Water buffalo production in the Brazilian Amazon Basin: a review

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Abstract

The Brazilian Amazon has witnessed, in the last decades, an increase in the water buffalo (*Bubalus bubalis*) inventory, with interesting productivity results. As the Brazilian Amazon contains the main water buffalo population in the Americas, the aim of this work is to review its most relevant production systems and some peculiarities about meat and milk production in this territory. The opening section describes the Amazon Basin, the most common water buffalo breeds, a brief history of the local livestock farming beginning in 1644. Also, it presents how water buffaloes gradually replaced bovine herds, especially where the latter had a lower productive performance. The use of extensive or more intensified models is pointed out and the ecosystems in which buffaloes are raised are detailed since native or cultivated pastures can be used in floodplains or drylands. Buffalo raising is favored in the Amazon due to the climate, soil, genetic variability of forages, animal adaptability, and physical space. Thus, it is clear that buffaloes have a high potential for meat and milk production and are an alternative in the use of altered areas of the Amazon; and, in the recent past, the low profitability of buffalo farming in traditional production systems in the Amazon was the reason which made this activity economically unattractive. Most recent technologies as outdoor confinements and silvopastoral systems are pointed out as more suitable regarding land-use policies, and buffalo farming for meat and milk production fits perfectly in this context, with productivity and beneficial socioeconomic.

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Introduction

The Amazon, a vast region that encompasses different countries (Brazil, Peru, Colombia, Ecuador, Venezuela, Bolivia, Guyana, Suriname, and French Guiana) in South America, has a total area of about 7 million km² and is the largest forest in the world (FAO 2020). It is located in the tropical region, conducting intense energy exchanges between its continental surface and the atmosphere. It is composed by the Amazon River basin and thousands of tributaries, representing the largest river network in the world, and contains nearly one-fifth of the fresh water on the surface of the Earth. With an annual discharge about 200,000 m³s⁻¹, the Amazon River contributes 16-18% of the continental discharge to the oceans (Moreira-Turcq et al. 2003).

In Brazil, the Amazon also refers to the nine states that are included in this vast region. The Legal Amazon (Fig. 1) is the largest socio-geographic division in Brazil. It was created in 1966, by the Brazilian government, to plan and promote its economic and social development. It involves a vast area of Brazilian North region, within the states of Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, Tocantins and Mato Grosso states, and also part of Maranhão, located west of the 44th meridian. It has an area of approximately 5.2 million km², which corresponds to about 61% of the Brazilian territory, and contains around 24 million inhabitants. It was estimated that the Legal Amazon accounted for 8.6% of Brazil's total gross domestic product in 2016, having increased from a share of 6.9% in 2002. The sector with the highest contribution was agriculture, to which the Legal Amazon represented 21% in terms of gross domestic product in 2016 (Pasqualli 2020).

Fig. 1

figure 1

Maps representing the administrative limits of the Legal Amazon in Brazil (a), and the whole Brazilian territory considering the number of water buffalo heads raised in each federal state (b). Maps were based on public-domain material provided by the Brazilian Institute of Geography and Statistics-IBGE (2019)

Full size image

This region has witnessed during the last decades an increase in the water buffalo (*Bubalus bubalis*) inventory with interesting results regarding productivity. Today the Legal Amazon is the main buffalo production region in South America and one of the most relevant outside of Asia. This aspect generated increased income for ranchers and jobs in the various segments of the production chain. In this context, several studies have pointed out that there is potential for growing production in the Legal Amazon to meet the higher demand for meat and dairy products without additional deforestation, especially in livestock areas (Homma 2015; Cerri et al. 2018; Santos et al. 2019).

The purpose of raising water buffaloes in the Brazilian Amazon region is to produce meat and milk in a sustainable way. A system is sustainable if it is acceptable now and if its expected future effects are

acceptable, in particular in relation to resource availability, consequences of functioning, and moral standards from an environmental point of view (Broom 2014). In the knowledge that each system has its own pros and cons, the sustainable water buffalo production is carried out using two management systems. The first is an extensive management system that uses traditional production areas in which buffaloes are raised on native pasture ecosystems in dryland (also known as “terra-firme”) and in periodically flooded land (“várzea”) along the Amazon River and tributaries. It occurs mostly in the Marajó Island on the Amazon mouth, the banks of the river and its tributaries, and in the states of Amapá and Roraima. The other management system is conducted in areas of intense cattle ranching where cultivated pastures have been occupying previously human-changed areas and where herds have more productive animals. Indeed, initiatives to incorporate planted forests to cultivated pastures in these areas have been fostered by public and private entities.

Currently, the Brazilian buffalo herd accounts for 1.37 million heads, 73% of them raised on the Legal Amazon, namely more than 1 million heads (IBGE 2018). It is important to mention that the Pará state is the largest producer of buffalos in Brazil, which are predominantly raised in the Marajó Island and in the Lower and Middle Amazon regions. The Lower Amazon region refers to the northwest quarter of the Pará state and includes 13 municipalities most of which are located along the Amazon River, the focus of settlement until the 1970s. The physical landscape of the Lower Amazon is characterized by the annual flood of the Amazon River and highly seasonal rainfall. There are many relatively stable floodplain islands in the Lower Amazon River. Most of these consist of periodically flooded land (WinklerPrins 2006). The Middle Amazon extends from Paran do Careiro and the merge of the Solimes and Negro rivers (in the Amazonas state) to the mouth of the Tapajs River, where the important city of Santarm is located. The area comprises the low vrzas, most readily flooded during the rising waters, and the high vrzas that reach more than 10 m above the level of the rivers during the low water period (Ab’Sber 2010).

In the Amazon, water buffaloes find a favorable habitat, with the prevalence of three subspecies (bubalis, kerebau, and fulvus). These animals are grouped in the Mediterranean, Murrah, Jafarabadi, and Carabao breeds, in addition to the Baio type (Fig. 2), by the Brazilian Buffaloes Breeders Association (ABCB) that characterizes buffalo breeds, establishing a racial pattern for each of them. The Mediterranean breed, selected in Italy, has an aptitude for meat and milk. It has black, long, strong, and thick horns, with an oval or triangular section, directed backwards, outwards, and upwards, ending in a semicircular or lyre shape. The Murrah breed, originally from Northwest India, is considered the best milk producer among buffalo breeds. This breed has small horns, of oval or triangular section, coming out backwards, outwards, downwards, and upwards, with the tip twisted inwards and curled (ABCB 2020).

Fig. 2

figure 2

Specimens of water buffaloes of the Murrah (a), Mediterranean (b), Carabao (c), and Jafarabadi (d) breeds raised in the Brazilian Amazon. Animals of the Baio type (e). Group of very docile crossbred Murrah × Mediterranean steers waiting in the corral to be managed (f) (photo courtesy: a-d, and f Garcia, A.R.; e Lourenço Junior, J.B.)

Full size image

The Jafarabadi breed came from India (Gujarat state) and it has an aptitude for meat and milk production. Buffalo Carabao or “rosilho” is originally from Indochina, in Southwest Asia. It is the breed most adapted to swampy regions and, due to its rusticity, it has good development of muscle mass and strong limbs (ABCB 2020). This breed is used for meat production and for work, and it has a characteristic rosette or dark gray skin and hair. On the other hand, the Mediterranean, Murrah, and Jafarabadi breeds have black hair, horns, hooves, and nasal mucosa (ABCB 2020). The Baio type buffalo is not considered a breed by the ABCB. These animals have a bay or brownish color, dairy and meat aptitude, and were introduced in Brazil in 1962 alongside with the Murrah breed, first going to the Leão Farm, a private property located in Alagoas state, in Northeastern Brazil.

Water buffaloes are excellent producers of meat and milk, and are very interesting as draft animals (Fig. 3). They are considered to have a lower ecological impact than conventional livestock, particularly cattle. Buffaloes are able to produce and reproduce in native pastures on periodically flooded lands (Garcia 2006), areas that are very adverse for cattle ranching.

Fig. 3

figure 3

Mounted police on water buffaloes, in Belém, Pará state, Brazil (a) and buffalo been used as a draft animal by the Amazon Military Command of the Brazilian Army (b) (photo courtesy a Associação Paraense dos Criadores de Búfalos (APCB); b Brazilian Army)

Full size image

In the above mentioned context, the objective of this work is to conduct a literature review on the production of water buffaloes in the Brazilian Amazon, its most relevant production systems, and some peculiarities about meat and milk production in this territory Furthermore, we highlight the history of the species in the region, the ecosystems used for buffalo production, the different production systems and their productivity, and the current challenges posed to the production of these animals.

History of water buffalo in the Amazon region

Livestock farming in the Brazilian Amazon began in 1644 by Portuguese settlers, using European and African cattle (*Bos taurus*) transported from Europe and from the Cape Verde islands. They were initially raised in suburban homes' backyards, in Belém, the Pará state capital, and were later transferred to Marajó Island (Lourengo Junior and Garcia 2006). There they formed a local creole breed termed "Pé-duro" (hard hoof), rustic animals of small size and reduced weight. These animals were deemed as having lower productivity, being inadequate for the market demand for meat and milk (Carvalho et al. 2010). The solution was crossing these animals with Zebu breeds (*Bos indicus*) such as Nelore, Gir, Guzará, and Indubrasil, which were more adaptable than taurine breeds to harsh tropical local conditions. This somewhat raised animal productivity in the local extensive systems. This way, farmers with more financial resources kept purchasing selected bovine sires and dams of these breeds from southern Brazil in order to improve their herds (Soares 1963) and the local inventory soon became composed mostly of *Bos indicus* type animals, particularly Nelore cattle.

Nevertheless, the performance of cattle was still considered well below what was required to supply the local growing population at that time. As a consequence, the water buffaloes' introduction was an alternative to use the different ecosystems of native and cultivated pastures of flooded and dry lands in the Amazon, mainly due to its outstanding productivity in meat, milk, and labor under hot and humid local tropical climate harsh conditions (Santiago 2016). In addition, buffaloes have a higher tolerance to diseases and parasites, which was a major problem in some areas of cattle production (Leenstra et al. 2006). Therefore, in the swamp or flooded areas, where cattle would have difficulty in adapting, water buffalo became a potential domestic species to be raised, particularly in periodically flooded areas (Lourengo Junior and Garcia 2006).

Following the course of history, the buffalo was successfully introduced into Brazil, specifically on Marajó Island, a large delta island in the Pará state, by private ranchers. The pioneer was Vicente Chermont de Miranda, who imported some Mediterranean animals from Italy in 1890. From that point onwards, the import of buffaloes occurred in different regions of Brazil (ABCB 2020). On Marajó Island, buffaloes lived under natural conditions and, in the late 1950s, ranchers on the island began to raise them in managed production systems. At the start of the 1970s, animals of the Murrah and Jafarabadi breeds were introduced in the North and Southeastern regions of Brazil (Santiago 2016). In the 1980s, the Brazilian Agricultural Research Corporation-Embrapa led an import of frozen semen of Mediterranean (from Italy), and Murrah and Jafarabadi bulls (from Bulgaria) that helped to achieve a yearly genetic gain for traits like meat and milk (Embrapa 2006). In this way, in just over a century, water buffaloes adapted well to tropical conditions in the Amazon, where they have demonstrated a high aptitude for meat and milk production as well as for animal draft (ABCB 2020).

Since then, the Amazonian buffaloes have been selected to be more productive (Marques et al. 2019a), long-lived, and very docile. They have consistently achieved high reproductive and productive efficiency, with a capacity to properly use the available territory and to transform low-quality roughage into products of high aggregated value (Batista et al. 1982). Furthermore, as previously described, the

buffalo production represents a viable alternative for the efficient use of flooded areas that otherwise are not usable by other more conventional species such as cattle or small ruminants.

Basic aspects of buffalo milk and meat markets in the Brazilian Amazon

Brazil has 1,370,941 buffaloes, the majority in the North of the country, especially in the Pará state, which holds 37.90% of the national inventory (Oliveira et al. 2020a). Thus, Pará state may be considered a major driver for the buffalo milk and meat production and market in the Brazilian Amazon. Buffalo rearing in the Amazon has grown in recent decades due to its profitability, which generated increased incomes for producers, in addition to job creation in the production chain (Lourenço Junior and Garcia 2006).

In Pará state, buffalo farming is conducted on properties with less than 200 ha, which are considered “small farms” for the region (Oliveira et al. 2020a). These properties represent 67.91% of the production units and concentrate 36.72% of the buffalo herd. On the other hand, properties larger than 1000 ha represent only 6.87% of the total units, but concentrate 34.97% of the herd. Smallholder farmers adopt extensive systems, mainly using native pastures. In addition, these properties are rudimentary fenced and characterized by a low-technology use, with consequent low productivity, being usually complementary activities. Although Pará state has the largest water buffalo inventory in Brazil, it represents only 14.06% of Brazilian milk production. The milk, despite being a differentiated product, with excellent properties for cheese production, has a very limited production level as the herd is more specialized in meat production (Oliveira et al. 2020a).

On the other hand, an analysis of milk production growth in Pará state and Brazil shows that the number of milked buffaloes increased in the 2006-2017 period. Indeed, Pará state and Brazil showed significant growth with a rate of 4.90% and 8.73%, respectively (IBGE 2018). This growth is essentially related to both the larger number of milked animals and the development of specific technologies for water buffalo farming. These technologies include management strategies (Silva et al. 2015; Joele et al. 2016; Pantoja et al. 2018), reproductive techniques (Santos et al. 2014; Barros et al. 2016; Marin et al. 2019), sanitary control (Otaka et al. 2017), and processes for electronic animal identification (Garcia et al. 2020). In addition, there is growing interest in the buffalo milk quality as it has been increasingly used for dairy product manufacture, due to the high protein and fat contents, which allows higher yields for the dairy industry. Indeed, buffalo milk yield makes it excellent for technologies’ application in the manufacture of its derivatives such as cream, cheese, raw milk yogurt, and yogurt with fruit addition (Monteiro et al. 2015).

In spite of the asymmetry of information related to the consumption of water buffalo meat in Brazil (Marques et al. 2015), the product is highly appreciated by the public that consumes it in traditional dishes or barbecues. However, many abattoirs pay less for buffalo meat in comparison to beef. One of the reasons is precisely the fact that production and consumption are not promoted (Silva and Nardi

Junior 2014). In some regions, buffalo meat is not adequately marketed and many of the positive aspects of its consumption are not highlighted (Jorge et al. 2005).

Buffalo meat prices fluctuate over the years and are strongly affected by the season. Furthermore, prices are also driven by product availability in the markets of the different states. This is caused in turn by environmental conditions, such as climatic variations, that strongly influence pasture quality and quantity, and therefore animal performance. These factors regulate the supply and market price. Between March and June, when the supply reaches its peak, the price is reduced, while from August to December, prices reach the highest values, due to low product supply. Producers specialized in the production of younger animals and continuous growth paths have therefore to invest in supplementary feeding in order to meet the nutritional demands and allow the slaughter of animals with adequate market weight, and value (Oliveira et al. 2020a).

Producing water buffalo in the Amazon region: major ecosystems

In the Brazilian Amazon, water buffalo production is basically developed in four distinct pasture ecosystems: (1) native flooded pastures on Marajó Island; (2) native flooded pastures in the Lower and Middle Amazon regions; (3) native pastures in dryland, and (4) cultivated pastures in dryland, in areas previously used for other agricultural purposes, either in monoculture or in integrated systems that deliberately combine pastures, trees, and animals in the same area and at the same time (Fig. 4). In this latter ecosystem, forage grasses that have high productivity and nutritive value have been used to feed herds that have an improved genetic profile. Buffaloes are also raised in systems that integrate native and cultivated pastures (Townsend et al. 2012).

Fig. 4

figure 4

Water buffalo herd in the pasture in different ecosystems in Brazil. Native flooded pastures in Lower Amazon (a); native flooded pastures in Santarém (b); cultivated pastures in dryland in Belém do Pará (c); cultivated pastures in silvopastoral system in dryland (d) (photo courtesy: a, c, d Garcia, A.R.; b, Silva, J.A.R.)

Full size image

The native pastures on Marajó Island are located in stable ecosystems that have been used for cattle ranching in an extensive management system for more than 300 years with low levels of degradation (Lourenço Junior et al. 2002). The native flooded pastures, mostly in the Lower and Middle Amazon regions, have played an important role in the context of regional livestock production. Besides being the main source of food for livestock, the importance of these native pastures increases with the demand for more animal-based protein and, for this reason, an interest in buffalo production has also increased, given the production potential of this ecosystem. The main limitations of these pastures, however, are

the difficulty in managing the herds during the high-water season when the pasture areas are mostly flooded, and when these floods are prolonged (Costa et al. 2010a; Townsend et al. 2012).

The native pastures in floodplains have a fundamental role in the development of water buffalo farming in the Brazilian Amazon because they have a high potential for the production of forage grasses with high nutritive value (Camarão et al. 2002). These pastures are located on the banks of the Amazon River and its tributaries, lakes with sediment-laden water, and areas in the estuary of the Amazon River. The largest extensions of these pastures are in the Lower and Middle Amazon regions and part of Marajó Island (Lourenço Junior and Garcia 2006).

With respect to animal feeding, grasses are one of the main components of the ecosystem of Marajó Island and are locally termed “amphibians” because they are able to survive floating or submersed during the period of high water and vegetate during the period of low water when the waters recede (Camarão et al. 2004). During the period of high water, which coincides with the rainy season, these pastures are inaccessible to many animals and, during this period, only buffaloes are able to use them. In floodplain pastures, there is a predominance of the grasses *Echinochloa polystachya*, *Hymenachne amplexicaulis*, *Paspalum fasciculatum*, *Paspalum repens*, *Leersia hexandra*, and *Oryza* sp. (Lourenço Junior and Garcia 2006).

The grasses that compose native pastures in floodplains have high production potential and nutritive value, with an average crude protein content of 13.3% and in vitro digestibility of organic matter of 52.3%. The soils have good fertility and are flooded during 6 months of the year, from January to July, and receive the deposition of sediments that are in suspension in the Amazon River and its tributaries. The minerals in these forage grasses are sufficient for maintenance and production needs of the animals. Therefore, the biggest problem is the flooding itself (Camarão et al. 1997).

With respect to pastures that have been cultivated during recent years, *Brachiaria brizantha* has been the most planted grass by ranchers in the Amazon region due to its high productivity, persistence, good sprouting capacity, and tolerance to drought and fire, besides its high nutritive value (Tonato et al. 2019). Plants from this genus can adapt to varied conditions of soil and climate, but their expansion is mostly due to their adaption to conditions of low and medium soil fertility that are prevalent in the Amazon, where they are able to produce a satisfactory quality of forage (Camarão and Marques 1995). In addition to *Brachiaria brizantha*, there are other promising grasses currently being used from the genera *Brachiaria* (*Brachiaria humidicola*), *Panicum* (*Panicum maximum*), and *Andropogon* (*Andropogon gayanus*). Also, African Bermuda grass (*Cynodon nlemfuensis*) has demonstrated excellent adaptation to the different soil types, stimulating production increases in buffalo meat and milk (Corrêa and Santos 2003).

Cattle ranching is a very important activity for socioeconomic development of the Lower and Middle Amazon regions, despite historical conflicts between buffalo ranchers and other floodplain users, such as fishermen (Sheikh et al. 2006). In these ecosystems, pastures are best used during the dry season. During the rainy season, producers transport their animals from the floodplain to higher lands (locally known as tesos) or keep animals most of the time in elevated corrals (locally known as marombas) (Fig. 5), which have sub-optimal sanitary control and nutrition conditions. Another alternative is to remove the cattle from the floodplains and take them to dryland that has well-drained native pastures and savannahs (campos de cobertos). From a socioeconomic, ecological, and biological point of view, the best alternative in this region is the use of a dual system that integrates native pastures during the dry season when there is a high availability of good quality forage, with pasture formed by cultivated grasses that are abundant and of high quality during the rainy season (Serrão et al. 1990; Lourenço Junior and Garcia 2006). It is a way to ensure the appropriate nutritional intake for animals without the need for transitory and overloaded corral usage. Anticipating the buffalo transfer to uplands increases somewhat more technology to this system, especially during the dryland maintenance. In addition, it is a rational strategy to minimize the competition for land use and consequent potential conflict in the floodplain during the year (Sheikh et al. 2006).

Fig. 5

figure 5

Buffaloes kept in maromba-type corral (a) and occupying flooded area (b) during the rainy season, in the Lower Amazon, Pará state, Brazil (photo courtesy: a, b Lourenço Júnior, J.B.)

Full size image

This system consists of weaner calves in native pasture in floodplains, which are then weaned at the start of the dry season in August and then remain in this ecosystem during the entire dry season. Subsequently, at the start of the rainy season, they are transferred to cultivated pastures in dryland for fattening from January to August, where they remain in pastures with up to three heads/hectare with mineral mix supplementation. This system has excellent productive and economic performance for finishing buffaloes and allows animals to reach 450 kg of live weight with at least 2 years of age, with females having their best weight gains and with positive effects on reproduction (Lourenço Junior et al. 1994).

Nonetheless, due to lower efficiency on land use, the traditional systems have been gradually replaced by more productive systems of perennial pastures in drylands, as a result of technology incorporation. Intensive production has better productivity per hectare, allowing the pastures perpetuation and, throughout the years, increasing physicochemical and microbiological properties of the soil. The use of better adapted gramineous, adequate level of fertilization, pasture management, and eventually supplemental feeding during the critical period of the year contributes positively to increase buffaloes' productivity. The use of cultivated and fertilized pastures on buffalo farming also allows to reincorporate

large areas of degraded pastures to the productive process and reducing the agricultural expansion in these very sensitive tropical areas thus decreasing logging and forest burning. Intensive rotational grazing systems in the Brazilian Amazon have gains per hectare from 3 to 4 times higher to the ones found in the traditional systems, with stocking rate up to 3.2 livestock units/ha/year (Lourenço Junior et al. 2002).

In the wake of global society expectations for more equilibrated livestock production and reduction in greenhouse gas emissions (Ku-Vera et al. 2020), the integrated crop-livestock-forest systems appear as an evolution of single pastured-based farming and a positive alternative to be adopted (FAO 2019). Among these, it is worth highlighting the silvopastoral systems, which combine shrubs/trees, and forages with livestock operations, and are gaining importance in the tropics. A myriad of arrangements of silvopastoral systems have been tested in the Brazilian Amazon since the 1970s (Table 1), but they initially did not attract much attention from farmers, mainly because the first chosen tree species were of low commercial value (Lourenço Junior et al. 2010).

Table 1 Characteristics of some silvopastoral systems deployed in the Brazilian Amazon since 1970s, according to their animal, grazing, and forest components*

Full size table

Currently, with the increase in the cost of land, higher demand for certified wood, and competitiveness in livestock production, there is a tendency to incorporate higher market value and rapid growth tree species, such as African mahogany (*Khaya ivorensis*), Indian neem (*Azadirachta indica*), Teak (*Tectona grandis*), Brazilian mahogany (*Swietenia macrophylla* King), and Ipê Rosa (*Tabebuia rosea*) (Lourenço Junior et al. 2010). Additionally, different grass combinations with timber trees, fruit trees, food plants, fiber-producing plants, medicinal plants, and trees that produce oil and fat have also been tested in the Amazon region (Barros et al. 2003; Maneschky et al. 2008; Garcia et al. 2009; Costa et al. 2010b; Silva and Schwartz 2019). Besides the meat, milk, and wood outputs, the silvopastoral systems are used to produce raw material for food, cosmetics, and biofuel industries.

Silvopastoral systems have been validated in experimental fields of the Brazilian Amazon, with outstanding results in terms of forest and forage production (Oliveira 2011), animal performance (Lourenço Junior et al. 2006; Magalhães et al. 2011; Joele et al. 2013), thermal comfort (Garcia et al. 2011; Silva et al. 2015; Santos et al. 2020), and animal health (Moraes Júnior et al. 2010). The favorable results achieved with buffalo production in silvopastoral systems reveal the importance of management for the productivity and sustainability of livestock raising in the Amazon (Castro et al. 2008). For instance, carcasses from buffaloes raised in silvopastoral system presented more prime cuts, associated with better-texture meat, within the standard parameters for good tenderness, characteristic color traits, and suitable chemical composition (Joele et al. 2013). Thus, these models have been transferred and adopted by private properties in the Brazilian Amazon, for the buffalo and cattle production as well.

Meat production

The buffalo meat is an attractive product for consumers, characterized by a dark red color usually attributed to a higher myoglobin content (Tateo et al. 2007), with white fat interspersed, characteristics that consumers associate with good organoleptic qualities. Additionally, its fibers are thicker than those from beef. It is however similar to bovine meat in its basic structure, chemical composition, and taste properties. The pattern in fat deposition is slightly different from that of beef, with less accumulation of inter and intramuscular fat, which results in poorer marbling scores (Rodrigues and Andrade 2004).

Depending on buffalo age, variations in the percentages of fat in the carcass will inevitably occur (Infascelli et al. 2004). The carcass and fresh meat quality of buffalo meat obtained from 10-month-old male buffalo calves are more tender than the meat from adult animals; therefore, the animal should be slaughtered at younger ages in order to obtain better carcass yields and meat quality (Singh et al. 2018).

The chemical components of buffalo meat are the same as those in beef but in variable proportions. Buffalo meat has a lower degree of marbling, leaner meat, more protein, greater pigmentation, and more dry matter than bovine meat. It has 9% less cholesterol, 10% more minerals, and has 55% less calories and 10% more proteins, and a higher concentrations in K, Mn, Fe, Zn, Cu, and P (Tamburrano et al. 2019). In addition, buffalo meat has PUFA levels of 24.3% vs. 22.3% and n-6 fatty acid levels of 23.7% vs. 21.5% in comparison to beef (Infascelli et al. 2005). Due to these similarities and, in some cases, superiority in terms of nutrient composition compared to conventional meats (beef) and white meat (chicken), buffalo meat is an important source for the production of transformed products, of exceptional quality, such as local smoked sausages (Neres et al. 2014).

For many decades, buffaloes raised in the Amazon region were fed a very fibrous diet, with low levels of protein and energy, with predominance of native grasses. For this reason, they developed adaptations in their digestive system, which allowed them to increase efficiency of using fibrous material (Batista et al. 1982; Wang et al. 2020). It led buffaloes to have a better feed conversion ratio than bovines when they are fed lower quality forages (Kandeean et al. 2009). This indicates that buffaloes have an enormous potential for meat production in these very harsh conditions.

Studies with different buffalo breed/types and production systems demonstrate profitable performance for meat production when buffaloes are adequately fed. Acceptable performances in native pasture ecosystems are obtained when animals are managed on pasture where grasses with good forage availability and quality, such as *Echinochloa polystachya*, *Hymenachne amplexicaulis*, *Leersia hexandra*, *Oryza* spp., and *Paspalum repens*, predominate in the herbaceous strata. In pastures with a predominance of *Paspalum fasciculatum*, grass with lower nutritional value and reduced forage availability, weight performance is slightly reduced (Camarão et al. 2002).

Previous studies carried in the Brazilian Amazon have shown differences in weight gain among more specialized production systems, such as intensive or semi-intensive rotational grazing, compared to

those considered less specialized, as continuous grazing (Table 2). This comparative set of results shows a positive increase in performance over the years that occurred as a consequence of the development and adoption of diverse specific technologies to boost the buffalo productivity. In general, the more technologies are incorporated in the system of production, the greater gains in buffaloes' growth are observed. Nonetheless, an occasional lower weight gain in rotated and semi-rotated system pastures may occur if low stocking rates are adopted for these systems (Kee et al. 1991).

Table 2 Mean performance of water buffaloes for meat production according to buffalo breeds/type raised in different ecosystems and production systems in the Amazon

Full size table

Despite of the newest technologies available, buffalo farming also presents some limitations regarding its profitability, particularly in extensive systems. Lack of infrastructure and electric power supply, difficulties in controlling production and implementing productive techniques, and the lack of continuous adequate sanitary practices and mineral supplementation of the herd are not uncommon in the extensive farming in remote rural properties (Barbosa 2005). In this context, confinement arises as an interesting alternative for finishing a part of the animals when available forage is not sufficient. The system of rearing buffaloes in confinement may be a viable management strategy, being a production intensifier and, consequently, with positive consequences on animal productivity, during certain periods of the year. Such approach allows redirecting animals from rangeland farms to agro-industrial poles engaged in buffaloes' confinement and finishing, which are strategically established closer to the slaughterhouses.

However, in the Amazon, the high market prices of corn and soy, the main ingredients for the feedlot animal diet, might limit the intensification possibilities. Additionally, the growing demand for a more rational use of feed resources worldwide has increased the need for research on the use of alternatives for animal nutrition, in order to avoid ingredients also used for human consumption (Calabrò et al. 2014). Therefore, grain replacement, especially corn and soy, by other energy sources in ruminant feeding, such as food industry by-products from the Amazon, becomes of high social, economic, and environmental importance. Thus, a very important tonnage of crop by-products produced locally would no longer be discarded into the environment. In this sense, research has successfully driven Amazonian agricultural and food industry by-products to feed ruminants, with positive results on meat and milk production. By-products derived from the processing of palm oil (*Elaeis guineensis* Jacq) (Lourenço Junior et al. 1998; Costa et al. 2009; Bringel et al. 2011; Santos et al. 2014; Pinho et al. 2016; Nahúm et al. 2019; Silva et al. 2020), coconut (*Cocos nucifera* L) (Souza Júnior et al. 2011; Santos et al. 2017), cupuaçu (*Theobroma grandiflorum* Schum) (Rodrigues et al. 2015), murumuru (*Astrocaryum murumuru*) (Menezes et al. 2016; Lima et al. 2020 in press), babaçu (*Attalea speciosa*) (Faccini et al. 2017), Brazilian nut (*Bertholletia excelsa* Bonpl.) (Budél et al. 2017), and Açai palm (*Euterpe oleracea*) (Oliveira et al. 2020b) have been converted at a low cost to feedstuffs for buffaloes, bovine, and sheep as well.

In a study that compared physical and chemical characteristics of carcasses from crossbreed Murrah/Mediterranean steers raised in a traditional pasture system or in a silvopastoral system with supplementation based on Amazonian by-products, animals from the latter group had better carcass conformation and fat distribution. Additionally, significant differences in the marbling of the Longissimus dorsi muscle and the weights of the hindquarters were registered, with an increase in the production of the prime cuts (Joele et al. 2013). A complementary study showed that the meat produced from buffaloes fed with concentrate based on coconut meal had a higher percentage of stearic acid (C18:0) and linoleic acid (C18:2), which have beneficial effects to human health (Joele et al. 2014).

Additionally, totally confined feedlots offer the advantage of increasing daily weight gains by comparison to pasture-based systems. This management strategy can be used in smaller properties or in large feedlots. For instance, in a private confinement carried out in 2019 in Tomé-Açu, Pará state, buffaloes fed a diet based on dried distillers' grains barley, corn silage, and cultivated pastures had an average daily weight gain of 1.02 and 1.12 kg (Fig. 6). These animals entered the production system with an average live weight of 397 and 218 kg, and were slaughtered with an average weight of 517 and 433 kg. The animals remained in confinement period for 117 and 192 days, and were slaughtered respectively at around 36 or 18 months old, the latter intended to produce premium meat (Rodrigues 2021 in press). As confined buffaloes rapidly gaining weight generate significant amounts of metabolic heat, some precautions must be taken in order to always provide animal welfare and avoid thermal stress. In outdoor confinements, high temperature and humidity and animal manure accumulation can cause discomfort and, consequently, reduce feedlot economic performance (Costa et al. 2002). Thus, beyond the regular sanitary measures to guarantee the animal health, additional practices to control the physical environment, quality and water availability, and animal thermal balance must be taken to increase confined buffalo productivity (Garcia 2013).

Fig. 6

figure 6

Confinement of buffalo steers (a) in Tomé-Açu, Pará state, Brazil, and vacuum-packed smoked sausage made using buffalo meat (b) (photo courtesy: a Silva, J.A.R.; b Lourenço Junior, J.B.)

Full size image

Buffaloes slaughtered after being finished in a feedlot present desirable features on sensory panel testing, and therefore the use of young buffaloes for meat production with excellent sensorial qualities should be stimulated (Naveena and Kiran 2014). Studies showed that consumers in Pará state accept better buffalo meat based on characteristics such as taste, color, succulence, and tenderness (Marques et al. 2016; Pontes et al. 2018). Nonetheless, in order to improve the commercialization of buffalo meat in the local market, it is necessary to process young animals, improve traceability mechanisms, standardize, and properly label the final product being sold. In Pará state, the majority of consumers of animal origin products (90.9%) state that they do not consume meat from buffaloes, although being

aware of the large population of these animals raised in the region. According to the interviewed, this is because buffalo meat is not available in local markets (52.7%) and that they are not aware of its benefits (43.9%). However, 90% are willing to include buffalo meat in their meals. This represents a commercial opportunity as long as actions are taken that will increase its supply and regulate the distribution to markets where buffalo meat is sold, and also that public and private institutions involved in the production chain intensify marketing efforts in order to promote its benefits (Marques et al. 2015).

On the other hand, there is a part of consumers in the Amazon that regularly and consciously acquire the “baby buffalo” meat. According to the classification of the Buffaloes Breeders Association of Pará Sate, the expression “baby buffalo” is used for animals that are slaughtered between 18 and 24 months old, with 400-500 kg of live weight. The meat of such animals has a very good taste with less fat and cholesterol. This meat is sold in Belém, Pará, being highly appreciated by consumers with higher schooling and income (Hampson et al. 2018). This type of consumer is well informed, pays a high price for “baby buffalo” steaks in the market, and perceives it as a healthier meat. Notwithstanding, among the secondary cuts, such as chuck steak, the prices in the local market are not high. One alternative to enhance the profit is to aggregate value to these cuts by transforming them into derivative products such as canned foods or hamburgers (Neres et al. 2016), smoked sausage (figure 6) (Neres et al. 2014), and dried meat or jerked beef (Lourenço Junior et al. 2015), which could be an incentive for meat processing in local industries.

Milk production

One of the most important products of buffaloes is milk. In many countries, milk is the main purpose of raising buffalo, especially in Italy (Borghese 2011) and some Asian countries (Zhang et al. 2020), unlike in Brazil, where most of the buffalo herds are used in meat production. However, Brazilian buffalo milk production is an expanding activity. Currently, only 17% of the 437,000 females raised in the country are routinely milked and 85% of their milk is used for the industrial production of cheese or other dairy products. Nonetheless, milk production has shown excellent results so that the market uptake of certified-origin milk increased more than 800% from 2001 to 2018. There are an estimated of 150 buffalo dairy industries in Brazil, which annually transform 75 million liters of buffalo milk in 22 thousand tons of dairy products, generating gross annual revenues of around US\$ 156 million for the industries and about US\$ 41 million for the farmers (Bernardes 2013). Thus, buffalo milk production has been considered an alternative for the improvement of social and economic aspects of the agricultural sector through the transformation and commercialization of its products.

Buffaloes have exceptional productive longevity, especially when they are well managed and receive adequate feed to meet their nutritional demands for maintenance and production (Marques et al. 2020). In Brazil, buffaloes generally produce between 1500 and 4500 L of milk per lactation, and the average of the national herd ranges from 1482 to 1650 kg of milk (Ramos et al. 2006). In the Brazilian Amazon, buffalo milk is produced in properties that vary from semi-subsistence to intensified farms. The small farms are characterized by extensive and low-technology production, which results in reduced

productivity. In general, these properties are located in flooded areas and distant from the consumer centers, which hampers efficient flow of production and does not stimulate the development of their full productive potential. Nevertheless, there are numerous properties in the Brazilian Amazon that are developing buffalo farming for milk production in cultivated pastures of good availability and nutritional value (Quinzeiro Neto et al. 2014). In cultivated pastures of *Brachiaria* and *Panicum* in the Eastern Amazon, Murrah, Mediterranean, and crossbred animals produced, in a daily milking, 1806 kg of milk over 262 days with 6.96% fat (Marques et al. 2020). Generally speaking the more intensified a system of production proves to be, the greater the buffaloes' response to milk production (Table 3).

Table 3 Milk production of Baio type, Mediterranean, Murrah, and crossbreed Murrah-Mediterranean buffaloes from Eastern Amazon

Full size table

Buffalo milk has specific characteristics that differentiate it from any other type of milk. Its values of lipids, proteins, lactose, total solids, and mineral residue are of nutritional significance. One of the most remarkable characteristics of buffalo milk is its completely white color due to the presence of vitamin A and the absence of carotenoid pigments (Fig. 7). Therefore, butter and milk produced from this milk are completely white. Another important aspect of this milk is that even though it does not have much more lactose compared to bovine milk, it has a sweeter taste (Hühn et al. 1991).

Fig. 7

figure 7

Water buffalo milk and dairy goods produced in Marajó Island. Fresh milk and cheese (a); traditional fresh cheese (b); buffalo mozzarella (c), and buffalo yogurt with an addition of natural Amazonian fruits pulp (d) (photo courtesy: a-d Lourenço Junior, J.B.)

Full size image

Compared to bovine milk, buffalo milk has 33% less cholesterol, 48% more protein, 59% more calcium, and 47% more phosphorus (Nascimento and Moura-Carvalho 1993). Other similar studies have described the superiority of buffalo milk properties compared to bovine milk, in terms of chemical composition (Hühn et al. 1991; Figueiredo et al. 2010). These attributes are very interesting to both industry and consumers because products made from buffalo milk have a higher market value. Paradoxically, however, there is still a lack of production in order to completely fill the market niches that pay better prices for premium products. The growing interest in the elaboration of buffalo dairy products is also associated with its high level of fat, lactose, and minerals, which have great nutritional value and may complement the daily requirements of children and adults (Neves 2002). Regarding the industrial yield, buffalo milk is 40% more profitable than the bovine milk for transformation into dairy products (Teixeira et al. 2005).

Among the products elaborated in Brazil from the buffalo milk, mozzarella cheese, the typical fresh cheese first developed in Italy in the sixteenth century and produced exclusively with buffalo milk (Jana and Mandal 2011), may be highlighted. Mozzarella has a unique flavor, aroma, and texture and it is commercialized in several shapes, such as balls, knots, braids, or bars, being packed in serum or not (Neves 2002). The mozzarella produced in the Amazon region is exported to other regions of Brazil and to other countries. However, the most important dairy product in the Amazon is the Marajó cheese, an artisanal product that has been produced for more than 100 years and represents the socioeconomic basis of small farmers living in the Marajó Island (Kamimura et al. 2019). This genuine product from Pará state has a protocol of production established and protected by law (Adepará 2011) and has potential to reach international markets. In addition, other cheeses are made in local industries in the Brazilian Amazon, such as the Minas Frescal, Provolone, and Ricotta cheeses (Hühn et al. 1991).

Other buffalo milk-derived products have excellent physical and chemical characteristics and are good alternatives for human consumption (Neres et al. 2014). For instance, ice cream enriched with açai (*Euterpe oleracea*) pulp has been suggested as functional food for human health (Monteiro et al. 2015). Last but not the least, the “milk jam,” a pasty-consistent and caramel-colored sweet, and yogurts enriched with Amazonian fruits pulp, such as açai (*Euterpe oleracea*) (Oliveira et al. 2011), mango (*Mangifera indica*) (Neres et al. 2012), cupuaçu (*Theobroma grandiflorum*), Brazilian nut (*Bertholletia excelsa*) (Siqueira et al. 2011), and pitanga (*Eugenia uniflora*) (Modesto Júnior et al. 2016) are goods with considerable market potential that have been on the focus of the industries and consumers due to their authentic and pleasant flavors.

Towards a new production paradigm

One of the most remarkable traits of water buffaloes is the rusticity and adaptation abilities. This characteristic promoted the false idea that buffalo is a species that would have a high level of production under any environmental condition. However, the animal productivity is related to adaptability, and heat stress appears to be the major factor which negatively influences buffalo production in many parts of the world as Asia (Manjari et al. 2015; Liu et al. 2019), South America (Barros et al. 2016; Galloso-Hernández et al. 2020; Pereira et al. 2020), Europe (Costa et al. 2020), and Africa (Megahed et al. 2008). In this sense, the water buffalo, like any other species, needs to be properly managed in order to reduce exposure to adverse environmental factors and to guarantee its health, welfare, and a high level of productivity.

The most part of the Brazilian Amazon is under the influence of wet equatorial climate, characterized by consistently high temperatures (daily average air temperature varying from 24 to 26°C), with plentiful precipitation, high air humidity, and very little annual temperature variation. This combination has proved to be challenging to livestock productivity (Garcia 2013). Currently, global warming is increasing, jeopardizing ecosystems and food security, as it impairs the worldwide plan to enhance sustainable animal production in the next decades to satisfy the growing demand for animal-sourced foods. It is now well accepted that the increasing concern with the thermal comfort of agricultural animals is justifiable

for nations located in temperate zones where heat loads are becoming more frequent as well for countries in the tropics (Bernabucci 2019). In general, in warmer zones such as the Amazon, thermal stress is one of the main problems in animal production that reduces the weight gain, milk production, reproductive efficiency, and work capacity (Moraes Júnior 2008; Magalhães et al. 2011).

Since it is expected that farming systems will be progressively affected by climate change and the frequency and magnitude of heat stress events will increase in the coming decades, studies on heat stress mitigation and identification of more resilient animals become of the utmost importance (Giro et al. 2019; Ji et al. 2020). In practice, the difficulty in determining an accurate heat stress level of buffaloes in equatorial zone has been stimulating systematic studies about more adjusted thermal indexes to identify mitigation requirements (Silva et al. 2015). Recent studies showed that beyond the classics Temperature and Humidity Index-THI (Thom 1959) and the Black Globe Temperature and Humidity Index-BGHI (Buffington et al. 1981), the Climate Conditions Comfort Index for Buffaloes (CCCIB) and the Environmental Comfort Index for Buffaloes (ECIB) (Silva et al. 2015) are the most efficient biophysical indexes to evaluate thermal stress status of buffaloes raised in the Amazon (Pantoja et al. 2018).

In spite of their adaptability to diverse environmental conditions, water buffaloes have species-specific anatomical features, such as a high melanin concentration in skin and hair, and a small density of sweat glands and hair follicles. Such attributes lead buffalo bodies to absorb a great deal of solar radiation. In addition, buffaloes possess a less efficient evaporative cooling system due to a rather poor sweating ability, consequent of their apocrine-type sweat glands, which are inefficient for body heat elimination (Marai and Haeeb 2010). Thus, under intense solar radiation, buffaloes may undergo a series of drastic changes in biological functions that include depression of feed intake, disturbances in water metabolism, impaired protein, energy and mineral balances, enzymatic reactions, hormonal secretions, and blood metabolites (Moraes Júnior et al. 2010; Garcia et al. 2011; Silva et al. 2014; Joset et al. 2018).

For the majority of domestic species, it has been demonstrated that body temperature increases in response to enhanced air temperature that worsens with high humidity and intense solar radiation, as it occurs in the Amazon. When homeothermic animals are submitted to hot environments, they employ various thermoregulation mechanisms in order to attain thermal equilibrium. These mechanisms dissipate thermal energy to avoid overheating through generalized vasodilation, and increase in peripheral blood flow, sweating, and respiratory rhythm. In this context, alterations in rectal temperature and respiratory frequency are the clinical parameters typically used to evaluate thermal comfort and adaptability of an animal to adverse conditions (Silva et al. 2011).

In buffaloes, the heat loss through breathing (panting) is more efficient than sweating, reinforcing the importance of the respiratory system for the buffaloes' homeothermy. Normal respiratory range of water buffaloes varies between 18 and 30 breaths/minute for animals in thermal comfort (Shafie 1985). Besides respiratory frequency, the rectal temperature and heart rate rapidly raise due to the increase in air temperature. In a study carried out on Marajó Island in the hottest hours of the day (2:00 pm) during

the dry season, the respiratory frequency of buffaloes raised in an unshaded traditional system was 53.49 ± 20.48 compared to 30.30 ± 7.13 from buffaloes raised in a shaded system. Similarly, rectal temperature was higher when animals were raised in an unshaded traditional system especially during the hottest hours of the day (10:00 a.m., 2:00 p.m., and 6:00 p.m.), with values of 38.63 ± 0.50 , 39.19 ± 0.59 , and $38.65 \pm 0.51^{\circ}\text{C}$, respectively (Joset et al. 2018). These results showed that there was higher accumulation of body heat and more demand for energy for thermolysis in the buffaloes exposed to direct solar radiation, reducing the available energy for milk or meat production (Garcia et al. 2011).

Since buffaloes have a dark coat and intensely absorb infrared radiation, the skin temperature can be an important indicator of thermal stress due to variation in climate that happens throughout the year, mainly due to seasonal temperature increases (Barros et al. 2016; Brcko et al. 2020). Amazonian environment has a high potential to cause thermal stress in buffaloes during the afternoon when the temperature is higher, and the use of shade is necessary in order to reduce the directly radiant energy transference from the environment to the animals just as to facilitate the dissipation of body heat (Moraes Júnior et al. 2010; Garcia et al. 2011; Silva et al. 2014; Pantoja et al. 2018).

In a thermal stress condition, buffaloes attempt to reduce the production of endogenous heat, reducing the dry matter consumption and consequently the metabolic rate. A reduction of serum concentration of triiodothyronine and thyroxine hormones and a significant increase of cortisol were observed in buffaloes kept in unshaded pastures in the Eastern Amazon (Silva et al. 2014). Furthermore, various adaptive behavioral mechanisms have an important role to promote thermal comfort, such as searching for shade and cooler areas, changing stance to reduce muscular activity, and increasing water intake. In order to aid in maintenance of homeothermy, stressed buffaloes try to be immersed in water or mud (Ablas et al. 2007). However, freshwater is a finite and precious resource and must be conserved so that interferences of animals to bathe must be avoided. Fortunately, it has been shown that immersion in water is not essential for the survival of buffaloes since they can normally maintain all physiological and behavioral features as long as adequate shade is available (Moraes Júnior et al. 2010; Garcia et al. 2011; Joele et al. 2016). The adoption of silvopastoral systems, a productive strategy that incorporates the use of tree in pastures, reduces the negative effects of solar radiation, provides greater thermal comfort to the animals, and increases animal welfare and productivity (Silva et al. 2014; Santos et al. 2020). A recent study carried on Marajó Island proved that buffaloes graze and ruminate longer when they are raised in pastures in which shaded areas are available (Almeida et al. 2019).

As previously stated, silvopastoral systems are an alternative for tropical agriculture and ranching, and they have the objective of optimizing the land use and are able to integrate livestock, forage species, and trees (Castro et al. 2008; Joele et al. 2016). When these systems are associated with intensively rotated pastures, an alternative production system results, which has higher productive indexes and provides greater comfort to animals due to the shade and high-quality forage available in the pastures (Oliveira 2011; Pezzopane et al. 2019). This type of arrangement is based on an efficient use of natural resources and on the optimization of forage cultivation and animal development, which increases overall system productivity. Greater yields per area can make cattle ranching viable in areas with

previously degraded pastures, avoiding deforestation and promoting the recovery of degraded areas (Lourengo Junior et al. 2006; Moraes Júnior et al. 2010; Magalhães et al. 2011; Joele et al. 2013).

Due to the benefits from greater animal comfort, productivity is optimized through greater production of meat and milk. In well-managed silvopastoral systems, the weight of calves at weaning is higher (Moraes Júnior et al. 2010). In addition, the time required for males to reach slaughter age is decreased, and females reach the puberty earlier, increasing their productive life. In fact, water buffaloes raised in pastures with different conditions of natural shading in the Brazilian Amazon had largest weight gains during dry season when animals grazed in partial or total shaded areas (Magalhães et al. 2011). Furthermore, when compared the meat from buffaloes raised in traditional to silvopastoral systems, the latter tended to have a higher proportion of polyunsaturated fatty acids, which is considered healthy for humans (Joele et al. 2016).

Final considerations

Buffaloes have high potential for meat and milk production and are an alternative in the use of altered areas of the Amazon, aiming to produce protein of excellent quality. However, in a recent past, the low profitability of buffalo farming in traditional production systems in the Amazon made this activity economically unattractive. This fact induced the ranchers to transfer part of their animals to areas with pastures cultivated in dryland, or to invest in the recovery of these areas, when altered, as a way to increase productivity and make the activity competitive.

From a biological point of view, buffalo raising is favored in the Amazon due to the climate, soil, genetic variability of forages, animal adaptability, and physical space. In this region, for a long time, meat production was considered the main activity of buffalo farming. Buffalo meat has an attractive flavor and high nutritional value, and is healthier because it contains less saturated fats and low cholesterol, being suitable for people of all ages as a source of protein, as it contains all essential amino acids. Additionally, it is an important source for the production of derivatives of exceptional quality.

Until a few decades ago, buffaloes were not used in commercial milk production in the Brazilian Amazon, mainly because they were produced in extensive systems, in areas of flooded and remote lands, generally with difficult access to consumer centers. However, milk production in cultivated pastures, of good availability and good nutritional value, is a viable alternative to increase the socioeconomic standard of small and medium farms, considering the buffalo's milk productivity and its exceptional productive longevity, docility, fertility, and disease resistance, especially when well managed. For this reason, currently, dairy farming is growing, considering the potential of the species to produce milk, at low costs, as well as the growing demand of the consumer market for buffalo dairy products. The yield of processing milk, about 40% higher than that of bovine milk, is another favorable characteristic. However, despite the advances, there is a need for adoption on a wider scale of technological innovations generated by regional research and teaching institutions, such as the Brazilian

Agricultural Research Corporation-Embrapa and the universities Federal Rural University of Amazonia-UFRA, Federal University of Pará-UFPA, Federal University of Western Pará-UFOPA, and State University of Pará-UEPA.

In the near future, crop-livestock-forest integration systems, including silvopastoral ones, which involve animal production integrated with silviculture, will gain more and more relevance, as they are based on the productive incorporation of areas altered by inappropriate previous use. These systems add value to the land, by incorporating the tree component, enable better nutrient cycling and greater animal comfort, and represent an attractive alternative to maximize land use, with sustainability. Buffalo farming for meat and milk production fits perfectly in this context, with productivity and beneficial socioeconomic effects. The greatest highlight will be the perfect identity with the Amazonian environment, which allows the production of the “organic buffalo,” different from the “green buffalo,” currently produced, as it will be an animal bred in different prophylactic and health care conditions. These will dismiss the use of drugs and pesticides that can cause damage to humans and the Amazonian ecosystems.

The intensive production of buffalo meat and milk on pasture cultivated in dryland is fully sustainable from a biological, economic, environmental, and social point of view. The biological one uses long cycle pastures and an increase in their quantitative and qualitative production. In the economic aspect, livestock systems in intensive rotational grazing show results three to five times higher than traditional ones, which makes the activity extremely profitable. In environmental terms, the adoption of technology allows the recovery of altered areas, which reduces the pressure of deforestation in new forest areas. In the environmental point of view, the adoption of technology allows the recovery of altered areas, which reduces the pressure of deforestation in intact areas. Society benefits to the extent that buffalo livestock effectively contributes to keeping people in the countryside, avoids rural exodus, and generates jobs in the processing, transportation, distribution, and commercialization of meat and milk, and their derivatives, throughout the production chain.

Data Availability

Not applicable.

Code availability

Not applicable.

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Contributions

JARS, ARG, AMA, and JBLJ substantially contributed to the conception and design of the article; JARS, ARG, and JBLJ performed the literature search and interpreted the relevant literature; JARS, ARG, and ASB prepared the tables and figures; JARS, ARG, and ASB drafted the manuscript; ARG, AMA, and JBLR critically revised the work.

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Ethics declarations

Ethics approval

Not applicable.

Consent to participate

All the authors consent to participate in publication.

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