Meta-analysis and systematic literature review of climate change effects on livestock welfare

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Abstract

Climate change is a phenomenon that includes different dramatic events that deeply affect the physiology of animal species both directly and indirectly with qualitative–quantitative impacts on livestock performances and health. The implications of climate change on animal welfare and on production demand are complex and call for a multidisciplinary approach which involved both animal science and economic sciences. The current technical report will describe the activities performed by the fellow while placed at the University of Foggia, Department of Agriculture, Natural Resources and Engineering, in Italy. Furthermore, the work programme offered by the hosting site consisted in performing a systematic literature review, following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) Statement, and a quantitative synthesis of the literature on the impact of climate change events (e.g. heat stress) on livestock welfare and productivity and the effect of heat relieving strategies on the animals' performance.

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The EFSA Journal is a publication of the European Food Safety Authority, a European agency funded by the European Union.

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1.   Introduction

1.1.   Climate change and livestock welfare

Climate change is a complex phenomenon that includes different dramatic events, such as global warming, floods and droughts, and all these events deeply affect the physiology of animal species both directly and indirectly with semi-quantitative impacts on livestock performances and health. The implications of climate change on animal welfare and on production demand are complex and call for a multidisciplinary approach which involves both animal science and economic sciences.

According to Filipe et al. (2020), global warming is the main and strongest phenomenon associated with climate change. Furthermore, the Earth's temperature is increasing by 0.2°C per decade and it is estimated that by 2,100, it will be increased by 1.4–5.8°C. Also, most of the studies on climate change effects on immune system and, thus, animal's welfare and health, focus on the increasing temperatures worldwide. Heat stress has several negative consequences on livestock, with activation of mechanisms that either aim at reducing the production of heat due to metabolism or increase inflammatory responses or lead to immune-suppression, such as: (i) decrease in daily intake; (ii) increase in peripheral cortisol levels; (iii) production of heat shock proteins (HSPs).

To the best of our knowledge, this is the first meta-analyses performed on the impact of climate change (e.g. heat stress) on livestock welfare, particularly on the effects on ruminants' performance and health. We have put higher relevance on the temperature rise events (i.e. heat stress), due to the conspicuous number of studies published on the effects that temperature has on livestock (Rahbar et al., 2019; Ahmad Para et al., 2018) and, in consideration of the relevant influence that changes in temperature have on the immune response system of different species. This latter aspect has been rarely investigated.

According to Baumgard and Rhoads (2013), it undermines genetic, nutritional, pharmaceutical and management advances made by the animal agriculture industries.

When the ambient temperature and other environmental conditions create a situation that is either below or above the respective threshold values, the animal's efficiency is compromised mainly because nutrients are diverted to maintain euthermia, as preserving a safe body temperature becomes the highest priority, and product synthesis (e.g. milk or meat) is deemphasised.

Heat stress negatively impacts a variety of productive parameters including: (a) milk yield and composition, (b) growth, (c) reproduction and (d) carcass traits.

In addition, a heat load: (1) increases health care costs, and (2) animals can even succumb to severe thermal stress, especially lactating cows and animals without shade.

Livestock welfare can be evaluated considering the Welfare Quality Protocol, using four categories for all species. These are described as good feeding, good housing, good health and good behaviour (Welfare Quality®, 2009). Good feeding includes two criteria: absence of prolonged hunger and absence of prolonged thirst. Good housing includes three criteria: comfort around resting, thermal comfort and ease of movement. The first criterion is measured as time needed to lie down, animals colliding with housing equipment during lying down, number of animals lying partly or completely outside the lying area and cleanliness of different body parts (udders, flank/upper legs and lower legs). Moreover, good health includes three different criteria: absence of injuries (lameness), absence of disease and absence of pain induced by management procedures. Finally, good behaviour, although not represented in our study due to the type of experiments used in our systematic literature review, it encompasses four criteria: expression of social behaviours, expression of other behaviours, good human–animal relationship and positive emotional state.

1.2.   Heat stress and Temperature–humidity index (THI)

Heat stress is caused by a combination of environmental factors (temperature, relative humidity, solar radiation, air movement and precipitation).

Thom (1959) introduced a temperature–humidity index (THI) to characterise the combined effect of the environmental climatic conditions (dry temperature, relative humidity, dew point). Both temperature and humidity can act together as stressors for animals. According to Correa-Calderon et al. (2004), many indices combining these different environmental factors could be used to measure the level of heat stress (Correa-Calderon et al., 2004). However, most studies on heat stress in livestock focused mainly on temperature and relative humidity due to data on temperature and humidity records being able to be obtained from a meteorological station located nearby, in contrast to

the publicly unavailable data regarding the amount of thermal radiation received by the animal, wind speed and rainfall. The parameter that describes heat load on animals and is a good indicator of stressful thermal climatic conditions is the THI, combining both temperature and humidity and measures animal comfort.

Furthermore, in relation to THIs measuring sensitivity, according to Habeeb et al. (2018), THI is better predictors of body temperature in heat-stressed cows than other measurements of environmental conditions. Also, THI serves as indicators to heat stress of climatic conditions with relation to production and reproduction of farm animals, which in our case, the accounted species were, besides bovine, ovine and caprine. THI indices can be placed into classes to indicate the degree of heat stress and the terms used to describe these classes and the ranges of THI used to define each class are arbitrary. In our study, we classified the degrees of heat stress according to Marai et al. (2007) and Marai et al. (2001) for small ruminants (ovine and caprine) (Marai, et al., 2007; Marai et al., 2001).

Depending on the study, THI may be calculated using different equations, for instance:

$THI = 0.8 \, dbT + RH \times (dbT - 14.4) + 46.4$; where dbT is dry bulb temperature (^{o}C) and RH is relative humidity in decimal form. A THI of 74 or less is considered normal, 75–78 is alert status, 79–83 is danger status and a THI equal to or above 84 is an emergency (Tom, 1959). In Fahrenheit, the THI is arrived at from a combination of wet and dry bulb air temperature for a particular day and expressed in a formula as follows:

$$THI = 0.72(W^{\circ}C + D^{\circ}C) + 40.6,$$

where $W^{\circ}C$ = wet bulb and $D^{\circ}C$ = dry bulb. In this case, THI values of 70 or less are considered comfortable, 75–78 stressful, and values greater than 78 cause extreme distress and animals are unable to maintain thermoregulatory mechanisms or normal temperature (McDowell et al., 1976).

From Marai et al. (2007), the changes in THI mean values may also depend upon the equation used. For instance, when temperature is measured ($^{\circ}$F, Fahrenheit), the equation to determine THI is as follows (LPHSI, 1990):

$$THI = db^{\circ}F - [(0.55 - 0.55 \, RH)(db^{\circ}F - 58)],$$

where $db^{\circ}F$ is the dry bulb temperature in $^{\circ}$F and RH is the relative humidity (RH%)/100, for sheep and goats.

The obtained values indicate the following (LPHSI, 1990): THI < 82 (absence of heat stress); 82 to < 84 (moderate heat stress); 84 to < 86 (severe heat stress); and over 86 (extreme severe heat stress). However, when the temperature is expressed in $^{\circ}$C, the equation changes as follows:

$$THI = db^{\circ}C - [(0.31 - 0.31 \, RH)(db^{\circ}C - 14.4)],$$

where $db^{\circ}C$ is the dry bulb temperature ($^{\circ}$C) and RH is the relative humidity (RH%)/100. The values obtained indicate the following: THI < 22.2 (absence of heat stress); THI from 22.2 to < 23.3 (moderate heat stress); THI from 23.3 to < 25.6 (severe heat stress) and THI ≥ 25.6 (extreme severe heat stress).

This way, according to Johnson et al. (1989), THI is still the simplest and most practical index for measuring environmental warmth which causes heat stress in cattle, hence, being thoroughly used for estimation of the level of heat stress.

2. Description of work programme

2.1. Aims

As part of the EU-FORA fellowship, the study aims at involving the fellow in all the activities required for investigating the impact of climate change events (e.g. heat stress) on livestock welfare and productivity and the effect of heat-relieving strategies on the animals' performance, through a SLR, following the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) Statement, and a quantitative synthesis of the literature on the issue.

2.2.   Activities/Methods

For development of the work programme, the priority of the hosting site was to provide the fellow with the basic theoretical background required to perform a meta-analysis with a systematic literature review. The fellow joined a working team from both animal and socio-economic sciences with proved expertise in the use of meta-analytic tools and received training on specific topics such as:

– Performing a meta-regression analysis (MRA);
– Handling of electronic databases (e.g. Scopus);
– Performing PRISMA guidelines for data screening on climate change and livestock welfare;
– Developing inclusion/exclusion criteria regarding climate change effects, particularly regarding heat stress, and livestock welfare, with access to the available databases on the subject;
– Overview of the animal welfare protocol used for Bovine (dairy and beef production), ovine and caprine species;
– Statistical analysis of the data extracted;
– Software tools that can be applied to meta-analysis, that were introduced to the fellow within the scope of course on 'Risk Analysis and Risk Management in Agriculture: Updates on Modelling and Applications' (e.g. STATA, R and R Studio).

2.2.1.   Experience gained on meta-regression analysis (MRA): systematic literature review (SLR) and semi-quantitative analysis

In order to combine both climate change effects in livestock welfare and productivity, a review of the already performed meta-analytical studies on the subject of interest was conducted. Using the Scopus electronic database, the results, with refinement for category 'article' written in 'English' from peer-reviewed journals, and with criteria selected regarding only bovine, ovine and caprine species, for data screening and extraction were selected nine articles (Table 1).

Table 1:   Search strings, rationale for inserting the systematic literature review, results I (without refinement) and II (with refinement) of the data screening, regarding possible already performed meta-analytical studies on climate change and livestock welfare

Editor	Tool[a]	Purpose	Search strings	Results I[b]	Results II[c]
Morgado JN et al.	Scopus	Investigate for already existing meta-analysis on the topic	TITLE-ABS-KEY ("Climate change" OR climat* OR "extreme weather" OR "heat stress" OR "Increased atmospheric carbon dioxide concentration" OR "precipitation variation" AND "animal welfare" OR "BCS" OR "Body weight" OR "Respiration rate" OR "conception rate" OR "rectal temperature" OR "milk yield" OR "carcass weight" OR "fat thickness" OR "behavioural alteration" AND "meta-analysis")	45	9

(a): Electronic database used for search string used.
(b): Number of results without refinement for category 'article' written only in 'English', from peer-reviewed journals.
(c): Number of results, with refinement, selected for screening regarding the criteria in study, including only bovine, ovine and caprine species.

After this first step, the research question and the scope of the SLR were thus defined and further developed.

Therefore, in this study, a higher relevance was put on the temperature rise events (i.e. heat stress), due to the conspicuous number of studies published on the effects that temperature has on livestock (Rahbar et al., 2019; Ahmad Para et al., 2018) and, in consideration of the relevant influence that changes in temperature have on the immune response and health system of different species.

The SLR was conducted using the Scopus database for data sourcing, following all the PRISMA guidelines for screening (Appendix A). The search keywords were selected under four interconnected categories: climate change (CC); animal welfare; species; management strategy.

To be included in the database, studies followed these parameters: category 'Article', written in 'English', from peer-reviewed journals; only bovine, caprine and ovine species; and, for each experimental group, the THI was reported.

For data extraction, the decision for inclusion relied on the following two criteria: experiments had to analyse the animals' performance under both heat stress (HS) and thermoneutral conditions (TN); and control (TN) and heat stress groups had to encompass a management strategy to compare and observe the different effects.

2.2.2. Semi-quantitative analysis

In the count noun sense, a descriptive statistic is a summary statistic that quantitatively describes or summarises features from a collection of information (Mann, 1995), with the aim to summarise a sample. Some measures that are commonly used to describe a data set are measures of central tendency and measures of variability or dispersion. In this analysis, the measures of central tendency included the mean and median, while measures of variability include the standard deviation, the minimum and maximum values of the variables.

The type of indicators found in the studies was from different categories, from which the following can be highlighted: body temperature (rectal temperature, respiration rate); blood parameters (glucose, insulin, BUN, NEFA, pH); milk production and composition (milk yield, protein yield, lactose yield); reproduction and conception rate.

The indicators were classified according to species either all together or individually and to the variation of the Delta THI (severe or otherwise).

In Table 2, an overview of the indicators' descriptive analysis is considered. Three main categories (cat.) were used to estimate the influence of the CC impacts on bovine, ovine and caprine (described as 'all species'), with or without applying management strategies (e.g., dietary interventions; bed treatment; use of fans and or sprinklers). These were defined as: category one (Cat.1), to estimate the impact in control conditions and without management strategies; category 2 (Cat.2), in treatment conditions and with management strategies; and category 3 (Cat. 3), for estimating the impact of adaptation strategies in animals' performances. The level/magnitude of impact that may or not influence the performance of all the species considered was also qualitatively estimated. Performance in our study may encompass milk production, conception rate and reproduction rate, growth rate and carcass traits.

Table 2: Overview of the indicators' descriptive analysis considering climate change categories 1, 2 and 3

Category (Cat.)	Climate change (CC)	CCs conditions' description	Species	Worst performance RF[a]	Changes in performance[b]
1	Impact (control)	Impact in control conditions comparing both TN and HS: control TN vs. control HS	All species[1]	0.26	+
2	Impact (with treatment[2])	Impact in treatment conditions comparing both TN and HS	All species	0.15	+++
3	Adaptation	Adaptation effects comparing both experiments in control in HS with treatment in HS	All species	0.14	++

(a): Relative frequency (%).

(b): Expressed qualitatively as the level/magnitude of impact (e.g. +, ++ or +++) that influences all species performance (e.g. worst or improved) for all species:+: climate change impacted for the worst the animals' performance, e.g. low impact on the improvement of the performance; +++: climate change impacted for an improved performance of the animals (highest improvement); ++: climate change impacted towards a better performance of the animals, putting into evidence the adaptive capacity of the animals (intermediate improvement).

(1): All species refer to bovine, ovine and caprine.

(2): Treatment refers to the strategy (e.g. nutritional, mechanical) applied to the animals during experiments to better understand the impact of heat stress and changes on performance of animals.

From the overview, Cat 3 estimates proved that the management (i.e. altered nutritional programs; mechanical, e.g. cooling) strategies applied in the experiments were useful adaptation strategies. In Appendix B statistical descriptive are presented for the different species, as well as the different impacts climate change events (e.g. heat stress) affected the performance (e.g. negatively, positively).

3. Conclusions

3.1. Conclusions from the meta-analytic study

To our knowledge, this was also the first study that classified and analysed indicators regarding direct/indirect effects on performance and animal welfare principles. Expert consultation was also used, thus considered a valid methodological approach for the CC effects on animal welfare and productivity.

According to Vlasova and Saif (2021), the growing world population (7.8 billion) exerts an increased pressure on the cattle industry amongst others. High yielding dairy cattle and their calves are more vulnerable to various diseases leading to shorter life expectancy and reduced environmental fitness. This indicates that improved understanding of cattle immune function is needed to provide optimal tools to combat the existing and future pathogens and improve food security.

From our study, insights were provided on the influence of different treatments/experiments under different climate conditions, and also for the need for adaptation strategies that may help improve animal's welfare as well as their productivity, foreseeing a need for future research on this subject.

3.2. Scientific activities of the fellowship

During the fellowship, the fellow developed the following scientific activities and awarded:

- Presentation online for the Scholar Programs webinar, organised by the Rector's delegate for Scholar Programs of the University of Foggia, on the topic 'EFSA: opportunities for PhD, Post-Doc and Senior scholars', on 22 June 2021;
- One-week Summer School course, organised by Wageningen School of Social Sciences (WASS) on the subject of 'Risk Analysis and Risk Management in Agriculture: Updates on Modelling and Applications'. Held online from 5 July 2021 until 9 July 2021;
- Abstract acceptance for presenting at the LVII Congress of Italian Society of Agrarian Economics or 'Società Italiana di Economia Agraria' (SIDEA) under the topics of 'Enterprises in between innovation, market and environment: the new frontiers of analysis of the agrarian and food companies' (L'impresa tra innovazione, mercato e ambiente: le nuove frontiere di analisi dell'impresa agraria e alimentare) from 16 to 17 September 2021, in Bologna, Italy;
- Abstract acceptance for presenting and attendance at the XXIX Congress of the Italian Society of Agro-food economics or 'Società Italian di Economia Agro-alimentare' (SIEA) under the topics of Brexit, The new Common Agricultural Policy (CAP), Covid-19: Italian agri-food restarts, from 30 September to 1 October 2021, in Verona, Italy.
- Poster presentation with this study's preliminary results to the ONE – Health, Environment, Society – Conference, 21–24 June 2022.

3.3. Conclusions from the participation in the fellowship programme

The main focus of the work programme was the development and application of a Systematic Literature Analysis and meta-analysis in order to estimate the climate change impacts on livestock welfare and productivity. The work plan provided training and knowledge on all the steps and tools required to perform a meta-analysis, taking as an example the CLimate change and Emerging risks for Food Safety (CLEFSA) project on emerging risks, in which animal health and welfare subjects are topics of interest. The fellow performed and was involved in all the activities of the meta-analysis process, from data collection, screening, extraction and analysis, establishing different scenarios of impact and future recommendations regarding adaptive strategies. The fellow had a very significant contribution during all the steps of the programme.

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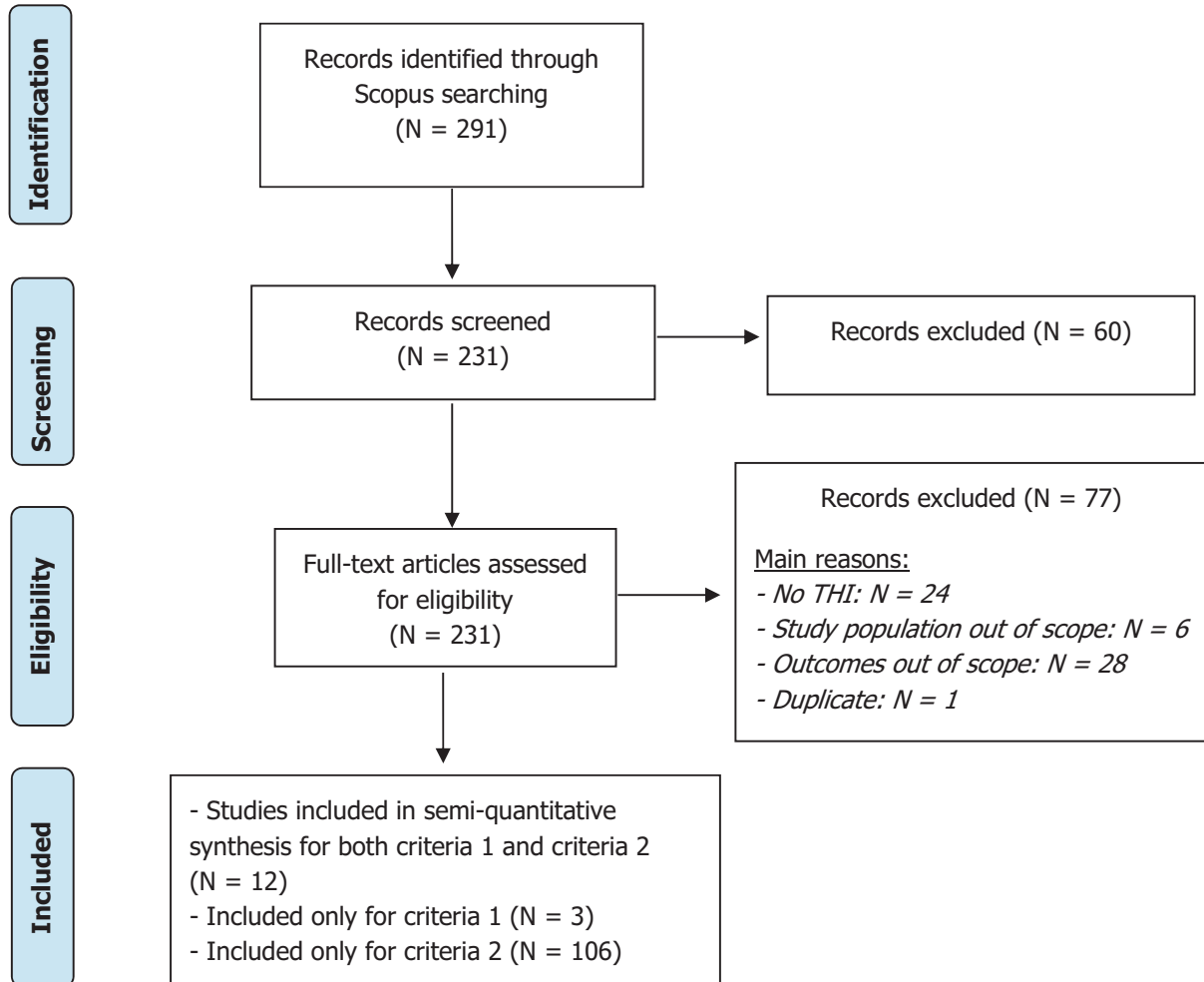
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Abbreviations

BUN	Blood Urea Nitrogen
Cat	Category
CC	Climate Change
CLEFSA	CLimate change and Emerging risks for Food Safety
HS	Heat Stress conditions
HSPs	Heat shock proteins
MRA	Meta-regression analysis
NEFA	Non-esterified Fatty Acids
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-analyses
SLR	Systematic Literature Review
THI	Temperature–Humidity index
TN	Thermoneutral conditions

Appendix A – PRISMA flow chart

A.1. PRISMA Flow chart of the search of the influence of climate change events (e.g. heat stress) on livestock welfare, health and productivity

Identification

Records identified through Scopus searching
(N = 291)

Screening

Records screened
(N = 231)

Records excluded (N = 60)

Eligibility

Full-text articles assessed for eligibility
(N = 231)

Records excluded (N = 77)

Main reasons:
- *No THI: N = 24*
- *Study population out of scope: N = 6*
- *Outcomes out of scope: N = 28*
- *Duplicate: N = 1*

Included

- Studies included in semi-quantitative synthesis for both criteria 1 and criteria 2 (N = 12)
- Included only for criteria 1 (N = 3)
- Included only for criteria 2 (N = 106)

Appendix B – Descriptive analysis of climate change effects on livestock

B.1. Descriptive analysis of the impacts of climate change events (e.g. heat stress) on livestock performance for studies that included both criteria 1 and criteria 2

Category (Cat.)	Climate change (CC)	Species	Worst performance RF[1][a]	Better performance RF[1][b]	No change RF[1][c]	NA RF[1][d]
1	Impact (control)	All species[2]	0.26	0.04	0.31	0,39
		Bovine	0.20	0.03	0.25	0.52
		Caprine	0.36	0.02	0.62	0
		Ovine	0.79	0.17	0.04	0
2	Impact (with treatment)	All species	0.15	0.02	0.34	0.49
		Bovine	0.20	0.03	0.3	0.47
		Caprine	0	0	0.55	0.45
		Ovine	0	0	0	1
3	Adaptation	All species	0.14	0.29	0.44	0.13
		Bovine	0.17	0.25	0.39	0.19
		Caprine	0.02	0.36	0.62	0
		Ovine	0.42	0.42	0.17	0

(a): Climate change effect on different animals' indicators that influence negatively the species performance (e.g. worst performance) expressed as a relative frequency (%).
(b): Climate change effect on different animals' indicators that influence positively the species performance (e.g. better performance) expressed as a relative frequency (%).
(c): No change observed on performance.
(d): Not applicable.
(1): RF stands for relative frequency (%).
(2): All species refer to bovine, ovine and caprine.