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Buffalo welfare: a literature review from 1992 to 2023 with a text mining and topic analysis approach

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ABSTRACT

Buffalo is a rustic animal; it can adapt and survive in various environments with different topography, climate and vegetation, and has a greater longevity than cattle. The high resistance to parasites, as well as the ability to improve the efficiency of feed consumption in case of forage shortage, means that even in marshy territories, where any other type of livestock or agricultural activity is impossible, buffalo farming can develop an economy. This review aims to present the key research topics, the evolution and geographic distribution of literature on buffalo welfare, and to underscore potentiality and existing knowledge gaps. A comprehensive search on the Scopus bibliometric database was carried out using various welfare-related keywords such as: 'buffalo welfare', 'buffalo calf welfare' and 'buffalo heifers' welfare'. The research identified 308 papers published in English from January 1992 to December 2023 that, after filtering, became 148 eligible records. Descriptive statistics revealed a significant exponential increase in studies on buffalo welfare since 2020, particularly in Italy, followed by Brazil. Text mining and topic analysis revealed that the most frequently mentioned terms were 'milk', 'water', 'behaviour', 'farm' and 'stun', confirming the role and the importance of this species in dairy production. Nine identified topics span diverse subject areas such as 'slaughter process', 'dairy production', 'general welfare', 'housing system', 'heat stress', 'reproduction performance', 'health status', 'breeding management', and 'stress evaluation'. Although academia shows an increasing interest in buffalo behaviour and welfare, continued research is necessary to fully comprehend how to ensure the welfare of this important species.

HIGHLIGHTS

- Overview of buffalo welfare in scientific literature
- Usage of new techniques as text mining and topic analysis for the review process
- Slaughter process and Dairy production were the most frequent topics

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Introduction

Buffalo (*Bubalus bubalis*) is the 5th species bred in the world after cows, sheep, goats and pigs with 203,939,158 heads (FAO 2023). Buffaloes are mainly reared for milk production and, globally, in 2021 buffalo milk production comes before cow's milk (15% and 81% of world milk production, respectively; FAO 2023). The buffalo population is constantly increasing in Europe, but more specifically in Italy, due to the production of a typical buffalo mozzarella cheese called 'Mozzarella di Bufala Campana PDO' exported both intra- and non-EU countries (Clal 2023). Asian

population and financial state largely rely on this species, which creates revenue for pastoral communities by giving them job security. Buffalo breeding is important for people below the poverty line and creates opportunities for small and young breeders (Mumtaz et al. 2021). Moreover, in most countries, buffaloes are not only reared for milk production but also for meat production and work (Borghese 2005, 2013), making this species globally important and this livestock sector very complex. As a result, this species is bred according to different management strategies. Indeed, in Asia and South America, buffaloes are under extensive or semi-intensive systems while in other areas of

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the world, like Italy, they are reared only intensively (Petrocchi Jasinski et al. 2023). In both management systems, an increasing interest in animal welfare is being witnessed. Initially, studies were influenced by ethical concepts and popular empathy, and then they were further influenced by economic and political interests that have grown around this topic to comply with both popular and ethical expectations (Future 2009; Lesimple 2020). Even if there is not a common definition of animal welfare, factors influencing it include resources available to the animal and physical environment, including space allocation (Napolitano et al. 2004; Salzano et al. 2019), bedding material (Chopra et al. 2022), management practices including feeding strategies (Napolitano et al. 2013; Mattiello et al. 2019) and transport plans (de la Cruz et al. 2018; Rodríguez-González et al. 2022). Environments also include thermal conditions under which animals are reared. Due to climate changes, also heat stress has become a crucial factor with detrimental effects on livestock wellbeing (Matera et al. 2022). So, it is evident that animal welfare encompasses several aspects, including the rearing, transport, and slaughter phases (EFSA 2023).

To better understand how buffalo welfare was studied in scientific literature, Text Mining (TM) and Topic Analysis (TA) techniques are used in this paper. These two analyses were performed to assess the most frequent words, their association and hidden relationship in buffalo welfare. Text mining can be defined as 'The knowledge discovery process which looks for identifying and analysing useful information on data which is interesting to users from big amounts of textual data, in order to find new structures, patterns or associations and to discover new facts and trends about the world itself' (Nalon et al. 2020). Both TM and TA are Machine Learning (ML) techniques that aim to convert unstructured text data into a structured format that can be analysed (Holzinger et al. 2014). The TM and TA allow us to analyse textual data, extract the main discussed topics and find associations between topics and words.

These two techniques have been applied to other zootechnical species like cattle, horses, camels and mountain livestock farming (Nalon et al. 2020, Zuliani et al. 2021; Benedetti et al. 2023; Masebo et al. 2023). To date, no studies have been carried out on buffaloes. That is why we deepen this field of study with the goal of learning more about the evolution of literature over the time and the most important topics in buffalo welfare.

Materials and methods

Data set

A literature search protocol using Scopus® was set up to identify the peer-reviewed scientific papers that covered the topic of 'buffalo welfare', 'buffalo calf welfare' and 'buffalo heifers' welfare'. The search was performed in February 2024 and was refined based on:

- the year of publication (from January 1992 to December 2023);
- the scientific area (Veterinary Agricultural and Biological Sciences topics);
- the article type (review and scientific article, conference papers);
- the language (English).

The first search string, 'buffalo AND welfare,' retrieved 267 records, the second search string, 'buffalo AND calf AND welfare,' retrieved 32 records and the third research string 'buffalo AND heifers' AND welfare' retrieved only 9 records. Records were collected in an electronic Excel workbook (Microsoft Excel®, v16.0). Each row represented a document while each column reported the title, authors, affiliations, abstracts, year of publication, type of record (e.g. article or review) and publication source (i.e. journal name or conference proceedings). After the collection phase, a preprocessing was needed to prepare a dataset for the final elaboration. The first step was the elimination of incomplete observations (e.g. missing abstracts, no authors, no source, or document type). The second step was to remove duplicates, since the same observation could have been included in all search strings analysed. Finally, one reviewer independently screened carefully all the records collected in the dataset and selected them for their eligibility for final inclusion. Criteria of inclusion covered buffalo welfare and behavioural science, while excluded records related to different species or topics (e.g. parasitology, infectious diseases, and molecular biology). Records considered not eligible were directly excluded. The last few records which were difficult to categorise were reviewed by a welfare expert to be either definitively included or deleted. At the end of cleaning phase, the number of records included was 148. Results of the systematic scientific literature search and the subsequent automatic and manual screening of records are represented schematically in Figure 1. The geographical affiliation for each row was selected according to the affiliation of the corresponding author, where not possible, to the first author.

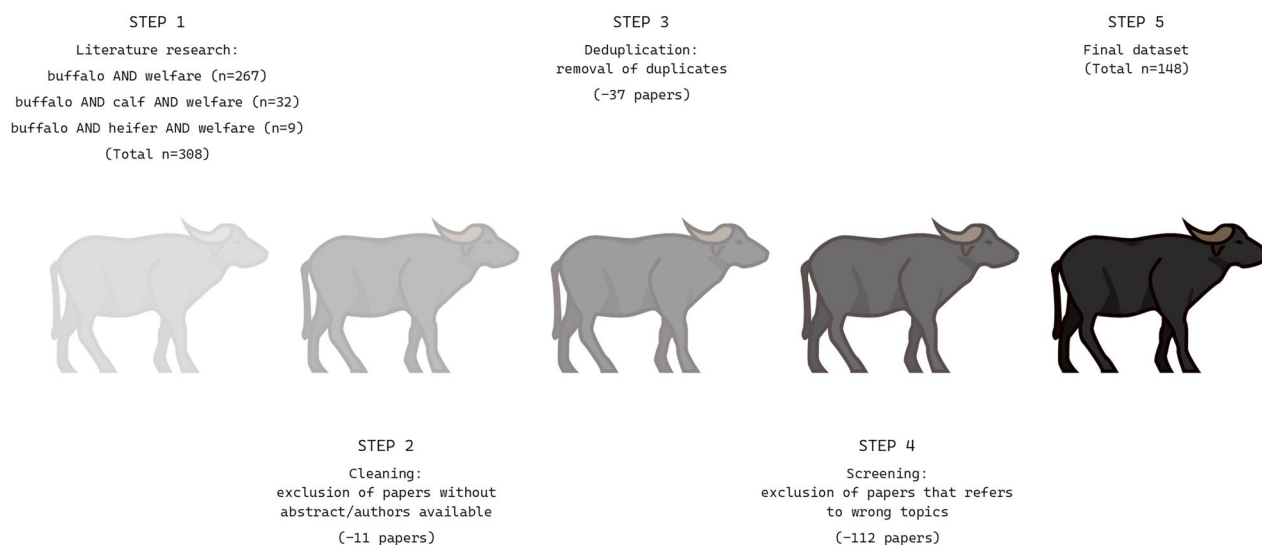


Figure 1. Preprocessing of scientific literature on raw data to obtain the final dataset. Information about exclusion is showed in the picture. Examples of not-relevant papers were infectious diseases and papers about the welfare of buffalo city (NY) population.

Some descriptive statistics were performed on the selected observations to profile the scientific corpus (i.e. authors, country of the corresponding author, title of the paper, abstract, year and journal of publication) based on information recorded from the Scopus® database. Descriptive statistics on year, country of publication and type of record were computed to profile the scientific corpus using Excel Pivot tables and graphics.

Text mining

The abstracts of collected papers were employed and arranged in a separate Excel spreadsheet which included two columns, namely 'progressive ID' and 'abstract' and prepared for the TM analysis. Starting with this, all steps were performed in R studio (RStudio Team 2022) environment using a combination of functions in the packages 'tm,' 'snowballC,' 'ggplot2,' 'dplyr' and 'tidyverse'. The corpus of records was sent to preprocessing steps according to Sebastiani (2002). Since some words in the corpus of records were spelled in both American and British English, the authors decided to standardise the corpus of documents using only British English. Different preprocessing phases are needed such as tokenization, stop-word removal and stemming-lemming process. The aim of tokenization was to convert text in meaningful parts, namely token (Uysal and Gunal 2014).

In details the steps involved for tokenization were:

- the conversion of all words in lowercase;
- the replacement of escape symbols and fonts ('@,' '/' or '*') in white space;

- the exclusion of certain characters such as punctuation, blanks and numerical digits.

The removal of 'stop words' had the aim to exclude the words that are employed in the research string or that provide irrelevant information about the content of the document common words as the articles, conjunctions and so on. In this work the following words: 'buffaloes,' 'buffalo,' 'calf,' 'welfare,' 'calves,' 'heifers,' 'heifer,' 'copyright,' 'sps,' 'aim,' 'group,' '%,' 'µg or kg,' 'vs,' 'groups,' 'significant,' 'observation,' 'observations,' 'significant,' 'significantly' were removed. The last step of the preprocessing phase was the application of stemming and lemming algorithms (Matuszewski 2023). Both the algorithms aimed to reduce words to their base or root forms and capture the core meaning of words by removing suffixes or prefixes. The main difference is that the result of the stemming may not be an actual word or may be a partial word otherwise lemming return a word based on dictionary form (Matuszewski 2023).

To deeply explore the text content, a matrix with documents along the rows and terms along the columns was built. This matrix is named Document Terms Matrix (DTM) and shows the frequency of each term in each document (Salton and Buckley 1988).

The Term Frequency – Inverse Document Frequency (TF-IDF) technique was utilised on DTM to assign a distinct weight to each term. This weight is determined by both the term's frequency within a specific document and its prevalence across the entire collection of records. This approach ensures that the

importance of each term is not only based on its frequency within a document but also considers its uniqueness and significance within the broader context of the entire dataset. A threshold of TF-IDF value greater than or equal to 1 was used to build a histogram of the most frequent words.

Moreover, a word cloud representation (<https://www.wordclouds.com/>) was employed. Bigger is the character size, higher is the TF-IDF value, hence highlighting the most recurrent words. Associations among the words that have $TF-IDF \geq 1$ were explored. Only correlations ≥ 0.5 were considered and associations were found by measuring the frequency of co-occurrence between two words. When the association value was close to 1, it showed that two words are often found together. Conversely, values near 0 are assigned when their co-occurrence is limited.

Topic analysis

The topic analysis aims to explore and understand the document content and extract meaningful information from the unstructured text data. Latent Dirichlet allocation (LDA) was chosen as the method for carrying out topic analysis on the DTM. This probabilistic model aims to unveil latent topics within a collection of documents, assuming the existence of K latent topics shared across the corpus (Srivastava and Sahami 2009). The analysis utilised functions from the R package 'topicmodels' leveraging the options of Gibbs sampling (Grün and Hornik 2011). Since the number of topics is in general not known, models with several different numbers (3, 5, 7, 9) of topics were fitted and evaluated. At the end of this process, nine topics were chosen because returned the most reasonable results, since in each topic there were more than 5% of documents. In this way, a good sample number on which performed the analysis was assured. To better visualise the topic and its most representative words, a bar histogram based on the beta values was built from this visualisation. Beta values represented the probability that words belonged to a specific topic. For each topic was found a name according to literature with a common consensus among the researchers.

As the final step, a thorough investigation into significant trends was undertaken. To accomplish this, a pivot table was constructed, capturing the frequency of each topic based on numbers of papers per year. Subsequently, an exponential function was employed to model the data and the coefficient of determination (R^2) was computed. A p -value less than 0.05 was

deemed statistically significant, indicating the presence of a meaningful trend in the data over time. At the end, the most frequent country for each topic was found.

Results

Descriptive statistics

The literature research yielded a total of 148 peer-reviewed papers. Figure 2 illustrated the temporal trend in the publication of these papers over the period spanning from 1992 to 2023. There was quite an exponential increase in the number of papers published over the time. From 1992 to 2009 the number of papers was fewer than five records per year, while from 2010 to 2023 there was an increase in annual publications, with a peak in 2023. Research articles represented the most common type of paper (76.4%; 113/148) followed by reviews (18.2%; 27/148), conference papers (3.4%; 5/148) and book chapters (2.0% 3/148).

The distribution of published papers by journal title (with at least two papers published on the topic in the period considered) was shown in Figure 3. The most representative journals were *Animals* from MDPI and *Italian Journal of Animal Science* from Taylor & Francis (21 and 10 documents, respectively). Figure 4 showed the dissemination of the 148 scientific papers across different countries and continent based on the affiliation country of corresponding author. Europe was the most productive continent in terms of papers wrote (67), followed by America and Asia (both with 34 publications) while Africa and Oceania produced less than 10. Moreover, a deeply analysis was performed to breakdown continents in countries.

Europe is mostly covered by Italy (50 documents). America was represented by two countries of South America: Brazil and Mexico (17 and 13 papers, respectively). India was the most representative country within the Asian block (13 papers). Egypt with seven papers was the only African country. Finally, Oceania produced only 6 papers.

Text mining results

After the preprocessing of the data and reduction of sparseness (i.e. exclusion of the 'rare words'), 1,517 terms were retained from the selected 148 records. Figure 5 showed the most frequent words with a weight over 1 ($TF-IDF \geq 1$). Only milk, water,

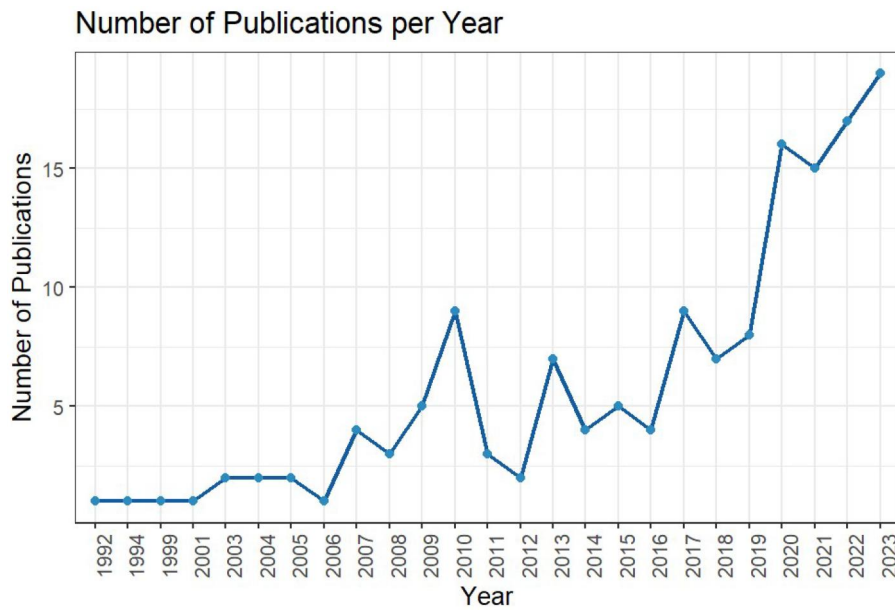


Figure 2. Peer-reviewed articles on the welfare of buffaloes published within the period 1992–2023.

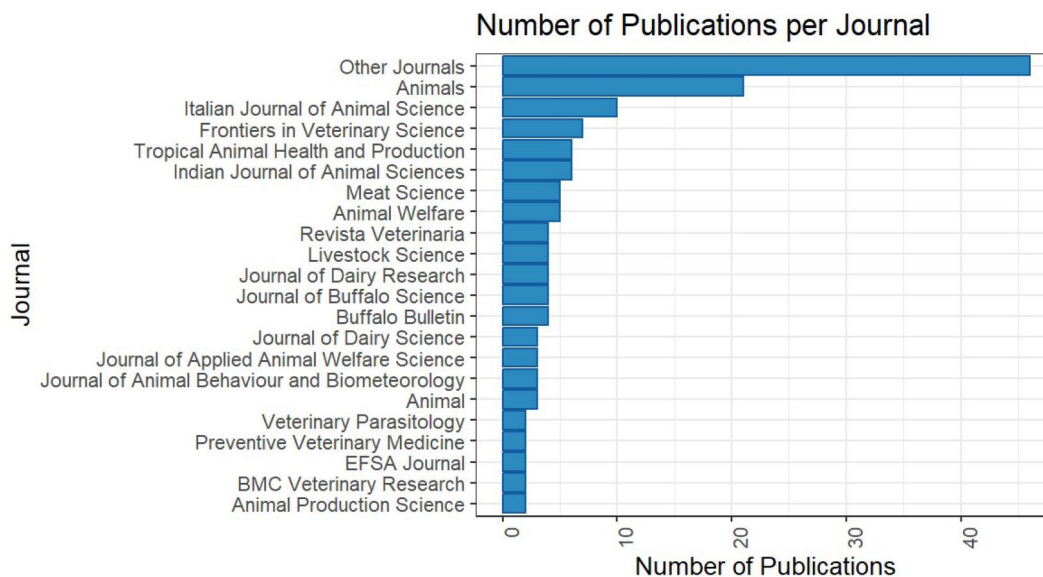


Figure 3. Distribution of published papers by journal name (with at least 2 papers published on the topic in the period considered).

behaviour and farm achieved a TD-IDF greater than 2. The other words with the highest TF-IDF were 'stun' (1.77), 'product' (1.62), 'cattl' (1.61), 'day' (1.44), 'system' (1.43) and 'strss' (1.38). A word cloud is shown in Figure 6. The size of each word mirrored its height, with the font size proportional to the TF-IDF of each word. A correlation coefficient of 0.5 was set to find the most important association between the most frequent words (with a weight ≥ 1) and the other words in the corpus. These correlations are presented in Table 1. Only significant correlations were shown.

Topic analysis results

Topic analysis returned nine topics. Coherent names were chosen based on the first 10 words and articles included in each topic. Figure 7 shows a histogram with the top 10 word for each topic. The most representative topic is topic 1 'Slaughters process' with 20 records, closely followed by topic 2, 'Dairy production,' with 18 documents. Topic 3 'General welfare' and 7 'Health status' counted 17 observations each. Topic 5 'Heat stress' and topic 9 'Stress evaluation' contained 16 records each. Finally, topic 4 'Housing system', topic 6 'Reproduction performance' and topic 8

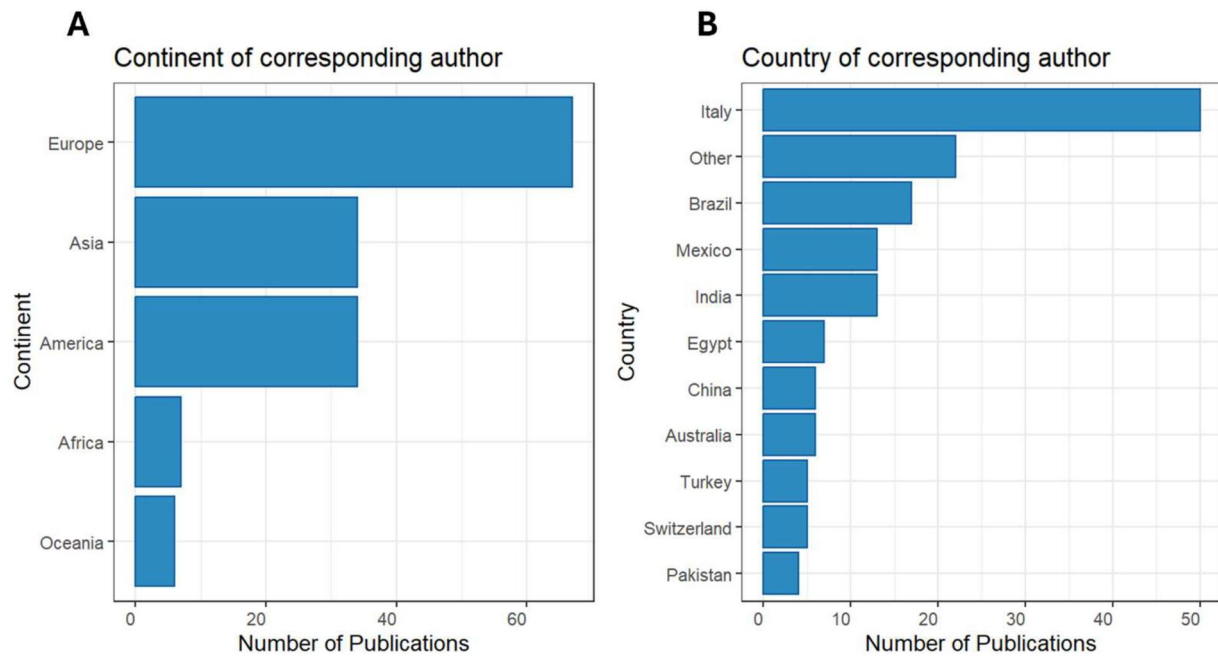


Figure 4. Graph bar depicting the distribution of the 148 scientific literature records selected for inclusion per continent (a) and country (b).

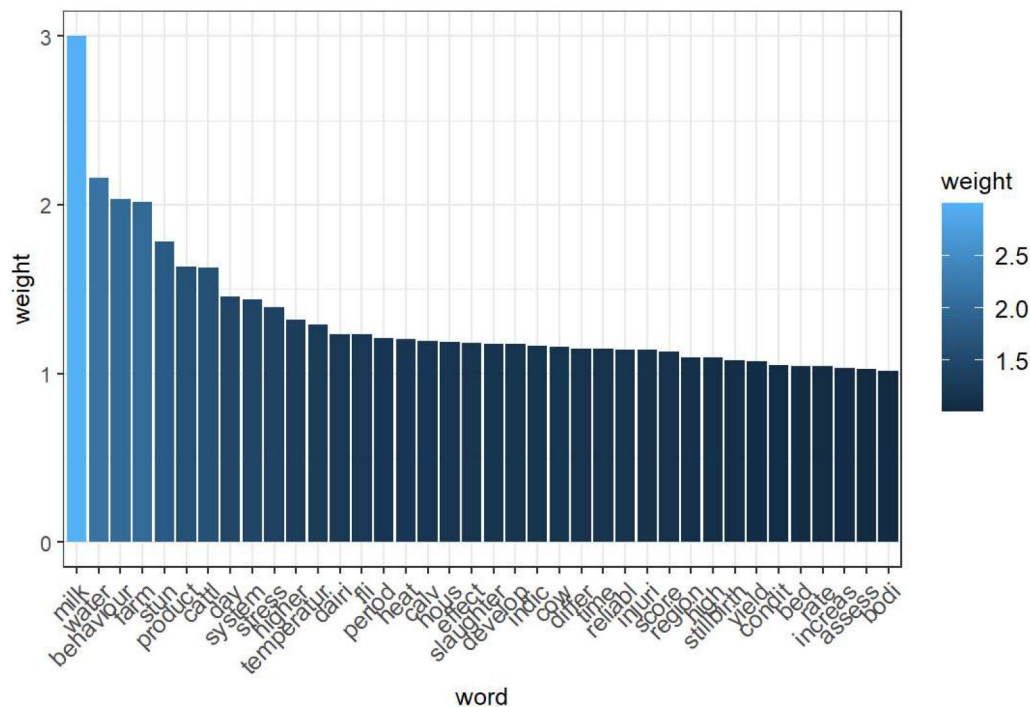


Figure 5. Histogram of the most relevant words based on their weight (TF-IDF > 1) of 148 documents selected for inclusion in the study.

'Breeding management' counted the smaller number of papers (15–14–15, respectively). A trend analysis was carried out to assess the topic tendency from 1992 to 2023. Topic 8 registered publications since 1992, while topics 2, 6, 7 and 9 were the most current topics, their first papers were published since 2010–2011 and increased in the last years. Topics 1, 2, 5, 6,

7, 8 and 9 showed a positive trend over time. Moreover, the trend of topics 1 and 9 was also significant ($p < 0.05$). Topic 3 and 4 slightly decreased during the considering period. For topic 2, 3, 4, 8 and 9, Italy represented the country with more papers published. Brazil counted more papers than other countries only for topic 5. Topics 1, 6 and 7 did not

Table 1. Correlation about the most frequent words (TF-IDF ≥ 1) and the other words present in the documents analysed.

Word (TF-IDF ≥ 1)	Associate words (correlation ≥ 0.5)
Asses	Qualit (0.53)
Bed	Mat (0.79) – Adg (0.76) – Straw (0.76) – Viz (0.76) – Rubber (0.74) – Floor (0.72) – Concret (0.70) – Cost (0.69) – Height (0.65) – Nonsignific (0.60) – Wither (0.53) – Manur (0.51)
Behaviour	Kick (0.53)
Bodi	Ovalbumin (0.60) – Outstretch (0.57) – Phytohemagglutinin (0.57) – Surfac (0.57) – Neither (0.56) – Height (0.55) – Mat (0.50)
Calv	Uterin (0.59) – Predict (0.56)
Cow	Nuzzl (0.53) – Snif (0.53) – Pool (0.51)
Day	Separ (0.51)
Farm	Discrimin (0.53)
Fli	Treat (0.79) – Hind (0.75) – Non treat (0.75) – Leg (0.57) – Count (0.56) – Lesion (0.51) – Northern (0.51)
Heat	Optimum (0.62) – Form (0.59) – Global (0.55) – Insid (0.54) – Outsid (0.51) – Winter (0.51)
Hous	Loos (0.89) – Util (0.84) – Januari (0.82) – Convent (0.80) – India (0.69) – Lamé (0.67) – August (0.62) – Cleanli (0.62) – Greater (0.61) – State (0.54) – Station (0.54)
Indic	Feasibl (0.69) – Valid (0.65) – Meaning (0.60) – Money (0.60) – Tendenc (0.60) – Thin (0.60) – Animal human (0.57) – Oral (0.57) – BCS (0.53) – Aggress (0.52)
Injury	Rub (0.87) – Ulcer (0.85) – Lacer (0.84) – Nostril (0.66) – Haryana (0.62) – Bangladesh (0.57) – Plus (0.57) – Swell (0.57) – Tail (0.55) – Tear (0.51) – Almost (0.51)
Period	Swim (0.58) – Eight (0.53)
Rate	Flow (0.70) – Sprinkler (0.68) – Groundwat (0.64) – Replic (0.61) – Eighteen (0.58) – Latin (0.58) – Combat (0.56) – Pakistan (0.53)
Region	Window (0.84) – Regio (0.82) – Nasali (0.75) – Orbitali (0.75) – Abdomin (0.62) – Special (0.57) – Short (0.55) – Nasal (0.52) – Limb (0.50) – Orbit (0.50)
Reliable	Feasibl (0.70) – Qualit (0.52) – Valid (0.52) – Coeffici (0.51)
Score	Loos (0.68) – Lamé (0.66) – Util (0.64) – Januari (0.63) – Convent (0.61) – Cleanli (0.56) – India (0.52)
Slaughter	Arriv (0.60) – Slaughterhous (0.56) – Arteri (0.51) – Carotid (0.51) – Link (0.51) – Pain (0.51) – Cut (0.50)
Stillbirth	Gestat (0.99) – Birth (0.80) – Egyptian (0.70) – Cross (0.68) – Length (0.66) – Threshold (0.65) – Born (0.62) – Contrarili (0.58) – Multipar (0.58) – Sas (0.56) – Impli (0.51) – Italian (0.51)
Stun	Frontal (0.83) – Bolt (0.72) – Captiv (0.68) – Skull (0.65) – Pneumat (0.63) – Psi (0.63) – Anatom (0.59) – Shot (0.56) – Collaps (0.51)
Temperature	Rectal (0.77) – Index (0.75) – Humid (0.72) – Koppen (0.61) – Distinct (0.59) – Flank (0.59) – Respiratori (0.57) – Variat (0.55) – Maximum (0.53) – Thermal (0.52) – Throughout (0.51) – Bst (0.50)
Yield	Stranger (0.56)

breeding, starting with the creation of the PDO Cheese Mozzarella di Bufala Campana in 1996 and of its own breed, the Italian Mediterranean Buffalo, in 2000. In these last three decades, buffalo farming underwent several changes in Italy, moving from traditional extensive housing techniques, based on the use of marshland environments, to intensive system, previously developed for dairy cattle. The lack of grazing areas and water for wallowing had a negative impact on buffalo behaviour and welfare (De Rosa et al. 2009) and probably for this reason, various studies have been performed to allow the expression of these behaviours and enhance animal productivity. Indeed, buffalo farming in Italy is still growing, has a thriving market and is one of the most technologically advanced in the world with brand new technologies such as (i) automated milking systems to measure milk quantity and quality, (ii) automatic feeders able to give the precise amount of feed required, (iii) wearable or environmental sensors to monitor animal

health and wellbeing (Berckmans 2014). These systems have allowed scientists, technicians and breeders to control all aspects of the herd, including, of course, animal welfare.

Following Italy, the second country was Brazil, where about 1.6 million buffaloes are bred (FAO 2023), mainly extensively compared to Italy. Moreover, in Brazil were reared different breeds, such as Murrah or Jafarabadi, with slightly different attitudes, behaviour and characteristics compared to the Italian Mediterranean Buffalo (Andrade et al. 2023).

Even if buffaloes are mainly bred in Asia (97,2%); (FAOSTAT 2019), only 34 papers have been published by Asian authors, often performed within international research projects or collaborations (Wang et al. 2022). Probably, researchers working in more advanced countries or research centres with a long history of recognised scientific expertise often play important roles in coordinating or directing international projects, which may explain why, based on the address of the

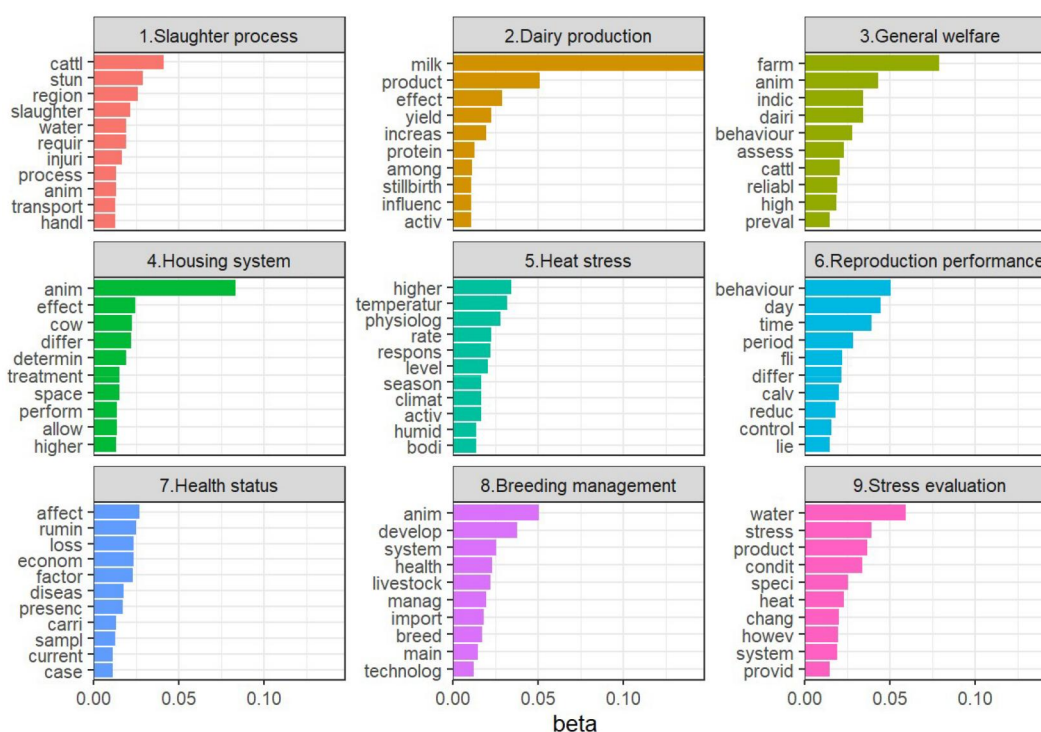


Figure 7. Result of topic analysis. For each topic the 10 most frequent words were shown. Some topics had more than 10 words because of the same beta value. Beta denoted the relative probability of each term belonging to that topic.

Table 2. Name of each topic, number of publications per topic, R^2 , p-value, country of prevalence and year of the first publications. The signs (+ or -) near the R^2 denoted a positive or negative trend.

Topic	Number and percentage of publications per topic	R^2 and trend direction	p-value	Country	Year of first publication
1. Slaughters process	20 (13.51 %)	0.523 +	0.01	–	2001
2. Dairy production	18 (12.16 %)	0.122 +	0.70	Italy	2010
3. General welfare	17 (11.49 %)	0.006 ±	0.88	Italy	2003
4. Housing system	15 (10.14 %)	0.041 –	0.53	Italy	1999
5. Heat stress	16 (10.81 %)	0.001 +	0.80	Brazil	2009
6. Reproduction performance	14 (9.46 %)	0.278 +	0.20	–	2011
7. Health status	17 (11.49 %)	0.025 +	0.54	–	2014
8. Breeding management	15 (10.14 %)	0.195 +	0.15	Italy	1992
9. Stress evaluation	16 (10.81 %)	0.679 +	0.01	Italy	2011

corresponding authors, Asia is not the first or the second continent publishing on buffalo welfare. However, buffaloes are a major global livestock of economic and social importance mainly in developing than in developed countries (Deb et al. 2016). According to our results, the first three most frequent words with the highest TF-IDF were ‘milk’, ‘water’ and ‘behaviour’. This is not surprising since buffalo milk and mozzarella cheese are famous and widespread all over the world (Ranucci et al. 2016). Buffalo milk has unique characteristics such as a higher energy content and lower cholesterol than bovine milk, it is very rich in calcium, magnesium, phosphorus, potassium, and zinc (Evangelista et al. 2022) and hence has the potential to have a major influence on nutrition and global health. Moreover, the meat and milk of buffaloes have distinct health-promoting properties compared with

other livestock such as cattle. The milk of Mediterranean buffaloes has more conjugated linoleic acid (Pegolo et al. 2017) and more health-promoting biomolecules than bovine milk (Servillo et al. 2018), that can be improved by working on welfare and feed management (Salzano et al. 2019, 2023). The second term was ‘water’, a precious alliance of buffalo welfare. Indeed, particularly in Italy, the farming intensification and the need to improve milk hygiene have reduced the number of pools or ponds, replacing them with spray systems. However, it has been shown that providing a housing system enriched with potholes and spontaneous vegetation, thus closer to natural conditions, improved the welfare and hence production of buffalo cows (De Rosa et al. 2009). Moreover, a reduced calving interval and a higher conception rate were observed in animals provided with a pool (Di

Palo et al. 2001). Therefore, for on-farm buffalo welfare, monitoring the provision of systems aiming at alleviating heat stress, particularly those allowing the expression of natural thermoregulatory behaviour, should be positively considered.

'Behaviour' was the third term associated with buffalo wellbeing (De Rosa et al. 2005). It was a term often associated with animal welfare in general, since we can find them in several species such as camels, horses, and others (Adamakopoulou et al. 2023; Benedetti et al. 2023; Masebo et al. 2023). Most of the documents found in this study analysed buffalo behaviours to get information about the health and welfare status of animals in intensive and extensive systems (Napolitano et al. 2013), under different climatic conditions and fed with different diets (Masucci et al. 2016). The evaluation of buffalo behaviour is typically based on the time spent on specific activities such as rumination, feeding, standing, etc., throughout the day. These methods provided valuable information for farmers, technicians, and veterinarians, allowing them to understand the typical time-budget of buffaloes and their response to external factors such as different housing systems (Napolitano et al. 2004) or feed management (Masucci et al. 2016). Moreover, knowing the normal behaviour of buffaloes may help technicians to timely understand anomalies. For example, Lanzoni et al. (2022) described the pre-calving behavioural pattern of heifers approaching calving. The term 'behaviour', hence, grouped all documents that studied systems and protocols to evaluate the welfare of animals through the analysis of behaviours (De Rosa et al. 2005). Animal welfare should not be simply limited to the animal's functioning and performance, but should also include the normal expression of species-specific behaviours such as wallowing and grazing (Tripaldi et al. 2004; De Rosa et al. 2009).

Topic 1 collected all the 'Slaughter procedures'. The topic gathered articles spaced all over the animal supply chain from the farm gate to slaughter (loading/unloading, markets, transportation, handling, lairage, stunning and slaughter). This topic highlighted how handling practices used to load and unload buffaloes and the transport phases to slaughterhouses are often difficult (Chandra and Das 2001; Gregory 2008) and animals may experience stress caused particularly by hot temperatures due to overstocking or inadequate ventilation (de la Cruz et al. 2018). In developing countries, buffaloes are not as calm as cattle, and this may create problems and overstress during handling, increased skin lesions and bruises to carcasses due to human interventions. This theme is also highlighted

by the presence of the word 'injury' which presented strong associations with the words 'ulcer' (0.85) and 'lacer' (0.84). Moreover, at the slaughterhouses the equipment is usually designed principally for cattle (Gascho et al. 2022) and the differences in some anatomical features may cause some problems during stunning (Ahsan et al. 2014), where present. The analyses of this topic shed light on several limitations of procedures, stunning positions and appropriate devices during the slaughter process that should be implemented as soon as possible to improve the general conditions of the animals, together with proper legislation.

The second was about 'Dairy production'. Most articles related to this topic were mostly from Italy. They have focused not so much on milk yield but on the behaviour of the animals during milking. Welfare during milking was analysed in the presence of unfamiliar people (Vanderly Andrea et al. 2015; Napolitano et al. 2019) and the parameters recorded were, i.e. milking period, rumination, defaecation, urination, kicking, reactivity, and temperament. This shows that even if the animals are reared for milk production, the welfare and behavioural component are particularly important.

The third topic was named 'General welfare' and has shown a slight negative trend over the years. This could be explained by the growing attention not only by experts/insiders but also by citizens on animal welfare, who have become more sectorized and specific. In this topic, the main papers covered generic evaluation of buffalo welfare in dairy farms considering different indexes such as body condition score (BCS), behaviours and cleanliness (De Rosa et al. 2009). Indeed, the lemming-stemming word 'indic' is reported and is found with 'BCS' (0.53). Moreover, the association between 'animal-human' (0.57) and 'aggress' (0.52) denoted that the relationship between buffaloes and farmers is an important way to evaluate welfare. It is possible that those papers contributed to build more modern and complex welfare protocols such as Classyfarm, or new animal-friendly legislations (Bonafos et al. 2010).

Topics 4 and 8 are the oldest ones, starting from 1992 and 1999 and were named 'Housing system' and 'Breeding management', respectively. In particular, in topic 4, the main themes covered were bedding materials and flooring (Sorathiya et al. 2019; Chopra et al. 2022) and space allowance (Napolitano et al. 2004; Masucci et al. 2016; El Sabry and Almasri 2022). Topic 8 has 15 articles and the trend is still positive, confirming the importance of breeding management. Most of

the articles come from Italy, where the transition from an extensive to an intensive breeding system, with all the problems linked to ensure a proper animal welfare, occurred.

One of the recent topics and one of the most important nowadays is Topic 5 'Heat stress'. It counts 16 articles and more than 60% were published after 2015. Climate change on planet Earth is causing increased temperature and more extreme events. Due to their inability to efficiently dissipate their body heat, elevated temperatures can cause severe discomfort for farm animals, and they have developed mechanisms to decrease the production of endogenous heat (reducing feed intake and production). The production and quality of milk, reproduction, and health are negatively affected by heat stress in tropical and subtropical countries where buffalo breeding is common. Improving buffalo thermotolerance can be achieved by using a genetic approach to counteract heat stress, but it's a lengthy process even though it's essential. Other ways to mitigate include nutritional strategies, like vitamin, mineral, and antioxidant consumption, and cooling strategies like shade, fans, sprinklers, and pools. If wallowing is unavailable, a combination of fans and sprinklers are good strategies for cooling the animals, and while wallowing was the best for improving production and reproduction performance and general welfare of animals, the use of cooling alternatives is still a good strategy (Petrocchi Jasinski et al. 2023). Indeed, some articles are precisely related to cooling strategies (Ahmad et al. 2019; Bah et al. 2021, 2022), i.e. the use of sprinklers, fans and shadows. Others are related to non-invasive techniques to measure temperature like infra-red thermography (Barros et al. 2016; Mota-Rojas et al. 2021). Between most frequent words, we can find 'climat' and 'temperatur'. Obviously, the latter word is associated with 'humid' and 'index' (0.72 and 0.75 respectively) due to the development and large use of temperature-humidity index (THI) as a bio-climatic indicator of heat stress. Another curious association is between 'temperatur' and 'Koppen' (0.61) a climate classification widely used.

Topic 6 was about 'Reproductive performance' and as with all farm animals, without reproduction there is no production. Articles related to this topic are inherent to pregnancy (Di Palo et al. 2009), calving (Lanzoni et al. 2022), weaning process (Kamboj and Kumar 2013; de la Cruz-Cruz et al. 2019) and mother-young bonding (Lanzoni et al. 2021, Orihuela et al. 2021). The first article concerning this topic appeared in 2011 but the majority were published in the last six years,

showing that attention to reproductive performance is a newborn issue that probably will increase its numerosness in the future. Moreover, between the most frequent words and their associations there are 'calv' and 'control' confirming a real interesting about these themes.

The seventh topic was 'Health status', confirming the role of health in maintaining animal welfare. Most of the articles focused their attention on some painful conditions such as castration (Guerra et al. 2021; Martins et al. 2011), mastitis (Malik and Verma 2017) rumenostomy (Teixeira et al. 2014) or parasite infections (D'Angelo et al. 2022; Naseem et al. 2022) that may affect the wellbeing of buffaloes. Castration is a common practice, and the papers focused their attention on the castration technique that has the minimum impact on buffalo welfare. For example, Guerra et al. (2021) introduced a protocol involving the administration of two distinct intramuscular doses of xylazine for premedication, followed by ketamine induction, in water buffalo calves undergoing isoflurane maintenance anaesthesia for routine castration surgery. Papers related to the impact of fly infestation showed that mosquitoes represented a problem, especially for buffaloes bred in extensive areas (Yadav et al. 2017). The word 'fli' presented an association with leg and lesion of 0.57 and 0.51, respectively, confirming the damage of these insects in farms.

Finally, the stemming-lemming words 'econom' and 'loss' gained a high beta value in Topic 7. This is an important issue since economic loss is an essential key point and is often a consequence of diseases and infections by parasites. Finally, Topic 9 'Stress evaluation' included all the papers with a scientific focus on buffalo behaviour in several stressful situations according to age (Orihuela et al. 2020; Toro et al. 2023) feeding responses (Wankar and Rindhe 2021; Neglia et al. 2023) and climatic conditions (Yáñez-Pizaña et al. 2020; Galloso-Hernández et al. 2021).

This study has some limitations due to the method used such as the use of synonymous during the first research on the Scopus® Database or the use of only Elsevier Database and not others such as Mendeley or Google Scholar or the so-called 'grey literature'. This kind of research may have reduced the number of papers recorded in our database. Another limitation could be due to the language of the data used (only English) or the choice to use only papers in which the abstract was available. For these reasons, out of 308 articles, we ended up with only 148 but we do hope for the most informative ones. Notwithstanding the limitations, this review analysed the literature related

to buffalo welfare, identifying the leading topics of buffalo scientific research and the ones that need more scientific-based evidence.

Conclusion

Most topics like 'Slaughters process', 'Breeding management', 'Dairy production', 'Heat stress' and 'Reproduction performance' are recent and are growing, showing a new interest in these issues. In addition, topics and most frequent words highlighted that animal welfare can be analysed under various aspects of buffalo supply chain. Even if this review includes only 148 articles, a well separated approach can be seen. Certainly, more studies are needed to deepen all these aspects of buffalo welfare, to have a more complete and solid scientific literature.

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The authors report there are no competing interests to declare.

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Data availability statement

Data will be shared on request.

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