protocol and objective

For the present study, we developed *a priori* protocol according to the PRISMA-P (Preferred Reporting Items for Systematic Reviews and Meta-analysis Protocol)[21] statement that is available from the corresponding author upon reasonable request. Besides, this study was reported following the PRISMA-ScR extension for scoping reviews.[18] We followed the methodological framework proposed by Arksey and O'Malley[22] and defined the following objective: determine the range, extension, and nature of research performed to assess the effect of heat stress on the physiological, productive, and reproductive traits of livestock.

A revision team was defined for each particular stage of the study: AML, ANC, and DD delimited inclusion criteria, defined search terms and carried out electronic database searches; DD retrieved and compiled information; AML, ANC and AM screening evidence based on titles and abstracts; AM and DD retrieved selected full texts and carried out the eligibility process; DD made a codebook to extract data; AML, ANC, and AM extracted data to construct the map database; AML and DD visualized and described the main findings; and AML and DD wrote the report.

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Research questions

The scope of the scoping review and systematic map was determined as multi-faceted because we expected to collate very heterogeneous studies, which would make the synthesis of results difficult using a systematic review.[19] In addition, given the extensive body of evidence on the topic, a broad approach was chosen to identify subtopics and evidence groups robust enough for future systematic reviews and meta-analyses as well as gaps in knowledge where primary research could be focused. To fulfill these needs in the present study, the following questions were defined:

Research question (RQ)-1: Which of the productive species is more frequently studied in primary research to evaluate the effect of heat stress? Which of the three parameters (reproductive, physiological or productive) is more often assessed in published research?

RQ-2: What are the publication trends according to the countries where the research was done? What is the trend in the frequency of publication for each productive species? Among the included languages, which is the preferred language of publication?

RQ-3: What type of study is most frequently used to assess the effect of heat stress? What conditions (climatic chamber, environmental conditions or *in vitro* conditions) are commonly used to induce heat stress to evaluate its effect?

RQ-4: Of the studied animals, which sex and age group are most frequently used in scientific research?

RQ-5: Which are the main journals that publish primary research on the effects of heat stress on the productive parameters of domestic animals?

RQ-6: Which groups of outcomes are most frequently assessed according to the parameters evaluated in each study?

Elegibility criteria

Inclusion criteria were defined according to the PICOS (Population, Intervention, Comparator, Outcomes, and Studies) approach of the PRISMA statement.[23] For our study, only full-text primary studies published in peer-reviewed journals in English, Spanish or, Portuguese from 1980 until 2018 were considered. The selected studies included a group of animals or cells exposed to heat stress conditions or high-temperature conditions, respectively, and a comparison group exposed either to thermal comfort conditions or physiological temperature. The compared outcomes of the treatment groups and control groups corresponded to productive, physiological, or reproductive parameters (Table 1).

Electronic database and search

We identified studies through specialized searches in the following electronic databases: PubMed, ScienceDirect, Scopus, Redalyc, and Virtual Health Library. Three independent reviewers (AML, ANC, and DD) performed the searches from 20 July to 8 August 2018 using predefined search terms (Table 2). Before the reviewers performed final searches, they conducted pilot searches to define the best terms that allowed more specific and sensitive searches. As shown in the representative

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Table 1. Eligibility criteria definitions according to PICOS approach

Acronym	Definition
(P) Population	Studies that assessed ovines, pigs, goats or, bovines of any breed, sex and age that described such populations as healthy, without disease, and that were evaluated at any productive, reproductive, and physiological stage in any geographic region.
(I) Intervention	We considered an intervention the exposure of groups of animals to heat stress conditions, either from a natural source (warm season of the year) or artificially by a climatic chamber. We also included studies that evaluated the effect of high-temperatures on cells or tissues of the productive animals *in vitro*.
(C) Comparator	We considered a control group a group of animals not exposed to heat stress. Such animals could have either been assessed in thermal comfort conditions during the cold season or artificially in a climatic chamber. In the case of *in vitro* studies, the control group was defined as cells or tissues cultured under physiological temperatures.
(O) Outcomes*	*Physiological*: heart rate, respiratory rate, body temperature, blood flow (uterine or fetal), cortisol concentration, thyroid hormones concentration, expression of metabolic indicators or, expression of heat shock proteins. *Productive*: water and food consumption, weight gain, milk production and composition, live birth weight, the weight of carcass or, feeding efficiency. *Reproductive*: fertility, semen traits, expression and duration of estrus, gestation rate, number of births, embryo number and quality, endocrine profiles, sex steroids concentration, oocytes, prolificacy or, fetal death.
(S) Studies	We considered only primary research conducted with experimental or cohort studies. We included articles only available as full texts and published in peer-reviewed journals in English, Spanish or, Portuguese from 1980 to 2018.

* Studies included at least one pre-defined outcome

Table 2. Search terms used to identify primary studies according to definitions of the PICOS approach

Acronym	Group	Search term
(P) Population	Bovine Porcine Ovine Caprine	cow OR bull OR bovine OR heifer OR calf OR cattle pig OR boar OR porcine OR sow OR swine OR piglet sheep OR ewe OR ovine OR ram OR ovis OR lambs goat OR does OR caprine OR capra OR buck
(I) Intervention		heat stress OR thermal stress OR climatic stress OR adverse climatic conditions OR environmental stress OR adverse temperatures OR heat tolerance OR high temperature OR high relative humidity OR temperature-humidity index
(S) Study	Study Date Language	experimental study OR quasi-experimental study OR cohort study 1980 to december 2018 English OR Portuguese OR Spanish

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searches summarized in Table S1, search terms were grouped to create specific search commands for each database and for each productive species. Once final searches were performed, records from all searches were gathered in EndNote X8 (Thompson Reuters, USA) to manage the bibliographic database.

Study selection

For the selection of studies, we used a sequential and systematic approach:[23] first, we eliminated duplicates and excluded studies based on title; then, we selected the articles for full text retrieval after reviewing the abstracts; and finally, we included the final studies after reviewing the full text in detail. In each stage, the reviewers corroborated the fulfillment of the inclusion criteria (Table 1). To assess consistency during the selection process, Kappa statistics was used to assess concordance between two reviewers. Before correction of any discrepancy, the following Kappa concordance values were obtained for each classification: ovine, 0.895 (< 0); bovine, 0.804 (< 0.001); caprine, 0.704 (< 0.001); and porcine, 0.681 (< 0). Whenever there was a discrepancy between reviewers, a referee solved the conflict to reach consensus.

Data collection and data charting

To synthesize evidence from selected studies, we constructed an extraction format for the meta-data, which is defined as the specific information that describes a study and its methodology. To accomplish this, the information was codified by defining categories within sets of variables to describe the design, methodology and main characteristics of each study. Data charting is considered one of the main objectives and a functional characteristic of a scoping review and a systematic map, because unlike systematic reviews, no summary of qualitative or quantitative results is made.[19] Table S2 presents the codification fields that reviewers used for the extraction of meta-data. Before final extraction, reviewers conducted two rounds of pilot tests to verify that extraction was objective, comprehensive, repeatable and adequate to reflect the content of each study. Once the extraction was completed, all available meta-data were collected into a map database from which the reviewers constructed informative summaries that allowed the visualization of results.

Synthesis of evidence

We used the registered information from the data charting to obtain simple numerical counts of the frequency of each defined outcome. In addition, individual outcomes were combined into complex contingency tables to group different coded categories, such as the number of studies per productive species according to the type of assessed outcome and the sex and age group of the animals. All graphs were constructed in Prism 9 (GraphPad Software, Inc.) and circos plots were constructed online for visualizing patterns of association.[24]

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Results

Study selection

Figure S1 depicts the screening and selection process for the articles. We identified and included a total of 466 articles, which were selected from 8 521 original records obtained from the electronic database search and hand searching. Of the 8 295 records found in electronic databases, 40.4 % (3 355 studies) were from PubMed, while ScienceDirect and Scopus contributed 27.1 and 23.3 % (2 249 and 1 934 studies, respectively). Additionally, 737 records were retrieved from the Virtual Health Library and 20 were retrieved from Redalyc. According to each productive species, the highest number of records found corresponded to bovines (44 %, 3 751 studies), followed by pigs with 2 646 studies (31 %), while the two species of small ruminants together made up 25 % (2 124) of the records.

After duplicate removal, 5 374 studies were screened based on title and abstract, of which 1 158 articles were selected for full text retrieval. We retrieved 88.8 % (1 028 studies) of the selected texts, of which 466 (45.3 %) were finally included, the main reasons for exclusion for the 562 studies that were not selected are summarized in Figure S1. For each productive species, a detailed list of the included studies with their corresponding citations is provided in Tables S3-6.

Classification of the studies according to their main characteristics

Of the 466 included studies in the systematic map, 49.8 % (232) corresponded to bovines, thus bovines were the most frequently assessed species in the research conducted on heat stress. Porcines and ovines contributed 104 and 86 studies, representing 22.1 and 18.4 %, of the total respectively. Finally, 44 studies conducted on goats, representing < 10 % of the total, were included. Regarding the parameters evaluated in the scientific research, the studies that focused on reproductive outcomes were most frequent, representing 42.7 % of the total, followed by studies assessing physiological outcomes (31.1 %), and research conducted on productive outcomes to assess the effects of heat stress (26.2 %).

As shown in Figure 1A, for the studies that included bovines or pigs, the reproductive parameters were the most frequently assessed (44.8 and 48 %, respectively), while for ovine, we found a similar contribution of studies with a physiologic or reproductive approach (43 % each). In contrast, the use of physiological parameters predominated in 63.6 % of the studies performed on goats.

Among the included studies, 65.2 % (304) assessed female animals, while males were used in 22.1 % of studies, and only 12.6 % of the research included animals of both sexes to determine the effects of heat stress (103 and 59 studies, respectively). Regarding the distribution of research according to sex and the parameters assessed, we found that half of the studies performed in females included a reproductive approach. Such a result contrasted with the research that used males or mixed sexes, as 45.6 and 61 % of the studies, respectively, analyzed changes in the physiological response to heat stress (Figure 1B).

With respect to the age group of the animals, 84.7 % of the studies (395) included adult animals, whereas earlier developmental stages were studied with low frequency: young animals, 36 studies (7.7 %); offspring, 23 studies (4.9 %); and mixed ages, 12 studies (2.6 %). As shown in Figure 1C, the distribution of publications according to age group and the assessed parameter indicated that a higher

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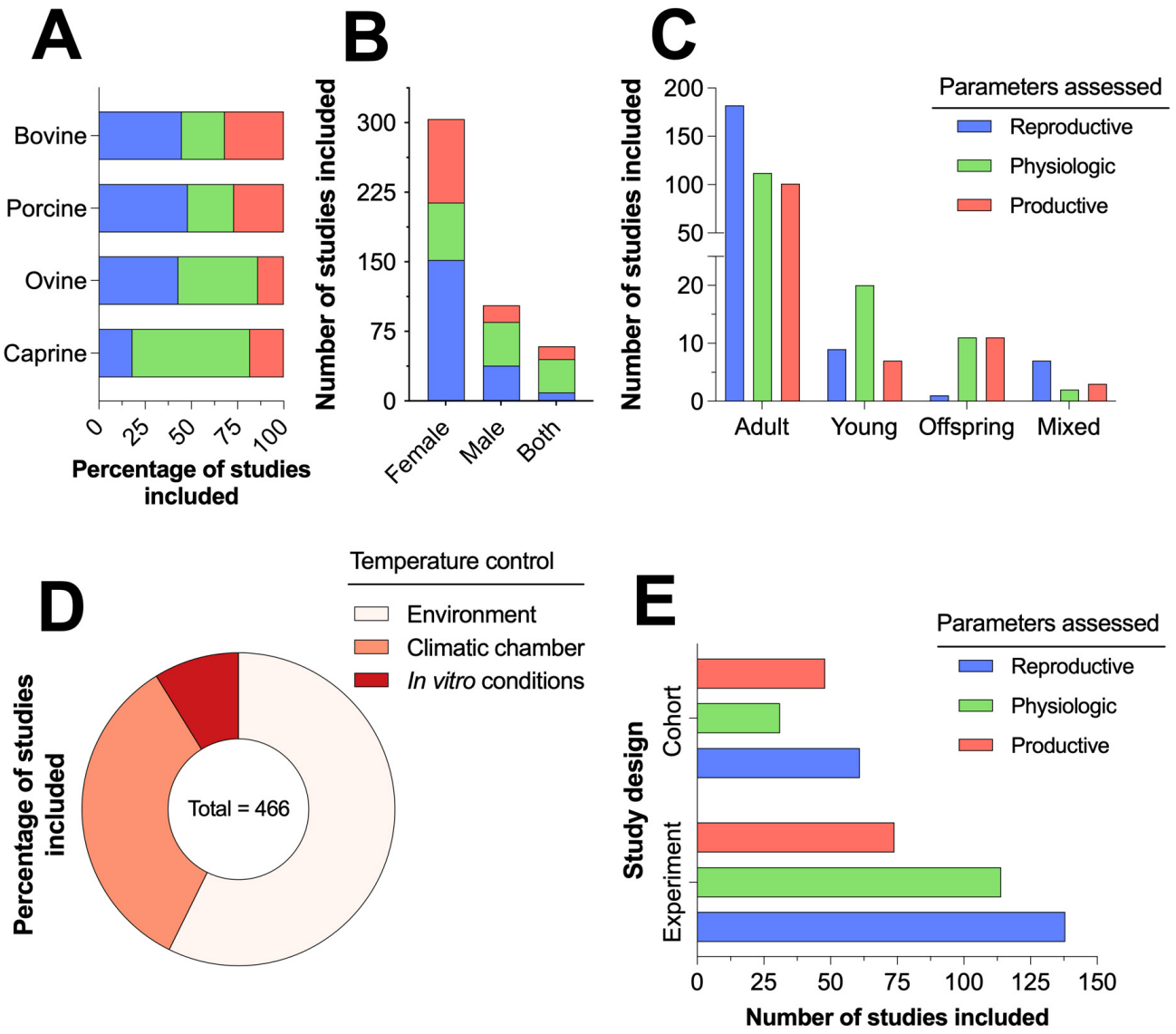

Figure 1. A) Distribution of the total number of articles per species according to the parameters assessed, B) number of articles according to the sex of the animals used in the research, C) published articles per group of age according to the parameters assessed, D) percentage of included articles according to the temperature control, and E) number of articles according to the study design and the assessed parameters.

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number of studies included adult animals in a reproductive approach (46.1%, 182 studies). In contrast, 55.5% of the research performed in young animals was centered on a physiological approach.

Study design and experimental conditions

Of the selected articles, 326 and 140 (70 and 30%) were experimental studies and cohort studies, respectively. In 57.3% of the articles, animals were exposed to natural conditions to induce heat stress, whereas in 33.9% of the studies, temperature and relative humidity were controlled experimentally by using a climatic chamber. Forty-one studies (8.8% of the total) evaluated the effect of high temperatures on different productive species cell types in vitro (Figure 1D). As shown in Figure 1E, in both study designs, the reproductive parameters were the main focus of the research.

Studies by sex of the livestock and their parameters evaluated

Among the four productive species, we observed a characteristic distribution of the publications according to the sex of the animals and the parameters assessed in each study. In bovines, 92.3% of the reproductive studies were performed on females. Similarly, > 90% of the studies assessing productive outcomes were performed on females (Figure 2A). In pigs, 54 and 35.7% of the studies assessing reproductive or productive outcomes, respectively, included females (Figure 2B). In bovines and pigs, 13.8 and 30.7%, respectively, of their respective studies were conducted on males.

Regarding ovines, studies performed on females ranged from 35.1 to 64.8%. Interestingly, in this species, we observed the highest total frequency of studies conducted on males (34.8%, 30/86 studies), and a physiological approach was most often used in studies performed with males (Figure 2C). Finally, for goats, 28/44 studies included physiological outcomes, of which 39.3% of the studies used females to assess the effect of heat stress. In contrast, 62.5% of the reproductive and productive studies were conducted on females (Figure 2D).

In total, 95.2% (444/466) of the articles included were published in English, 16 in Portuguese, and six in Spanish. More than 70% of the studies were conducted in two continents: the Americas, with 208/466 publications; and Asia, with 131 publications (insert Figure 3A). America was the main continent for research in bovines, pigs and ovines, whereas Asia contributed most of the investigations in goats (Figure 3A).

A total of 89.3% of the studies were conducted in the Americas, Asia, and Europe; therefore, we constructed circos plots to show the distribution of the articles per species according to the main countries of each continent where research was conducted. As depicted in Figure 3B, in the Americas, except for goats, the greatest number of studies was performed in the USA, with bovines at 61%; pigs at 64%, and ovines at 40%; followed by Brazil for bovines and ovines, although in Brazil, the highest number of studies was performed with goats. The four countries depicted in the figure constituted > 90% of the total research conducted within the continents.

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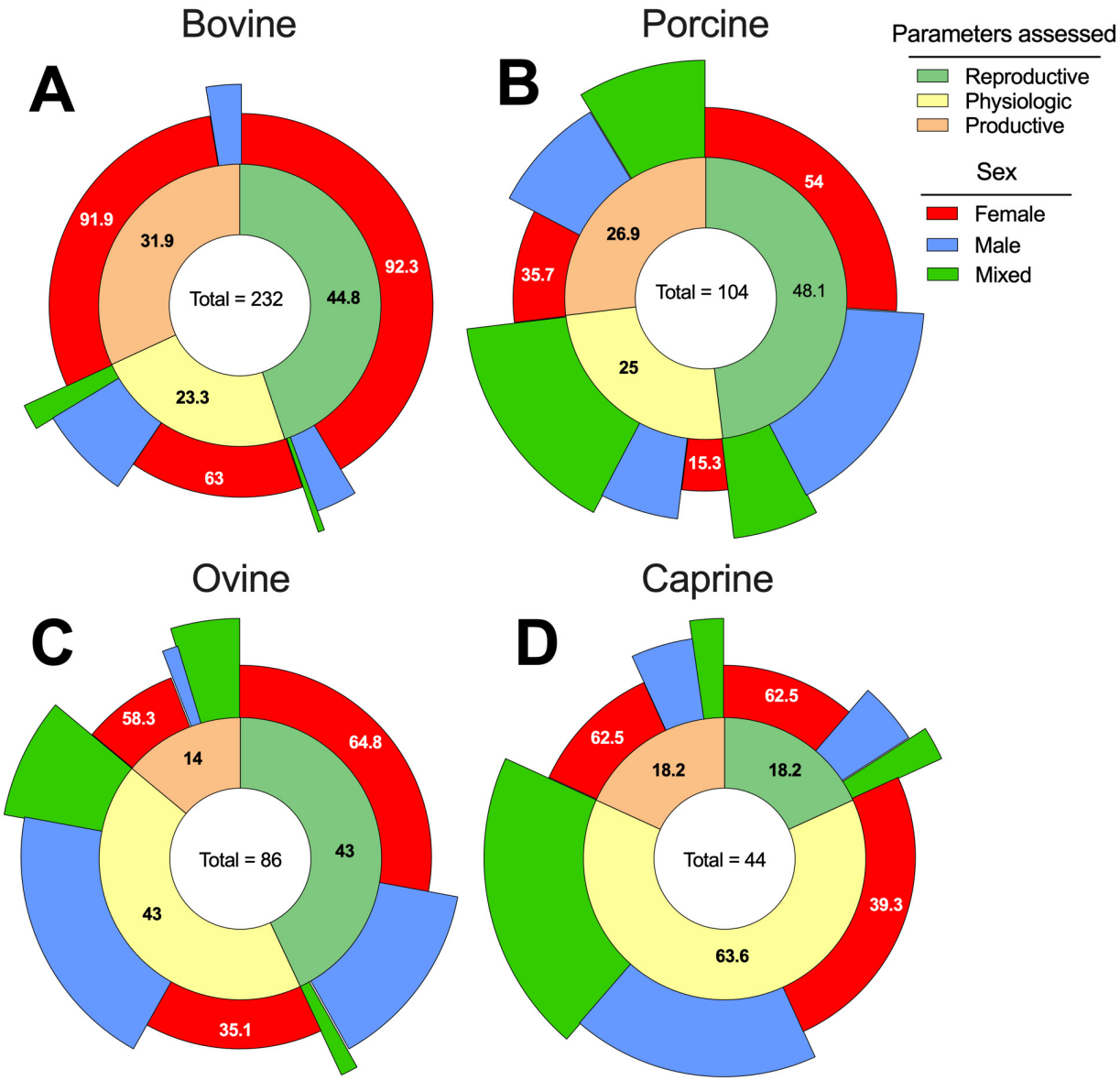

Figure 2. Percentage of articles of A) bovines, B) pigs, C) ovines, and D) goats according to the sex of the animals and the parameters assessed in the research.

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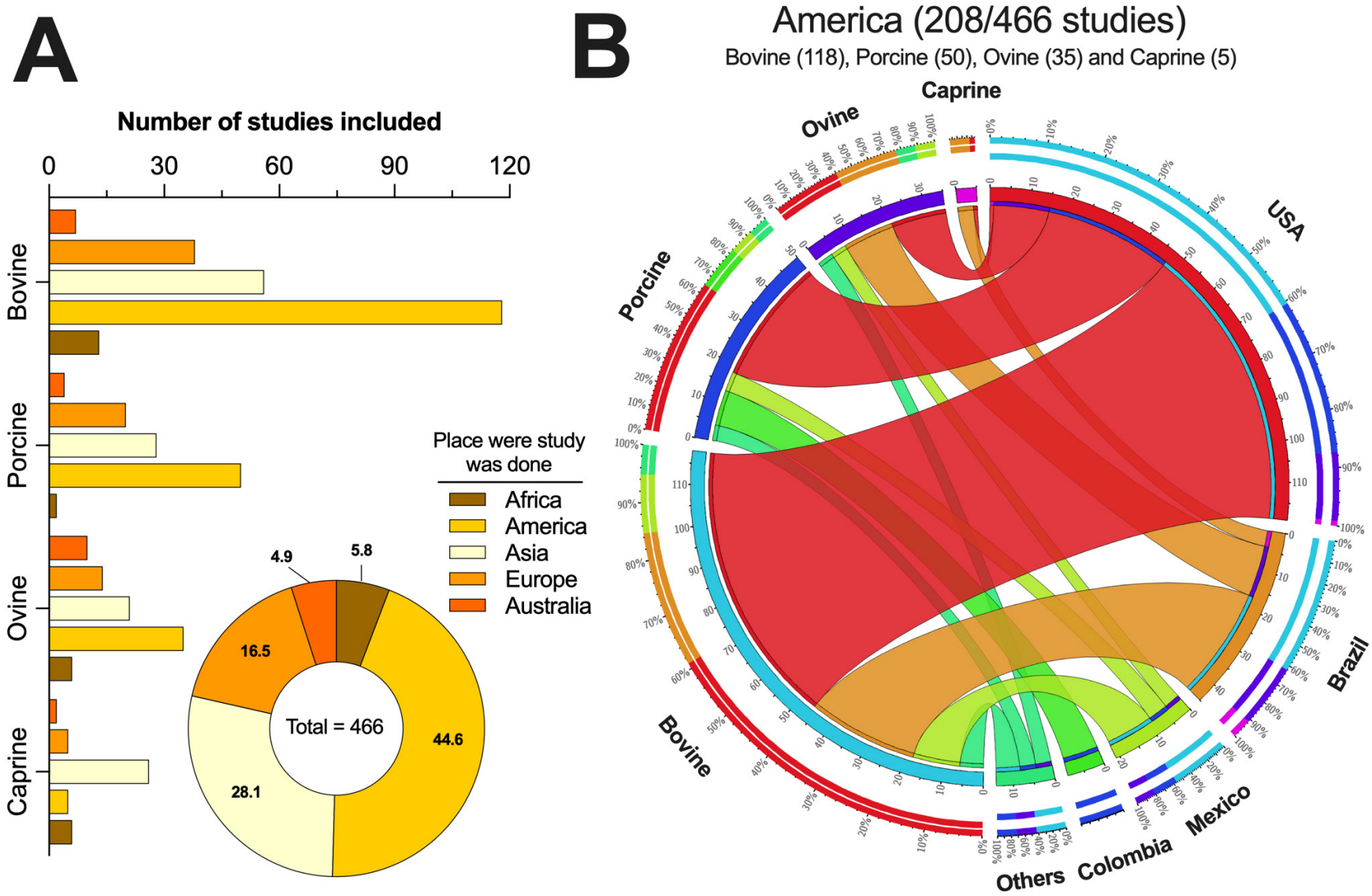

Figure 3. A) The number of articles per productive species according to the continent where the study was conducted, and B) circos plot of the association between the four main countries that published the highest number of articles from America. The insert shows the distribution of the articles per continent where the studies were performed.

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In Asia, India contributed the greatest number of publications for bovines, ovines, and goats (11, 9, and 16 studies, respectively), as China did for studies performed in pigs. Unlike the results from the Americas, in Asia, the research on heat stress was distributed among a greater diversity of countries; nevertheless, countries such as Thailand, Saudi Arabia, and Iran contributed few research studies. Due to this greater diversity, the "Others" group contained 34.4 % (45/131) of the published articles (Figure S2 A). Italy and Germany contributed 27.7 and 18.2 % of the total studies originating from Europe. In Italy, there were published studies for all four productive species, unlike Germany, where only bovines and pigs were included in the research. Spain and France took 3rd and 4th place, respectively, although France exclusively contributed studies on pigs. Similar to what we observed in Asia, the studies from Europe were unevenly distributed across a great variety of countries; therefore, the "Others" group contains one-third of the studies for this continent (Figure S2 B).

Frequency of publication of the studies

In Figure 4A, we present the cumulative relative frequency of publications from 1980–2018 for each species. For bovines, 21.1 % of the studies were published over the first two decades of the period, while in contrast, between 2000 and 2010, the number of studies doubled until they constituted nearly half the cumulated total. For pigs, only 10.5 % of the total studies were published during 1980–1990, almost half of the studies in pigs (51/104) were performed during the last six years. In ovine, we found two important periods for publications: 30.2 % of the studies were published during the first half of the period (1980–2000) and 44/86 studies (51.1 %) were published during the last decade of the period from 2010–2018. Finally, in goats, an uneven and intermittent accumulation of research during the period was detected, which resulted in a reduced number of studies by 2010 (36.6 %, 16/44 studies).

In violin plots depicted in Figure 4B, we present the temporal distribution of the number of published studies per species. As observed by the shape of the violins, in all four productive species, a great number of studies have been published since 2010. Such results indicate a recent interest in evaluating the effect of heat stress on these four species, particularly in pigs and goats. Moreover, both in pigs and goats, the median of the number of published articles is from recent years (2013 and 2015, respectively), mostly due to a reduced frequency of publication during the first three decades of the period (1980–2010).

Main journals where the studies are published

Figure 5A shows a circos plot for associations between the top five journals that published the higher number of studies per species. For each species, these top journals provided between 45.3 and 52.8 % of the total number of published articles. *Journal of Animal Science* consistently published studies on the four species and included 54 publications, followed by *Theriogenology* with 49 studies distributed across three species. Taken together, these two journals contributed 22.1 % of the total number of articles included in the systematic map. *Journal of Dairy Science* published the highest number of studies (44) for bovines, thus becoming the main

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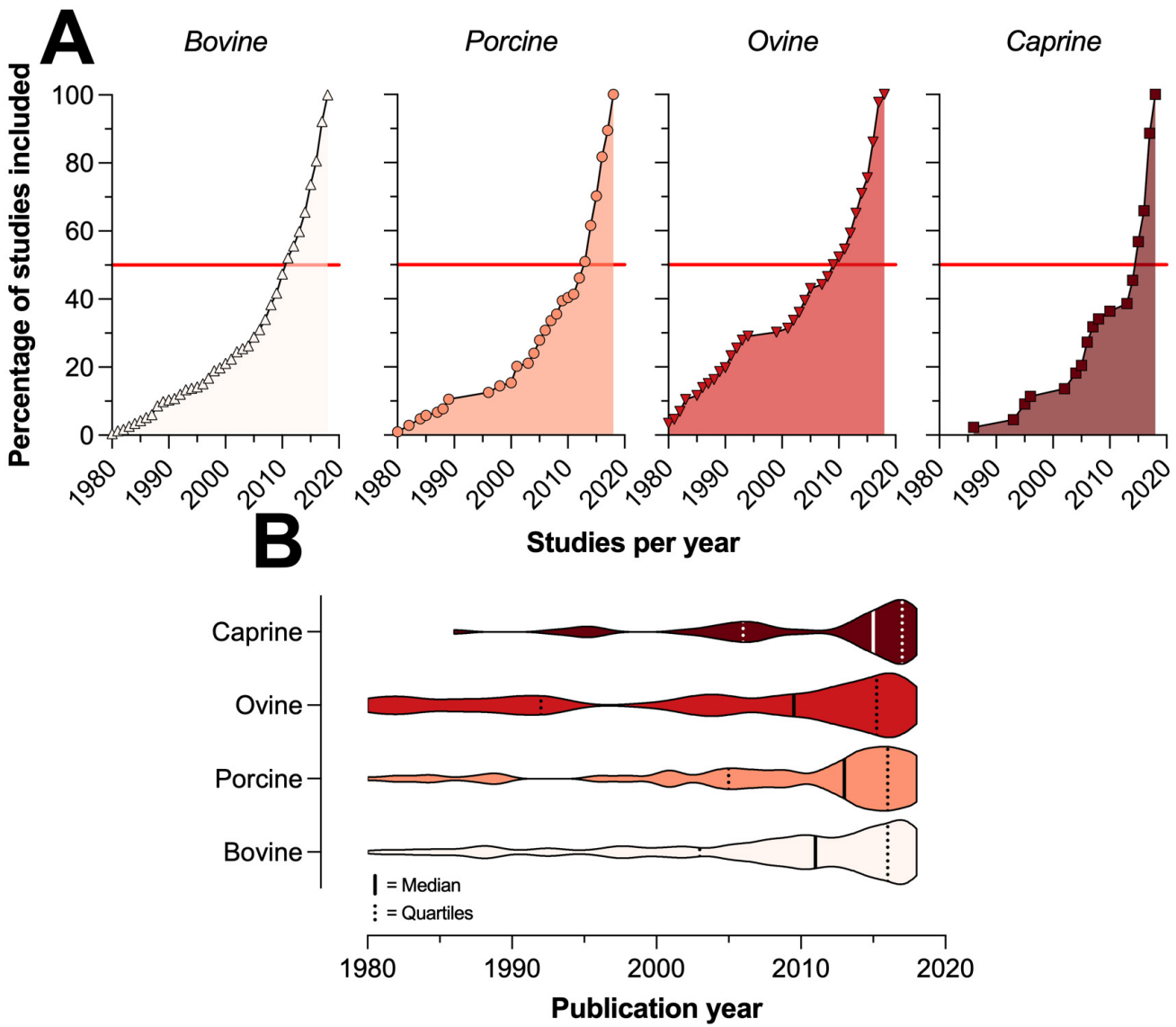

Figure 4. A) Relative cumulative distribution of the articles per species from 1980–2080, and B) violin plots of the temporal distribution of the number of published articles per species during the period. In A, the horizontal line was drawn to indicate the year in which 50 % of the studies accumulated over the period.

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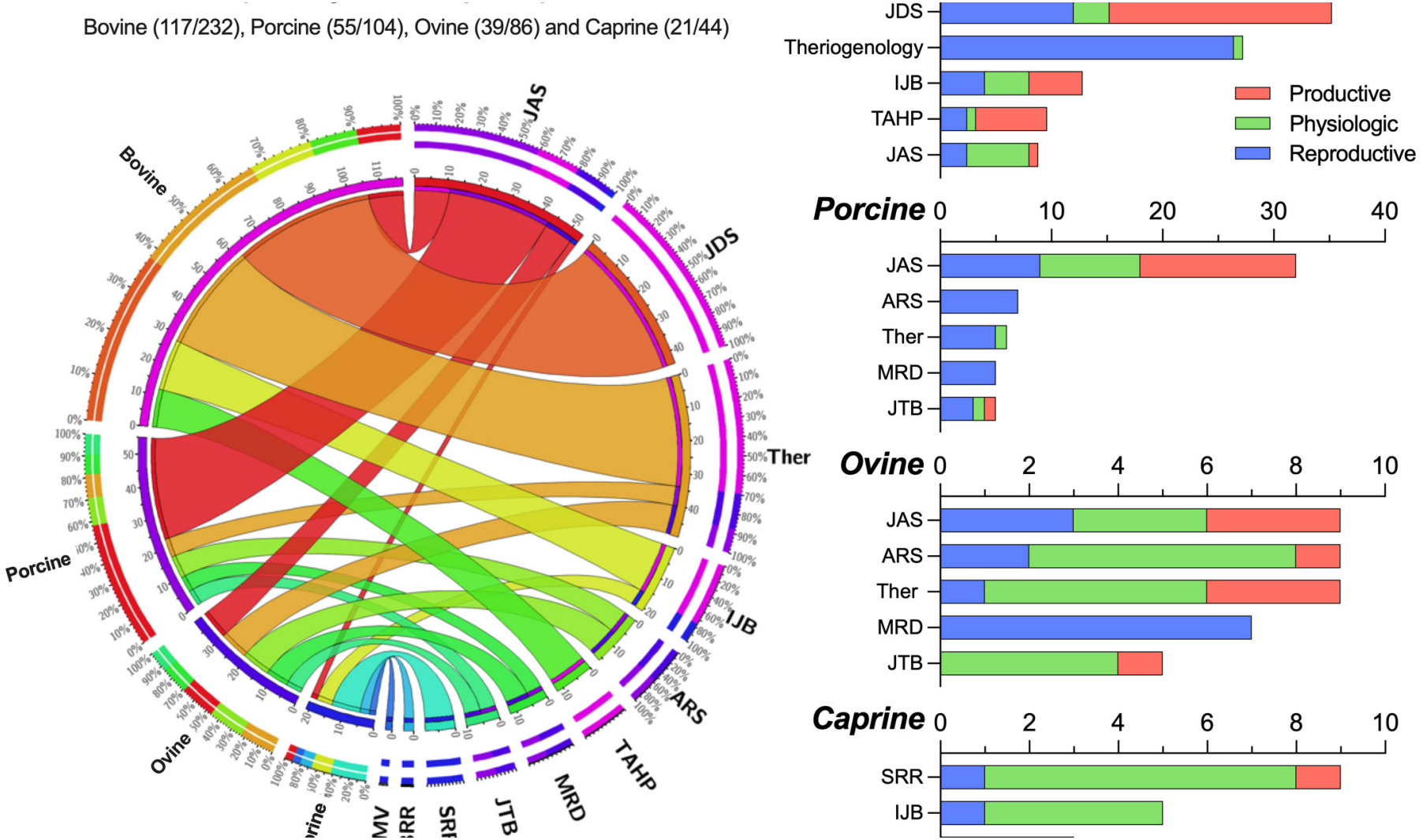

Figure 5. A) Circos plot of the association between the top five journals that published research on the four productive species, and B) number of articles published per species in the top five journals according to the parameter assessed. For bovines, the selected journals published 50.4 % of the total articles, 52.8 % for pigs, 45.3 % for ovines, and 47.7 % for goats. JAS, *Journal of Animal Science*; JDS, *Journal of Dairy Science*; Ther, *Theriogenology*; IJB, *International Journal of Biometeorology*; ARS, *Animal Reproduction Science*; TAHP, *Tropical Animal Health Production*; MRD, *Molecular Reproduction and Development*; JTB, *Journal of Thermal Biology*; SRR, *Small Ruminant Research*; BRR, *Biological Rhythm Research*; ABMV, *Arquivo Brasileiro de Medicina Veterinaria*.

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diffusion channel for research conducted with this group. The following three journals published 10.5 % of the total number of articles and were associated with two of the four species included in the map: *International Journal of Biometeorology, Animal Reproduction Science and Molecular Reproduction and Development*, with 21, 16, and 12 studies, respectively.

With regard to the specific contributions of the journals according to the species and the parameter assessed in each study, a distinctive pattern among farm animals was found (Figure 5B). Among the publications that included bovines, *Journal of Dairy Science and Tropical Animal Health Production* were characterized by a higher number of studies focused on productive parameters, whereas the studies published in *Theriogenology* and *Journal of Animal Science* mainly had a reproductive and physiological focus, respectively. Respect to the research performed in pigs, in 4 out of 5 main journals, reproductive parameters constituted the main focus of the studies. Among the journal that published studies on ovines and goats, there was a trend towards a higher number of articles focused on physiological parameters.

Assessed outcomes according to the study parameters and the productive species

In the donut plots in Figure 6, the relative contribution of each group of defined outcomes for each kind of parameter assessed in the studies is presented. Within the reproductive approach, we defined seven groups of outcomes; 33 % of the studies assessed the effect of heat stress on the reproductive performance of exposed animals Following reproductive performance, studies focused on the evaluation of embryo / oocytes or testicle parameters, each with 16.5 % of the studies (Figure 6A). In both the physiological and productive approaches, four groups of outcomes were included. In particular, 54.8 % of the studies assessed the response of physiological outcomes (respiration rate, body temperature, and heart rate, among others) in animals exposed to heat stress conditions. In addition, 28.7 % of the studies focusing on this parameter assessed changes in blood biochemistry or metabolic parameters due to heat stress (Figure 6B). Finally, as shown in Figure 6C, two groups of outcomes, milk production and composition and productive performance, constituted 79.5 % of the total studies that assessed productive parameters.

In Figure S3, we present the relative contribution of studies for each group of outcomes according to the species and the assessed parameter. Within the reproductive approach (Figure S3 A), most of the research performed in bovines and pigs assessed reproductive performance. Unlike bovines, in the remaining three farm animals, the studies conducted in male animals constituted 23.5 to 50 % of the total studies. Indeed, the study of testicle parameters was the most frequent outcome assessed in research conducted in goats. Among the studies that focused on physiology (Figure S3 B), the research performed on physiological outcomes ranged from 35.7 to 74.1 % of the total studies among the species. In contrast, studies in which gene expression was evaluated were less frequent, as these constituted < 10 % of the studies. Lastly, as shown in Figure S3 C, for bovines and goats, the greatest percentage of studies (52.7 and 62.5 %, respectively) assessed the effect of heat stress on the production and composition of milk. In contrast, 60.7 and 66.7 % of the studies conducted in pigs and ovines, respectively, evaluated productive performance.

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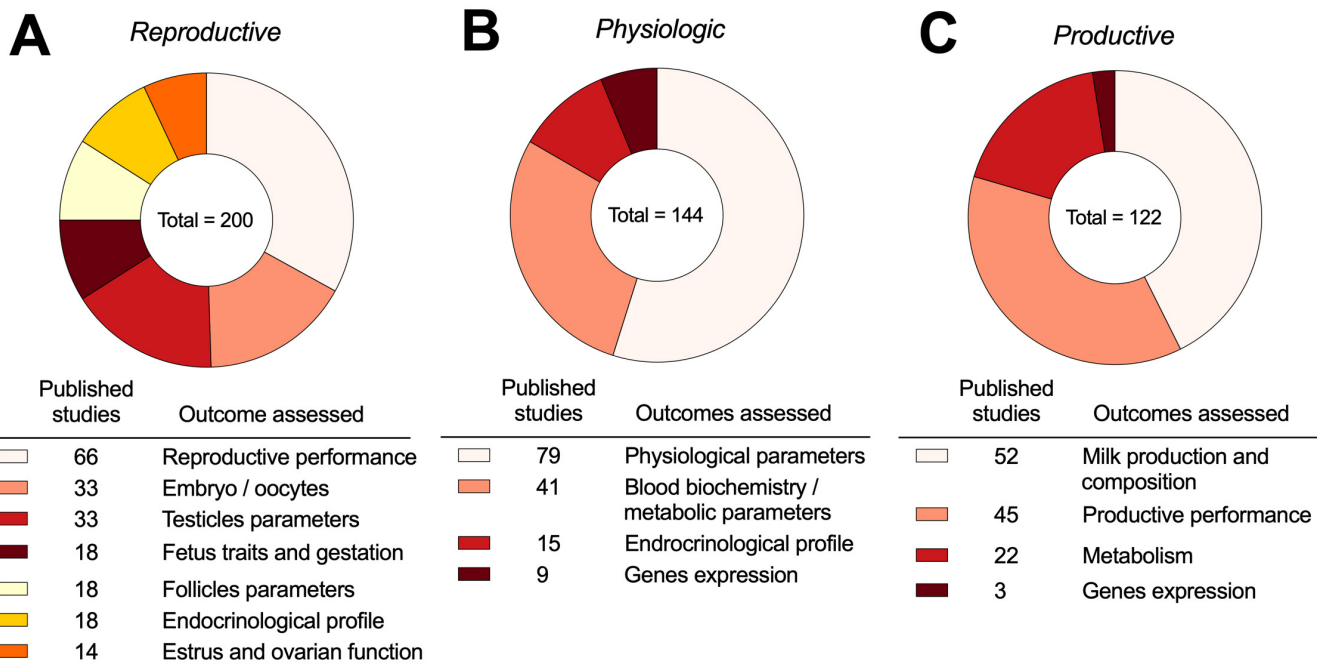

Figure 6. Distribution of the articles according to the group of outcomes included in the studies that assessed A) reproductive, B) physiologic, and C) productive parameters.

Discussion

General trends

In general, during the last 10 years, the number of primary studies that evaluated the effects of heat stress on farm animals increased. However, each productive species has shown differences in the accumulation of articles over time. In particular, 47.4 and 52.3 % of the studies conducted in bovines and ovines were published before 2010. In contrast, more than half of the scientific research conducted in pigs and goats has been published over the last six years. Seventy-two percent of the publications included in the systematic map were conducted in the Americas and Asia, with the USA and India being the two main countries with the highest number of studies published on the topic. Additionally, > 60 % of the research from the USA involved bovines, while in India, the highest percentage of publications involved goats.

Journal of Animal Science, *Journal of Dairy Science*, and *Theriogenology* were the main journals for publication of the studies included in the map. In addition, for each species, there was a differential pattern of journals in which scientific research was published. Studies that used bovines and pigs represented 72 % of the studies; such results demonstrate the fact that these two productive species are among the most important farm animals in which the effect of heat stress is assessed.[5,25] Furthermore, in these two species, the highest number of studies involved reproductive parameters, thus confirming the importance of studying the negative effects of heat stress upon reproductive outcomes. [7, 9, 26] Indeed, the results from these species determined the general trend of publications, as the evaluation of reproductive parameters was the most frequent approach in the scientific research included in the map.

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The studies performed with females outnumbered those that used males or a mixture or sexes. Likewise, in > 80 % of the publications used adult animals and only 23/466 studies determined the effect of heat stress upon offspring of the productive species. With respect to the study design, experimental studies predominated over cohort studies. In addition, in the experimental studies, reproductive parameters were the main focus, followed by physiological outcomes. In 33.9 % of the publications, a climatic chamber was used to artificially induce heat stress on experimental animals. Only < 9 % of the studies evaluated the effect of high temperatures on cells or tissues of the included species *in vitro*. Among the studies that focused on reproductive parameters, we defined seven groups of outcomes from the codification process. Therefore, in comparison to the publications that included physiological or productive approaches, the studies focused on reproduction included the highest diversity of assessed outcomes. Furthermore, in such studies, the effect of heat stress on males and females was independently evaluated on gonads and gametes. In the particular case of research focused on productive parameters, the main publication trend corresponded to the evaluation of the production and the composition of milk.

Gaps in knowledge

We found a low number of studies for caprine species across the databases. In addition, a deficit of research on the productive and reproductive parameters of goats was found; however, in some countries, goats are very important to produce milk and meat. Ovines predominate in the research on small ruminants. Indeed, several secondary studies focus only on ovines, thus excluding goats. [6,27,28] Given that reviewers conducted independent searches using different search commands in each database, it is possible that the reduced number of studies found for goats was associated with bias during the search process. In addition, during the mapping, we detected a lack of studies on meat cattle breeds. Indeed, only a few studies have assessed the effect of heat stress on bovine males during finalization. Given that the finalization process occurs mostly in exposed feedlot areas where summer conditions can cause heat stress, there is a need for conducting research on this topic. The research conducted in ovine was based mostly on wool breeds. Consequently, a limited amount of information available for hair breeds or mixed breeds of sheep was found.

Most of the studies (> 95 %) were published in English; therefore, there is a great disparity in the language in which research is published. Consequently, to disseminate knowledge about the negative effect of heat stress, more studies published in languages other than English are needed, especially in places where English is not the primary language and where the production of any of the four farm animals that we evaluated are affected by heat stress during warm seasons of the year, particularly in tropical and subtropical regions of the world).[12, 29]

Within the studies that assessed reproductive outcomes in bovine males, there has been limited research on testicle and spermatozoa parameters and traits. Such a result might be associated with the extended use of artificial insemination in productive installations dedicated to dairy cattle. Nonetheless, in tropical or subtropical places where the use of reproductive biotechnology is not very common, the eval-

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uation of the effect of heat stress on bulls is important to fully understand whether heat stress-associated male reproductive impairment should be expected.

Topics for future systematic reviews and meta-analysis

According to the number of primary studies found for bovines, it is possible to perform secondary studies on the effect of heat stress on the production and composition of milk in Holstein cows. Likewise, it is possible to estimate with meta-analyses the deficit in the reproductive performance of dairy cattle when exposed to heat stress conditions. For pigs, we consider it important to assess the reproductive and productive performance of males exposed to heat stress with secondary studies. Additionally, it might be useful to estimate the effect of heat stress on the testicle parameters as well as to estimate the reduction in semen and spermatozoa traits with a meta-analysis.

Limitations of the study

Due to the high volume of studies on the topic of interest, we consider that the main limitations for the study were the lack of full data extraction from each article in conjunction with the consequent absence of a quality assessment of the evidence. Likewise, the heterogeneous nature of the evidence made the generation of qualitative and quantitative summaries for the studies difficult.[30] Likewise, the broad approach of the topic also affected the synthesis of evidence because three groups of parameters and four species were included.

Consequently, we were unable to extract detailed content for each article, and the compilation of the map database was complicated due to the high heterogeneity among studies. It is possible that the inclusion of the temporal restriction (1980–2018) could have produced bias during the research process and in gathering data for some species. Similarly, the spatial distribution pattern of the studies could have been biased due to the idiomatic restriction imposed during the search and screening process. Such a restriction could have limited the inclusion of studies conducted in countries where research on the topic is published in a language other than the ones included in this research.

Conclusions

In the present scoping review and systematic map, we collated, classified and synthesized a high volume of studies that were highly heterogeneous due to the inclusion of three groups of parameters and four productive species. Nonetheless, all included studies allowed us to identify and synthesize an important body of evidence regarding the main outcomes of heat stress. The results presented herein outline the research trends on the topic of interest, which can guide primary research on specific subtopics among the species as well as define potential secondary studies, such as systematic reviews and meta-analyses. Increasing the number of studies performed on males using productive and reproductive approaches for pigs, ovines, and goats is recommended.

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Data availability

All supplementary data associated with this work is available in the web-appendix and the databases are available from the corresponding author upon reasonable request..

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Conflicts of interest

The authors have no conflict of interest to declare about this publication.

Author contributions

Use the "Contributor Roles Taxonomy" (CRediT) to describe authors' contributions.
Conceptualization, investigation, and methodology: DD, AML, ANC, AMP.
Data curation: AML, ANC.
Formal analysis, software, and visualization: DD.
Project administration: DD and AMP.
Resources and supervision: RJR, JJP, and SMG.
Writing-original draft: AML, ANC, MARG, and RJR.
Writing-review and editing: DD, RJ, and AMP.

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