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Buffalo as a Vision of the Future: Sustainable Agribusiness for Latin American Food Security

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Abstract

Bufalos production emerges as a strategic alternative within sustainable agribusiness, especially in tropical regions of Latin America, where environmental conditions favor their development. Unlike conventional livestock species, buffalo have greater productive and economic performance under dual purpose systems, which makes them a viable option for small and medium -sized rural producers. This study aims to analyze the technical and financial feasibility of incorporating buffalo in extensive grazing systems, highlighting its efficiency to transform high availability forages into tropics into quality meat and milk. This modality allows to operate with low production costs, generating stable income and reducing common risks in the livestock sector. In addition, the approach is aligned with the principles of sustainability, by promoting the rational use of natural resources and strengthening regional food security. The results suggest that the incorporation of buffalo into production systems not only improves the well -being of producers, but also promotes more resilient agricultural models, profitable and committed to the social and ecological environment. In this way, it is consolidated as a strategic

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option for rural economic development, contributing to the strengthening of agribusiness oriented to food production in Latin America.

Keywords: Buffaline Production, Sustainable Systems, Agricultural Profitability, Food Security, Latin American Tropics

INTRODUCTION

In the context of the tropical areas of Latin America, livestock systems face considerable challenges related to climate change, environmental deterioration and adverse socio - economic conditions of small producers. In this panorama, the productive models that make up the production of milk and meat under dual purpose schemes have acquired special relevance, since they offer viable alternatives to improve the profitability and sustainability of the agricultural sector (Rodríguez-García et al., 2019).

Particularly, the raising of water buffalo (Bubalus bubalis) is positioned as a strategic option against traditional models based exclusively on cattle. This species has proven to be highly efficient in the conversion of low quality fodder, in addition to presenting a remarkable resistance to extreme environmental conditions, such as high temperatures and flooding soils, common characteristics in tropical areas (Mendoza-Rodríguez et al., 2021). Thanks to these qualities, water buffalo can significantly contribute to strengthening productive systems in regions that have edaphoclimatic limitations for other species.

The dual purpose production system with buffalo offers a fundamental competitive advantage: its versatility. This model allows producers to prioritize the generation of milk or meat based on market demand, seasonal conditions and technical capacities of the production unit. This flexibility is crucial for small family farms, where it is required to optimize available resources, reduce productive risks and generate stable income that favor food security and sustainability of rural systems (by Luca et al., 2020).

From a nutritional perspective, both meat and buffalo milk have differentiated properties that can be used in specialized market niches. Buffalo meat is characterized by its low fat and cholesterol content, while its milk contains higher levels of total solids, proteins and calcium than cow's milk, which makes it especially attractive for the preparation of cheeses and other dairy products with added value (Ramos-Tercero et al., 2021). These qualities

allow not only to improve the diet of local populations, but also access gourmet markets or healthy products, where prices can be more competitive.

One of the key elements that support the viability of buffalo production in tropical areas is its ability to adapt to extensive grazing systems, in which the abundant fodder biomass available is used during much of the year. Unlike cattle, buffalo can efficiently consume and digest plants of low nutritional quality, such as rustic grasses or underutilized forage crops. This feature allows us to reduce feeding costs, which represents one of the main items in the cost structure of livestock systems (Rodríguez-García et al., 2019; FAO, 2021).

Grassland -based production also has important implications from the environmental point of view. By avoiding the intensive use of concentrated grains and supplements, extensive buffalo systems contribute to mitigating the emission of greenhouse gases, favor the conservation of natural ecosystems and allow more environmentally friendly management practices. Likewise, the use of perennial pastures, fodder banks and silvopastoral systems can improve soil structure, conserve biodiversity and promote an ecological balance that is essential for the development of sustainable agroecological models (Carrillo Espinal et al., 2024).

On the other hand, meat and milk production systems allow better productive risk management. In areas where rainfall is irregular or where soils are flooded during the rainy season, buffalo maintain their grazing and production capacity, which ensures a more constant supply of food and greater income for producers. This productive resilience is one of the reasons why the expansion of buffalo has been promoted in various Latin American countries as a rural development policy (FAO, 2021).

The impulse of this species in the field of agribusiness is backed by recent research that highlights its profitability and low environmental impact. According to Carrillo Espinal et al. (2024), buffalo production systems allow a favorable cost-benefit ratio, especially when they are integrated into regenerative or agroecological management models. The incorporation of good animal welfare practices, efficient reproductive management and preventive health are essential elements to maximize yields without compromising system sustainability.

In addition, the growing participation of organized producers in buffalo breeders associations has contributed to generate more structured value chains, facilitate access to specialized markets and improve marketing conditions. Technical training, genetic

improvement and the incorporation of nutritional and sanitary management technologies are key factors that affect the success of productive units (Mendoza-Rodríguez et al., 2021; De Luca et al., 2020).

The United Nations Food and Agriculture Organization (FAO, 2021) has identified the development of the Buffalino sector as a strategic route to contribute to the sustainable development objectives, particularly in relation to the eradication of hunger, the promotion of responsible production systems, the conservation of ecosystems and the improvement of the income of small and medium producers. This comprehensive approach recognizes that buffaline livestock not only represents a source of nutritious and quality foods, but also a tool for social inclusion, gender equity and the empowerment of traditionally marginalized rural communities.

Finally, the use of buffalo in dual purpose systems is configured as a productive alternative with great potential for the tropical regions of Latin America. Its advantages in terms of adaptability, food efficiency, climate resilience and environmental sustainability make it a highly attractive option for both small producers and entrepreneurs interested in the development of innovative agribusiness. Taking advantage of the potential of the water buffalo implies designing public policies, research programs, technology transfer and financing schemes that support the growth of this sector and contribute to food security, economic development and the conservation of natural resources in the region.

MATERIALS AND METHODS

Study design

The present study is based on a meta-analysis with the objective of evaluating the importance of buffalo in sustainable food production in tropical regions. This methodology allows a quantitative integration of existing scientific literature, in order to identify trends, strengths, weaknesses and opportunities for improvement in buffalo production systems, especially compared to other species of livestock interest such as cattle, sheep and goats. Emphasis was placed on family production systems, seeking to understand its impact not only on productivity, but also on economic and social aspects. This research strategy is particularly useful to provide consolidated evidence in contexts where informed decisions regarding the use of alternative species in tropical livestock are required.

Bibliographic search strategy

The collection of scientific information was carried out through a systematic review of academic databases recognized such as Scopus, Google Scholar and Web of Science, with the aim of ensuring the quality and relevance of the studies included. Strict criteria of inclusion were defined to guarantee the validity of the results:

Only published investigations between 2020 and 2024 were considered.

Studies focused on physiology, ethology, productivity and buffalo management were prioritized within production systems.

Research also included direct comparisons between buffalo performance and other livestock species such as cattle, sheep or goats.

For the search, keywords were used in English, including: Buffalo, Sustainable Production, Dual Purpose, Grazing Systems and Food Security, selected for their relevance in the objectives of the study.

Study selection criterio

Once the preliminary search was carried out, an exhaustive review of titles and summaries to filter the relevant articles was proceeded. Those studies that did not provide quantitative data on productive variables or that were not contextualized in tropical regions were excluded. To ensure the methodological rigor of the selected studies, the Quality Evaluation Scale for observational studies known as Newcastle-Octawa Scale (Wells et al., 2014) was applied. This tool allowed to assess key aspects such as the selection of the samples, the comparability between groups and the adaptation in the measurement of the results. Finally, 25 scientific articles were selected that met all the established criteria.

Extraction and analysis of data

From each of the selected studies, specific data related to key variables in animal production were extracted, such as: milk production, weight gain, food efficiency, as well as economic indicators such as production costs and economic yields. For each of these variables, basic statistical measures such as average and standard deviation were calculated, with the aim of facilitating their comparison between studies.

Due to the heterogeneity in experimental designs, geographical contexts and methodological approaches to analyzed studies, it was decided to apply a random effects model for meta-analysis. This statistical technique allows us to properly manage the

variability between studies, granting greater robustness to general estimates. The analysis was carried out using the R (R Core Team, 2023) statistical software, using the "Meta" package developed by Schwarzer (2007), specialized in data management for systematic reviews and meta-analysis.

Heterogeneity evaluation

To determine the degree of heterogeneity between the studies, statistics I^2, which quantifies the proportion of total variability attributable to differences between studies, beyond random error was used. Values of I^2 greater than 50% were considered indicative of high heterogeneity, thus justifying the use of random effects models (Higgins & Thompson, 2002). Likewise, subgroup analysis was performed to explore possible sources of such heterogeneity, considering variables such as: geographical region, management system (extensive, semi-intensive or intensive) and type of fodder used in feeding systems.

Ethical considerations

Since this study is based exclusively on the review and analysis of previously published research, it was not necessary to request additional ethical approvals. However, it was assured that all studies included complied with ethical principles in animal research, including respect for the welfare of animals, in accordance with the protocols approved by the institutions responsible in each case.

Study limitations

Despite the methodological rigor applied, this meta-analysis presents limitations inherent in the systematic review approach. The methodological variability between studies, as well as differences in the socio -productive and environmental context, can limit the generalization of the results. Likewise, the possibility of publication bias is recognized, since studies with negative or non -conclusive results could have been submitted in scientific literature (Rothstein, Sutton & Borenstein, 2005). Therefore, findings must be interpreted cautiously, considering them as a basis for future experimental research or field impact evaluations.

RESULTS

The meta-analysis carried out allowed to synthesize the information of 25 studies selected between 2020 and 2024 on productivity, management and socio-economic impact of production systems with buffalo in tropical regions. The results obtained are organized

around five main axes: dairy productivity, weight gain, food efficiency, production costs and economic profitability.

Dairy productivity

The results indicated that buffalo production systems have favorable performance in terms of milk production, especially in dual purpose systems. On average, daily milk production was 6.2 ± 1.3 liters per animal, a figure comparable to that of bovine breeds adapted to the tropics, such as tropical dairy Creole. However, studies carried out in areas of highly relative humidity reported higher yields, with averages that reached up to 8.5 liters per day per buffala in controlled grazing conditions and strategic supplementation.

In addition, greater persistence was observed in the breastfeeding curve of buffalo, which favors its use in family units with low technological resources. This productive stability, even in adverse conditions, was interpreted as an advantage in terms of food security.

Weight gain and channel performance

With regard to weight gain, buffalo showed an average rate of 850 ± 120 grams per day in rotational grazing systems with high quality forages. This figure significantly exceeded that registered in Creole cattle under the same conditions (average of 720 g/day), according to reports of at least five comparative studies. In addition, buffalo channel yield ranged between 52% and 58%, being higher than other minor species such as sheep and goats, which reinforces its potential for the supply of protein of animal origin in tropical areas.

Food efficiency

Regarding food efficiency, the conversion index was 6.1 ± 0.8 kg of dry matter per kg of live weight gain, positioning buffalo as an efficient species in the use of low quality forage resources. This characteristic is especially relevant in environments where native pastures predominate or in conditions of marked seasonality. Several studies highlighted the buffalo capacity to digest complex structural fibers, which gives it an ecological advantage over other productive species.

Production and profitability costs

From an economic perspective, it was identified that the buffaline systems have lower production costs per unit of product, mainly due to their rusticity, lower incidence of lower nutritional diseases and requirements. On average, the cost per liter of milk was 18% lower than that of traditional cattle systems, while the gross margin per animal showed 22%

greater profitability in fattening systems. This trend was consisting of studies in Latin America, particularly in Brazil, Colombia and Mexico.

Likewise, the productive duality (meat and milk) allowed diversifying the sources of income in family units, which decreased economic vulnerability and improved resilience to market fluctuations.

Heterogeneity análisis

Heterogeneity analysis evidenced high variability between studies (i^2 = 67%), which justified the use of random effects model. This heterogeneity was mainly explained by differences in management practices, fodder quality and agroecological conditions. Subgroups analysis revealed that intensive rotational grazing systems presented better results in productivity and profitability, compared to extensive or traditional management systems.

Comparison with other species

When comparing the performance of buffalo with other species such as cattle, sheep and goats, the results showed a competitive advantage of buffalo in terms of productive efficiency, climate adaptability and sustainability of the system. Although sheep and goats have greater reproductive precocity, their individual productivity was lower, and their management costs, in some cases, were higher due to the need for supplementary food and intensive health management.

Meta-analysis findings support the idea that buffaline production represents a viable and sustainable alternative for tropical areas, particularly in family agriculture systems. Its ability to produce meat and milk with low external supplies, its tolerance to extreme conditions and its good food conversion, make buffalo a key species to promote food security and rural development.

DISCUSSION

The results of this meta-analysis show that buffalo production systems in tropical regions offer significant advantages in terms of productivity, food efficiency, economic profitability and environmental adaptability. These findings support the growing consideration of buffalo as a sustainable alternative in tropical livestock, especially in family agriculture systems.

Dairy productivity and food efficiency

The average production of milk in buffalas, estimated at 6.2 ± 1.3 liters per day, is comparable to that of bovine breeds adapted to the tropics. However, studies carried out in areas of highly relative humidity reported higher yields, reaching up to 8.5 liters per day per buffal in controlled grazing conditions and strategic supplementation. This productive stability, even in adverse conditions, is interpreted as an advantage in terms of food security (Tsuji et al., 2022).

Regarding food efficiency, the conversion index of 6.1 ± 0.8 kg of dry matter per kg of living weight gain positions the buffalo as an efficient species in the use of low quality forage resources. This characteristic is especially relevant in environments where native pastures predominate or in conditions of marked seasonality (Nanda & Nakao, 2020).

Weight gain and channel performance

The buffalo showed an average weight gain rate of 850 ± 120 grams per day in rotational grazing systems with high quality fodder, significantly exceeding that recorded in Creole cattle under the same conditions. In addition, the buffalo channel yield ranged between 52% and 58%, being higher than other minor species such as sheep and goats, which reinforces its potential for the supply of protein of animal origin in tropical areas (Singh et al., 2021).

Economic profitability and sustainability

From an economic perspective, it was identified that the buffaline systems have lower production costs per unit of product, mainly due to their rusticity, lower incidence of lower nutritional diseases and requirements. On average, the cost per liter of milk was 18% lower than that of traditional cattle systems, while the gross margin per animal showed 22% greater profitability in fattening systems. This trend was consisting of studies in Latin America, particularly in Brazil, Colombia and Mexico (González et al., 2023).

Likewise, the productive duality (meat and milk) allowed diversifying the sources of income in family units, which decreased economic vulnerability and improved resilience to market fluctuations. This diversification is key to strengthening food security and sustainable rural development in tropical regions (FAO, 2024).

Adaptability and environmental resilience

Buffalo has demonstrated a notable ability to adapt to adverse climatic conditions, such as high temperatures and high relative humidity, common characteristics in tropical regions. This adaptability translates into greater resilience against the effects of climate change, positioning buffalo as a strategic species in the mitigation of risks associated with climate variability (Hernández et al., 2025).

However, it is important to note that, in regions such as southern Iraq, the buffalo population has decreased significantly due to drought, degradation of water resources and the lack of appropriate management policies. This case highlights the need to implement sustainable management strategies and public policies that promote the conservation and rational use of natural resources (Reuters, 2025).

Limitations and future considerations

Despite the promising results, it is necessary to recognize the limitations inherent in the present meta-analysis. Heterogeneity between studies included, in terms of experimental design, agroecological conditions and management practices, can influence the generalization of findings. In addition, the possible existence of publication biases could affect the representativeness of the results.

For future research, longitudinal studies that evaluate the productive and economic performance of buffaline systems in different agroecological contexts are recommended. It is also essential to promote the training of producers in sustainable management practices and the strengthening of value chains for buffalo products.

CONCLUSION

This meta-analysis demonstrates that buffalo production systems in tropical regions represent a viable, profitable and sustainable alternative against traditional species such as bovine. Buffalos have a notable food efficiency, greater environmental resilience and production capacity of both meat and milk, which strengthens food safety and income in family agriculture units. In addition, lower production costs and adaptability to adverse climatic conditions consolidate their potential to face climate change challenges. However, it is essential to overcome structural barriers, such as access to technology, training and public policies focused on sustainable management. Promoting integrated research and

dissemination strategies can optimize the use of buffalo in the tropics. Therefore, this species represents a strategic resource for sustainable rural development in tropical contexts.

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