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ENVIRONMENTAL PRACTICES USED IN BUFFALO MILK PRODUCTION: AN OVERVIEW OF STUDIES

PRÁTICAS AMBIENTAIS UTILIZADAS NA PRODUÇÃO DE LEITE DE BÚFALA: UMA VISÃO GERAL DOS ESTUDOS

PRÁCTICAS AMBIENTALES UTILIZADAS EN LA PRODUCCIÓN DE LECHE DE BÚFALO: UNA RESEÑA DE LOS ESTUDIOS

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ABSTRACT

Buffalo is the main supplier of milk in several countries. Due to the growing demand for food, the production and consumption of buffalo milk, as well as its dairy derivatives, have driven the exploration of this activity worldwide. However, the environmental impacts resulting from the activity are undeniable and have driven the search for more sustainable production methods and directed efforts in this direction. The study in question carried out a survey of work related to environmental practices used in buffalo production. A preliminary survey identified 463 studies for the keywords used, of which only 8% contained an environmental approach, including the Life Cycle Assessment (LCA) methodology, key tools for assessing environmental sustainability. The identified works evaluated, in addition to GHG emissions and their association with global warming potential, other impacts, such as abiotic depletion, acidification and eutrophication of waters. The results found demonstrate the contemporary nature of the topic. However, it is worth highlighting that there have been few studies carried out so far and, therefore, it is an opportune field of study for development of research, as sustainable measures are increasingly required in the various agricultural segments.

RESUMO

Buffalo é o principal fornecedor de leite em vários países. *Devido à crescente demanda por alimentos de alta qualidade, a produção e o consumo de leite de búfala, bem como de seus derivados lácteos, têm impulsionado a exploração desta atividade em todo o mundo. No entanto, os impactos ambientais decorrentes da atividade são inegáveis e têm impulsionado a busca por métodos de produção mais sustentáveis e direcionado esforços nesse sentido. O estudo em questão realizou um levantamento de trabalhos relacionados às práticas ambientais utilizadas na produção de búfalos e às metodologias de Gestão Ambiental. Um levantamento preliminar identificou 463 estudos para as palavras-chave utilizadas, dos quais apenas 8% continham uma abordagem ambiental, incluindo a metodologia de Avaliação do Ciclo de Vida (ACV), ferramenta-chave para avaliar a sustentabilidade ambiental. Os trabalhos identificados avaliaram, além das emissões de GEE e sua associação com o potencial de aquecimento global, outros impactos, como esgotamento abiótico, acidificação e eutrofização das águas. Os resultados encontrados demonstram a contemporaneidade do tema. Porém, vale destacar que poucos estudos foram realizados até o momento e, portanto, é um campo de estudo oportuno para desenvolvimento de pesquisas, visto que medidas sustentáveis são cada vez mais exigidas nos diversos segmentos agrícolas.*

RESUMEN

El ganado bufalino es el principal proveedor de leche en varios países. Debido a la creciente demanda de alimentos de alta calidad, la producción y consumo de leche de búfala, así como sus derivados lácteos, han impulsado la exploración de esta actividad en todo el mundo. Sin embargo, los impactos ambientales derivados de la actividad son innegables y han impulsado la búsqueda de métodos de producción más sostenibles, dirigiendo los esfuerzos en esta dirección. El estudio en cuestión realizó un levantamiento de trabajos relacionados con las prácticas ambientales utilizadas en la producción bufalina. Una encuesta preliminar identificó 463 estudios según las palabras clave utilizadas, de los cuales sólo el 8% contenía un enfoque ambiental, incluida la metodología de Análisis de Ciclo de Vida (ACV), una herramienta clave para evaluar la sostenibilidad ambiental. Los trabajos identificados evaluaron, además de las emisiones de GEI y su asociación con el potencial de calentamiento global, otros impactos, como el agotamiento abiótico, la acidificación y la eutrofización de las aguas. Los resultados encontrados demuestran la actualidad del tema. Sin embargo, cabe resaltar que hasta la fecha se han realizado pocos estudios y, por lo tanto, es un campo de estudio oportuno para desarrollo de investigaciones, ya que cada vez se requieren medidas sustentables en los diferentes segmentos agropecuarios.

INTRODUCTION

Milk has played a fundamental role throughout the development of human civilization, providing most essential nutrients in relevant quantities. It is also the most versatile of all food products, being considered an almost complete food for the human diet (Khedkar et al., 2016).

Among the milk-producing species, the buffalo (*Bubalus bubalis*) has been gaining more and more space in the livestock sector, due to the greater industrial performance of milk and the greater added value of dairy products (Bernardes, 2007). After bovine milk, buffalo milk is the second most produced, corresponding to more than 15% of world production (FAO, 2022) and, due to its high fat content (which can vary from 6 to 8.5%), it has preference over cow's milk in some regions of the world (FAO, 2013).

With the global increase in demand for high-quality proteins, an important aspect that accompanies the growth of the sector is related to the need to reduce the environmental impacts of milk production on the farm. Although livestock farming has developed by adopting more modern production methods and continuous improvements in efficiency, technological advancement and adoption of best practices (FAO and GDP, 2018; Chirone et al., 2022), milk production is at the center of many environmental challenges and addressing this important issue requires solutions that address how the livestock sector grows to meet growing demand.

Although the sector contributes significantly to the economy, livestock farming is a concern, as it is one of the most significant contributors to various environmental problems, both locally and globally. Furthermore, livestock production requires a large amount of resources and generates a large volume of greenhouse gases (GHG), through the animals' enteric emissions (Pirlo et. al, 2014).

Different strategies can contribute to a comprehensive approach to environmental management and identification, assessment and administration of impacts (Soares et al., 2021). Among the available instruments, Life Cycle Assessment (LCA) stands out, due to the possibility of evaluating the potential environmental impact of products and as an important method for scientific investigations and support for decision makers (Herrero et al., 2020; Visentin et al., 2020).

LCA addresses environmental aspects and potential environmental impacts throughout the life cycle of a product, from raw material acquisition to production, use, end-of-life treatment, recycling and final disposal and is carried out in four phases of in accordance with ISO 14040-44 standardization standards: (i) Definition of objective and scope, (ii) Life cycle inventory analysis (LCI), (iii) Life Cycle Impact Assessment (LCIA), and (iv) Interpretation of Results (ISO 2006a, 2006b).

In this sense, the study in question carried out a survey of work related to environmental practices used in buffalo production and the Environmental Management methodologies to evaluate the interactions between production and the environment, the interferences and impacts caused.

METHODOLOGY

A systematic search was carried out, with the aim of finding studies that address methodologies for evaluating the environmental impacts of buffalo production, with a greater focus on LCA studies. To carry out this, the Web of Science, Scopus and SciELO databases were used (https://apps.webofknowledge.com/; https://www.scopus.com/search/form.uri; http://search.scielo.org/?lang=pt), between October and November 2023.

For the search, keywords were selected based on concepts related to the research objective, these being "Life Cycle Assessment", "LCA", "Environmental Impact", "Carbon Footprint", "Clean Production", "Environmental management" and "Methane emissions", used one by one, and related to the words "Buffalo", "Bubalus Bubalis" and "Buffaloes", using the logical AND operator. In addition to the search in English, the same keywords were used in Spanish and Portuguese.

In order to select only results consistent with the research objective, they were examined by title and abstract. Studies related to buffalo production that had an environmental approach were selected, those that did not fit this criterion or were just repetitions were disregarded.

Among the studies that have some environmental approach, those that use LCA were highlighted. These, in turn, were analyzed regarding the characteristics of the system and/or product studied, functional unit, methodology used, categories of environmental impacts considered, geographic areas of study development, main environmental loads identified, and the limitations reported.

RESULTS AND DISCUSSION

Overview of LCA Studies

Initially, 463 results were obtained for the keywords used, of which 8% had some environmental approach aimed at buffalo livestock, which can be grouped into works related to: study of enteric emissions and carbon footprint (Pirlo et al., 2014a; Garg et al., 2016; Pordhiy & Gautam, 2023); valorization of byproducts of buffalo milk (Pantoja et al. 2022); environmental management methods (including LCA); nutritional care, among others. For the keywords in Portuguese and Spanish, no results were found compatible with the objectives of this work.

The studies that evaluate the impacts of buffalo milk production from a life cycle assessment perspective and main characteristics of the articles are described in Table I, emphasizing the objective of the study, the sample/geographical scale and the highlighted conclusions.

Table I. Summary of LCA studies of buffalo products

Author	Objective of the study	Sample/ Geographical Scale	Conclusions Featured
Pirlo et al. (2014a)	They assessed the carbon footprint of buffalo milk through a simplified life cycle assessment.	Six buffalo farms/ Italian Mediterranean.	The intensive production system required a large amount of purchased food, chemical fertilizers and fossil fuels. The estimated carbon footprint was 3.75 kg CO2eq per 1 kg of FPCM.
Pirlo et al. (2014b)	They quantified the environmental impact of milk production from Italian Mediterranean buffaloes and highlighted the characteristics	Six buffalo farms from the Italian Mediterranean.	The farm's activities presented different contributions to the impact categories considered (global warming, abiotic depletion, photochemical ozone formation, acidification and eutrophication). The study showed that

	of the farm that mainly affect its environmental performance.		there is a wide margin for improvement; increasing milk productivity and optimizing the use of feed are mainly highlighted.
Garg et al. (2016)	Explored the carbon footprint of milk production under the multifunctional system	60 small dairy farms in 12 geographically distinct villages in Western India.	The average carbon footprint (CF) of cow's milk was 2.3, 1.9 and 2.0 kg CO2-eq/kg FPCM on mass allocation, economic and digestibility bases, respectively, while for buffalo, CF milk was 3.0, 2.5 and 2.7 kg CO2-eq/kg FPCM, respectively.
Sábia et al. (2018)	They assessed the environmental effects of dairy buffalo farming affected by two different heifer farming systems (free range and confinement), using the Life Cycle Assessment approach.	An Italian farm dairy (primary data collected from heifers housed in confinement and on a natural Mediterranean pasture).	The buffalo farming system in confinement presented a reduction in impact compared to the Caipira (free-range) system in terms of Climate Change (9%), Terrestrial Acidification (10%), Marine Eutrophication (6%) and Water Depletion (11%), and was higher in terms of Agricultural Land Occupation (7%). Thus, conducting part of the dairy buffalo farming on natural pastures allowed the reduction of several sources of pollution and cost reduction.
Soares et al. (2019)	Evaluated the effect of intensifying feeding strategies on environmental impacts in different scenarios of animal management and buffalo milk production (Baseline system - BS, S1, S2, S3, S4, S5 and S6).	A farm in the south-central mesoregion of Bahia, Brazil.	The extensive, baseline scenario (BS) was the most impactful in the category's climate change, land use and water consumption, among all scenarios. The intensive scenarios S5 and S6 were the most impactful in the categories of terrestrial acidification, freshwater eutrophication and scarcity of fossil resources.
Alves et al. (2019)	Investigated the environmental performance of the production of 1 kg organic mozzarella cheese, carrying out an assessment of the attributional life cycle from start to finish.	An extensive organic buffalo milk production farm (farm stage) and a dairy industry (dairy factory stage), located in the south-central mesoregion of Bahia, Brazil.	The upstream process related to the production of organic buffalo milk was the one that contributed most to the category of impact of climate change on the cheese life cycle. Electricity and water consumption were those that most contributed to the impacts at the dairy factory level.
Berlese et al. (2019)	They evaluated the environmental impacts of the buffalo mozzarella cheese production chain and, through sensitivity analyses, the fattening of calves and the diversification of dairy production as strategies for mitigating environmental impacts.	Six farms specializing in the production of buffalo milk and a dairy plant processament, both located in Northeast Italy.	The environmental impact of 1 kg of packaged buffalo mozzarella cheese, considering the proposed scenarios and depending on the allocation method adopted, ranged from 29 to 34 kg CO2-eq for GWP, from 211 to 248 g SO2-eq for ACP and from 53 at 62 g PO43 eq for EUP. The results also show that a large part of GHG emissions derive from emissions from buffalo milk. Thus, mitigation strategies must be addressed especially at the farm level.
Chirone et al. (2022)	Assessed the environmental impacts of buffalo milk production using the Life Cycle Assessment Approach.	Three farms in southern Italy, covering a wide range of conditions, including organic farming.	Greenhouse gas emissions ranged from 1.5 to 2.5 kgCO2eq per kg of energy-corrected milk. The comparative analysis showed that no farm outperformed the other across the entire spectrum of categories and that buffalo dairy productivity is a key aspect of each farm's environmental performance.
Bragaglio et al. (2022)	They compared the sustainability of two dairy buffalo production systems, according to the methodological principles of life cycle assessment (LCA).	Five farms dairy with feeding based in corn silage (CS) and five intensive farms with feeding plans based on non-corn silage (NCS), all located in southern Italy.	The corn silage (CS)-based system had lower impacts than the corn silage-free system (SNC) for the potential impact categories of acidification and eutrophication. This was probably due to the high average dry matter productivity per hectare of corn silage.
Pordhiy & Gautam (2023)	Compared the carbon footprint of buffalo milk using the Life Cycle Assessment approach.	75 small farms and two organized buffalo farms in Hisar district of Haryana, India.	The average carbon footprint of milk produced by small rural farmers was 3.54 kg CO2 equivalent/L of milk and that organized farms was the 4.53 kg CO2 equivalent/L of milk.

Source: Authors (2024)

Among the results, 10 studies were detected that use the LCA methodology to identify the environmental impacts of buffalo farming. The majority of studies were carried out with dairy farms located in Italy (6 studies), followed by Brazil and India, each with two studies. The largest number of studies found in Italy are related to its long tradition of dairy production. Furthermore, the production of milk and its derivatives plays a significant role in the country's agriculture and food industry. In relation to India, the country stands out as the largest producer, being responsible for approximately 51% of all buffalo milk produced in the world (Arora & Khetra, 2017). This position in the ranking of the wold production explains the publications on the subject.

As for other ruminant species, buffalo production systems vary widely between different regions of the world (extensive, semi-intensive and confined). Among 10 studies identified by the bibliographic survey, one evaluated mixed dairy system of cattle and buffaloes (Garg et al., 2016). In India, the production of buffaloes and cows is often associated, with buffaloes being used for various purposes (milk and meat production, animal traction, for example) and can be raised in a mixed system, together with dairy cows. Other regions, with Italy, the mixed farming system of buffaloes and cows is not as common. The studies developed in this country deal with dealt exclusively with buffalo systems impacts (Pirlo et al. 2014a; Pirlo et al. 2014b; Sábia et al. 2018; Berlese et al. 2019, Chirone et al. 2022, Bragaglio et al., 2022).

Regarding the system boudary, two studies addressed the environmental performance of the production in dairy farm stage and dairy industry (dairy plant stage) for 1 kg of mozzarella (cadle-to-gate). The remaining studies only evaluated the stage of the farm, considering the stages from cradle to farm gate as the limit of the product system, which reveals the agricultural character of the many publications related to the product life cycle. The main functional unit used was 1 kg of fat and protein corrected milk (FPCM). The unit 1 kg of normalized buffalo milk – LBN (Pirlo et al. 2014b) and Functional Unit equal to kg of Energy Corrected buffalo Milk – ECM was used as well (Chirone et al., 2022).

Environmental Impacts

Generally, in addition to the immediate impacts of trampling and grazing, the breeding of dairy buffaloes is linked to potential environmental consequences, including abiotic depletion, photochemical oxidation, acidification, and eutrophication (Pirlo et al., 2014b).

The emission of greenhouse gases is highlighted in all studies that used LCA to quantify the environmental impacts of buffalo milk production and, as evidenced by the literature, Buffalo farming can be an environmental activity that causes environmental impacts that are greater than those caused by cattle.

Garg et al. (2016), when evaluating the carbon footprint of milk production on small farms in India, they observed that this indicator was higher for buffaloes than for cows (30-35%), depending on the allocation method considered. Buffalo farming can be an activity that potentially causes environmental impacts that are greater than those caused by cattle, as evidenced in the literature.

Habib & Khan (2018) identified that buffaloes were the animals that most contributed to GHG emissions from the livestock sector in Pakistan, followed by cattle, goats, sheep and poultry. Berlese et al. (2014b) observed that the environmental impact of 1 kg of FPCM, expressed in terms of global warming, was on average 6.4 and 6.1 kg of CO_2-eq realized without and with economic allocation, respectively. This value was four times higher than that found in a Brazilian semi-intensive bovine system (1.55 and 1.47 kg CO_2-eq kg $FPCM^{-1}$) (Carvalho et al., 2021). In a similar way, Chirone et al. (2022) also found that greenhouse gas emissions for dairy buffalo on farms in southern Italy were substantially greater than those reported from cattle (ranging from 0.58 to 1.68 kg CO_2-eq.).

The most environmentally damaging potential of the activity within livestock farming is due to the emission intensity, which can vary widely between different livestock products. According to FAO (2019), on average, intensities are higher for buffalo products compared to bovine products, and this is, among other factors, a direct function of gross energy needs and the CH_4 conversion rate.

While beef production emits 295 kg CO_2-eq. per kg of protein, buffalo meat production emits 404 kg CO_2-eq. per kg of protein. The same goes for milk. Cattle milk production emits almost 87 kg CO_2-eq. per kg of protein, a value approximately 61% lower than the production of buffalo milk (140 kg CO_2-eq per kg of protein) (FAO, 2013). Furthermore, the fact that dairy buffalo farms require energy inputs for the production and purchase of raw materials similar to those of dairy cows, but result in lower yields in terms of milk production, contributes to the impacts of the activities being greater, with milk productivity being arguably one of the most influential parameters in environmental impacts per unit of milk (Sábia et al., 2015; Chirone et al., 2022).

Enteric fermentation is by far the most important source of emissions (contributing approximately 60% of emissions in milk production). Other important sources of emissions include emissions from feed production and N_2O emissions from manure deposited during long periods of grazing (FAO, 2013), or managed in the soil in more intensive systems. These parameters are affected by several aspects that are related to farm management, such as feeding and manure management strategy, region of animal growth; but fundamentally, it also depends on the genetics of the animals, which is not related to the functioning of the farms (Chirone et al., 2022).

It is also noteworthy that two studies were identified (Cóndor et al., 2008; Xue et al., 2014) that obtained greenhouse gas (GHG) emission factors, for ruminant systems, including buffaloes. Despite not evaluating the potential impacts associated with buffalo farming, emission factors they are important for estimating GHG emissions from farming from parameters more reliable and support inventories of future studies of buffalo livestock using the LCA.

Cóndor et al. (2008) estimated a specific emission factor for enteric methane (CH_4) produced by Mediterranean buffaloes in Italy. For the analysis, the authors used national agricultural statistics, as well as information on agricultural and animal production conditions. The emission factor was estimated according to the Tier 2 model of the

Intergovernmental Panel on Climate Change (IPCC), with 73 kg CH4 / head per year being the estimated value for buffaloes, while for other categories of buffaloes it was 56 kg CH4 / head per annum. According to the authors, although the study is useful in preparing emissions inventories, more complementary studies on emissions associated with buffaloes are still needed, in order to increase the precision of the calculated emission factors.

Xue et al. (2014) evaluated the effect of increased demand for milk and meat consumption; and discontinued use of beef cattle and buffaloes as draft animals, in changes in methane (CH4), emissions from enteric fermentation and manure management in large ruminants in China. Emissions were developed from national statistics records from the Ministry of Agriculture of China, corresponding to the years 1988 to 2009 and the calculation was carried out using the Tier 1 and 2 method of IPCC methodologies. The results indicate that beef cattle were the main contributor to methane emissions, with 63.8% of total emissions in 2009, followed by dairy cattle (17.8%), buffaloes (10.3%) and yaks (8.1%). The same period also saw an increase in CH4 emissions from beef cattle, and a consistent decrease in emissions from buffalo and yaks, due to the decline in the population of these herds in recent years.

Popa et al. (2017) evaluated the evolution of methane emissions from enteric fermentation of cattle and buffaloes during the period 1984 and 2014 in Romania. The study was based on statistical data provided by the National Institute of Statistics and equations proposed by the Intergovernmental Panel on Climate Change (IPCC). The calculations indicated that methane emissions showed a decreasing trend due to the reduction in the number of animals and technological and genetic improvements on farms and at the animal level, respectively.

Recommendations

The studies showed that the farm's activities made different contributions to the impact categories considered in the studies. However, GHG emissions (CO2, CH4 and N2O), are identified in all studies as being important responsible for the potential impacts associated with Climate Change. The CH4 was the main source of GHG, mainly due to the enteric fermentation of animals. According to Pirlo et al. 2014b, there is ample room for improvement; the increase in milk productivity and the optimization of feed use are the main highlights. Regarding to Chirone et al. (2022), the dairy productivity of buffaloes is a fundamental aspect of the environmental performance of each farm.

In particular, the breading buffalo in an intensive system can be environmentally better when it comes to some categories. However, it may be detrimental to other impact categories. For example, the intensification of buffalo milk production increased the impact related to terrestrial acidification, freshwater eutrophication and the scarcity of fossil resources in the study by Soares et al., 2019, however, it decreased the impact related to land use, water consumption and climate change. One strategy to reduce various sources of pollution, costs, and compensations in intensification dairy could be to set up part of dairy buffalo farming on natural pastures, especially unproductive ones (Sabia et al. 2018).

Alves et al. (2019) and Berlese et al. (2019), identified that a large part of GHG emissions derive from emissions from buffalo milk in the cheese life cycle, thus, the upstream process related to the production of organic buffalo milk is what contributed most to the climate change impact category. Therefore, mitigation strategies must be addressed especially at the farm level.

Another strategy to reduce environmental impacts is the use of residues from processing plants in animal feed, resulting in low cost of diets. Replacing part of the supplements with whey reduces the amount of food purchased on the off farm and consequently, the associated environmental impacts, as observed by Soares et al. (2019).

Although estimating the sector's GHG emissions provides important information for proposing mitigation alternatives, identifying approaches to reduce them requires complementary analysis. Furthermore, as stated by Sabia et al. (2018), identifying best practices from an environmental point of view is not simple, as different systems often imply trade-offs between different forms of impact and, furthermore, solutions cannot be thought of solely from a single environmental aspect.

The publications collected reflect the global studies that have been developed on buffalo livestock. Brazilian studies have already been developing important work regarding the use of LCA in livestock production systems. However, there are still few studies on the conditions of buffalo production systems around the world, making this sector an opportunity for the application of the LCA methodology. According to Berlese et al. (2019), although there are many studies of LCA associated with bovine milk, few studies are available regarding the environmental impact of buffalo farming and milk processing.

FINAL CONSIDERATIONS

Ten studies were found that carried out LCA on buffaloes, among them, three carried out the Carbon Footprint of milk, and seven addressed a greater number of impact categories. Studies have found that CH4 is most responsible for GHG emissions and consequently global warming.

There are few publications that use LCA as a methodology for quantifying environmental impacts in buffalo livestock, consequently research on LCAs in buffalo livestock is in its initial stage, however, based on existing studies, and it is possible to perceive the main environmental impacts associated with the practice.

The development of new LCA studies in buffalo livestock is a promising option, as environmental awareness is expected to increase, as well as food demand and production.

It is important to highlight that, among the LCA studies related to buffalo milk production, none of them were dedicated to making a complete assessment, considering complex decision-making situations or when there are related trade-offs.

The efficiency of natural resource use and the environmental impacts of different systems, including GHG emissions, can vary considerably, as can the constraints and opportunities to reduce emissions. Therefore, it is essential to develop studies capable of promoting the understanding of different livestock systems and their dynamics in any analysis of emissions and plans to reduce them, especially when considering that in the near future specific rules regarding environmental impact may be available for agricultural enterprises, including limits on GHG emissions and other harmful gases.

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