Similarities and Differences between River Buffaloes and Cattle: Health, Physiological, Behavioral and Productivity Aspects

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Abstract: The river buffalo is an emerging production species worldwide; indeed, it is overtaking other cattle as a producer of meat and milk in some countries. Though both species belong to the Bovidae family, they show significant anatomical, physiological, and behavioral differences due to their different phylogenetic positions. The river buffalo is a rustic animal that can benefit from low-quality, fibrous forages due to its digestive system, in contrast to beef cattle or dairy cows. Besides, the buffalo cow’s reproductive apparatus has fewer cervical muscle rings and a shorter vagina and cervix. This species has maintained its seasonal breeding pattern, also in contrast to Bos indicus and Bos taurus. Even though buffaloes have an inefficient thermoregulating system, scarce hair, and a thicker epidermis, they are more resistant to tropical weather conditions if water for wallowing is available than dairy cows, which in turn adapt better to temperate zones. Due to the morphology of the river buffalo’s mammary glands, they produce less milk, while their conical teats with narrower sphincters decrease predisposition to mastitis compared to dairy cows. Thus, the study of the anatomical and physiological differences among river buffalo, Bos Taurus, and Bos Indicus will allow the implementation of strategies to improve the former’s productivity while also increasing welfare levels according to the production system in which they are raised.

Keywords: Behavior, buffalo production, buffalo disease, cattle, river buffalo, dairy.

1. INTRODUCTION

In recent years, the river buffalo (Bubalus bubalis) has emerged as a species with a promising future as an alternative economic activity and, more importantly, a source of food for human consumption [1]. Due to this surge, it has rapidly replaced other bovines (dairy and beef cattle) in production units due to its following capacities,

- to adapt complex habitats (river buffalo welfare),
- an excellent human-animal relationship [2-4],
- its reproductive and productive performance, which led to an expansion of herds [5-11].

River buffaloes are raised primarily in humid tropical regions. They now offer cattle-breeders an option for diversifying ranching species thanks to its capacity to adapt to environments where soils with deficient drainage predominate [12, 13]. This species has also shown the ability to efficiently utilize both natural and induced pastures generally of low-to-medium quality [14-16]). Given these conditions, the river buffalo has been raised for two, or even three, purposes, namely,
milk and meat production, and as a draft animal, with some breeds traditionally used for the production of mozzarella cheese. According to data from the United States Department of Agriculture (USDA), global production of fluid milk in 2018 was 605.8 million tons (MDT); 83.4% of this volume corresponded to cow’s milk, the rest from other species, with the river buffalo contributing 13% [17].

Regarding milk production, buffalo cows in Italy lactate for an average of 270 days, generating 2,462 kg/lactation with 8.07% and 4.65% of fat and proteins, respectively. In comparison, Holstein dairy cows have an average production of 9,690 kg/lactation with 3.77% of fat and 3.37% of protein. This indicates that buffalo cow milk has a high compositional value, while dairy cows produce more significant quantities [18]. Recent studies have also evaluated the physicochemical and quality properties of buffalo meat, and value-added products made with it (e.g., hamburgers and breaded meats, among others) that compete for consumer preferences with cattle-based products. In this context, though dairy cows, beef cattle and buffaloes all produce meat and milk, and are members of the Bovidae family, they present significant phylogenetical, morphological, and behavioral differences. The objective of this paper is to elucidate and analyze the anatomical and physiological characteristics and production systems of buffalo cows and compare them to those of cattle to identify key differences and similarities among these animals. Besides, this review seeks to verify the knowledge required to avoid mistakes when breeding buffaloes or adapting them to different production systems that could compromise their welfare and, as a consequence, undermine the productive and reproductive performance on which the profitability of dairy buffalo production units depends.

2. ANATOMY AND PHYSIOLOGY

Like dairy cows and beef cattle, river buffaloes belong to the Bovidae family. However, they occupy distinct phylogenetic positions and show anatomical, physiological, and behavioral differences due to their different karyotypes [19, 20]. They are incompatible for cross-breeding because the river buffalo belongs to the Bubalinae sub-family, while cattle belong to the Bovinae sub-family [21]. The main anatomical-physiological differences are found in the digestive tract, reproductive apparatus, thermoregulating system, mammary gland, and hooves [15] (Figure 1), which are associated with differences in productive and reproductive performances [22]. In the following sections, the most important morphophysiological and reproductive aspects that distinguish the river buffalo from dairy cows and beef cattle are described at length. See Figure 1 [1, 15, 21-35].

Digestive System

The digestive system of ruminants comprises several compartments – rumen, reticulum, omasum, abomasum – that allow these animals to hydrolyze and...
ferment the fibrous portion of the walls of the cells of forage plants. Though both buffalo and dairy cows are considered large ruminants [36]), river buffaloes present differences in their digestive system, such as longer length and higher capacity of the gastrointestinal tract, faster tract passage, more efficient digestion, and ruminal contractions, and microbiota with distinct characteristics (populations of microorganism, pH, protein synthesis), among others [13, 37]. These differences explain why river buffaloes can efficiently utilize the nutrients in food, especially in production systems where forages of low-to-medium quality predominate.

Studies by Leao et al. [38] that compared the digestive tracts of buffaloes with domestic cattle found that the former had higher food storage capacity because the rumen-recticum complex is significantly larger (Table 1). A study of adult animals demonstrated that the mean rate of food retention in domestic cattle is slower than in the river buffalo. However, the latter retained food in the rumen-recticum complex for more time [39]. Several authors have attributed the recent result to more efficient mastication and, consequently, more significant degradation of the fibrous fraction in the rumen [27-29]. Similarly, Sideney and Lyford [40] observed more developed rumen papillae in the buffalo, along with increased absorption of fermentation products [36].

Likewise, the rumen of dairy buffaloes and dairy cows present a diverse population of microorganisms that confer the ability to unfold the Beta linkages of the structural carbohydrates present in pasture [36]). Compared to the cow's rumen, the buffalo presents larger populations of cellulolytic, proteolytic, amylolytic, and lipolytic bacteria and fungi under identical dietary conditions [29, 37, 41, 42]. This enables the buffalo's rumen to degrade the cell walls of forages and the proteins in its diet more efficiently, thus achieving a higher rate of transformation of low-quality forage into volatile fatty acids (VFA) ammonia [30, 43, 44]. A characteristic associated with greenhouse gas production that favors the river buffalo is the prevalence of gas-producing bacteria, which is lower in this species (10%) than in dairy cows or beef cattle (20%). It is estimated that buffaloes produce smaller amounts of methane [13], which can be of value in controlling greenhouse gas emissions.

Regarding the reproductive apparatus of buffalo versus dairy cows, the organs are similar, but the latter's tract has less rigidity, is less muscular and slightly larger and heavier than the tract of buffalo cows [45, 46]. This may explain the high rate of uterine prolapses observed in dairy buffaloes [47]). In a study comparing the biometry of the reproductive apparatus, the weight of the ovaries, the length and width of the right ovary, the number of cervical muscle rings, and the length of the vagina and cervix were all greater in bovines than in Murrah buffaloes, whereas the thickness of the ovaries, the length of the left oviduct, the uterine corpus, and the length and amplitude of the left uterine horn were all higher in buffaloes than in bovines. Carvalho et al. [48] did not find differences between the length and width of the left ovary, the length of the right oviduct, or the length and width of the right uterine horn between these species [48].

**Breeding Seasonality**

Several factors influence breeding activity, including ecological and weather conditions, as these are closely related to the availability of food and the resulting reproductive efficiency. In this context, it is important to mention that dairy cows have been raised in zones using intensive production systems where high-quality food is offered year-round [49]. The breeding seasonality of dairy cows has been influenced and has been seen to decrease, due to the domestication process and the physical-biotic factors that exert effects on this species. However, in some wild animals, as well as in buffaloes and conventional cattle bred in open pasture systems, breeding seasonality continues

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**Table 1: Differences in the Digestive Systems of River Buffaloes and Cattle**

| Indicators                        | River buffalo | Cattle     | Authors          |
|----------------------------------|---------------|------------|------------------|
| Rumen-recticum (kg)              | 7.38          | 4.96-5.72  | Leao et al. [38] |
| Rate of passage through the rumen-recticum(h) | 40.65        | 33.44      | Bartocci et al. [39] |
| Average retention time in the gastrointestinal tract (h) | 57.73        | 64.55      | Bartocci et al. [39] |
| Volatile fatty acids in rumen liquid (meq / 100ml) | 5.3 – 11.2   | 4.8 – 10.4 | Angulo et al. [36] |
| Methane producing bacteria (%)   | 10            | 20         | Mendes and Lima, [13] |
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to be related to daylight hours and the availability of forage [16, 49] (Figure 2). River buffaloes adapt to environments with limited variation in heat and humidity, but when raised in zones far from the Equator with greater thermal and photoperiod variation during the year, their reproductive behavior becomes more varied. In fact, this species has been defined as seasonally polyestrous, with more evident manifestations of estrous in the autumn [16], the season with greater forage availability in tropical areas [50]. See Figure 2 [51].

The periods in which buffalo cows require maximum nutrition (onset of lactation and service) coincide conveniently with the normal growth curve of forage [21] (Figure 2). In the hemisphere north of the Equator, the availability of forage biomass increases as daylight time decreases; consequently, buffalo cows are seasonally polyestrous, short-day breeders, with higher manifestations of estrus in the autumn [16]). The importance of the duration of daylight in seasonal reproduction is well-documented. Melatonin acts on the pineal gland by disinhibiting active secretion of the luteinizing hormone (LH) that, together with the follicle-stimulating hormone (FSH), controls estradiol secretion. However, increased daylight time augments the hypothalamus’s sensitivity, generating a feedback mechanism that lowers the release of LH. This means that there is insufficient estradiol to stimulate ovulation in mammals [16, 52, 53].

In contrast, dairy cows do not present seasonal reproduction because they have been bred under different handling systems with levels of production that guarantee forage availability year-round. Meanwhile, dairy buffalo cows have maintained their pattern of seasonal reproduction even when they are bred in more intensive systems in which forage is readily available [49].

In the northern hemisphere, the optimal mating/service season runs from December to February with births occurring between October and December, followed by weaning in August or September. The two periods of most significant imbalance occur during the mid-term of gestation and lactation. It is important to note that the signs of estrous in buffalo cows are less evident than in domestic cattle, which presents breeders with a challenge. According to Gómez et al. [54], buffalo calves have a mean birth weight of 32-35 Kg with no difference between the sexes, while Martínez et al. [55] reported that an average male calf weighs 36.86 ±3.1 Kg. After birth, young buffaloes usually have their navels disinfected to prevent pathologies like omphalitis and omphalophlebitis, after which they should be fed by the mother within 4-6 hours to allow colostrum intake. In the event that a dam rejects her calf, it is necessary to recur to nursing since one buffalo cow can nourish up to four calves at a time.

Various authors have suggested that weaning is effectuated after 6-8 months [55]. A higher value (260 Kg) was reported by Bavera [56]), while Martinez et al. [55]) observed lower weights (130-154 Kg). Clearly,

Figure 2: The river buffalo’s reproductive cycle and development curve of forages in humid tropical areas of the northern hemisphere. Source: Muñoz-González et al. [51].

![Diagram of River Buffalo Reproductive Cycle](image-url)
this evidence reflects marked differences, likely related to food availability in different study areas [55], the amount and compositional quality of buffalo milk, and its effect on the weight of calves at weaning [54].

Regarding animals selected for meat production, some authors report marked weight gains. For example, Fundora [44] compared the growth of bufalypses and zebu cattle under the same feeding and pasture conditions during a 287-day experiment. They reported weight gain 1.6 times greater for the river buffaloes compared to the zebus. In a study conducted on buffaloes with an initial weight of 130.5 kg that was fed poor-quality forage, the daily weight gain measured was above 0.7 Kg, and those animals reached the slaughtering weight of 475 Kg at 23.1 months of age [31]. Bavera [56], meanwhile, reported weights as high as 550 kg at 24 months of age. The in-canal yield said, however, was only 54% because of the high combined weight of the animal's hide, head, and viscera [25].

Concerning buffalo cows used for milk production, studies have found markedly variable values for the age of the onset of puberty that range from 18-46 months [57]. Under favorable conditions in terms of the season of birth (i.e., if born in summertime), river buffaloes may reach puberty at between 15 and 18 months, while winter buffaloes may do so between 21 and 24 months because, though sufficiently grown at 15-18 months, they would be outside the breeding season [58]. According to Saini et al. [59], female Murrah buffaloes reach puberty at 36.5 months and a live weight of 355.8 Kg, but that under improved conditions of heat dissipation the age at first estrous could decrease to 33.1 months at a mean weight of 322.3 Kg.

The age at first service depends on when the animal reaches sexual maturity; that is when the female is capable of bringing gestation to term and raising her young. This may occur when 65% of the adult weight is reached. According to Crudeli [52], Nelore buffalo cows in Latin America with an average adult weight of 525 Kg should have their first service at around 340 Kg. The age at first service reported by Bedoya et al. [60] was 27.27 ± 1.97 months. It is important to evaluate the female's corporal condition at the moment of service since, for these animals to achieve the maximum reproductive performance, they must present a corporal condition rated at 3.5-4 and 3-3.5 (1-5 scale) at birth and first service, respectively [61]. With a corporal condition of 3.5, pregnancy rates as high as 86% have been obtained [16].

The gestation period in buffalo cows is almost one month longer than in domestic cattle, ranging from 299-340 days [52], with variation by breed: Murrah, 300-306 days; the Mediterranean, 311-315 days; Jafarabadis 330 days; and March buffaloes (Carabao) up to 340 days [16]. This is another property of the buffalo that generates advantages over other species, especially domestic cattle. Finally, about management, Di Palo et al. [62] suggest that the availability of wetlands, swamps, or watering holes may increase the fertility of buffalo cows under conditions of high temperature and humidity by mitigating heat stress [62].

The lactation stage begins after calving, with an average duration of 240-270 days [12]. According to Crudeli [52], studies in Brazil have recorded up to 5,200 Kg of milk per lactation, though under tropical conditions, lower productions are common. The onset of lactation is accompanied by a series of physiological modifications in the buffalo cow's uterus as she recovers from the pregnancy. These changes also prepare her for her next gestation. Studies of this process (puerperium) indicate that uterine involution ends around 18 days postpartum and that the female will experience her first estrous and ovulation on days 37 and 38 postpartum, respectively [16]. Due to the duration of gestation, it is vital to ensure that the time between calving and the subsequent conception does not exceed 60 days, so the ideal interval between parturitions is close to 12 months, but under normal commercial conditions the inter-calving interval should not exceed 13-14 months, and the corresponding conception should occur between days 85-115 postpartum [16]. Martinez et al. [55] found a between-calving interval of 13.93 ± 1.18 months, while Bedoya et al. [60] reported a similar figure of 13.83 ± 1.04 months. The reproductive aspect is of great economic importance because it affects the generational interval that translates into producing more animals in less time and, therefore, higher indices of productivity and profitability.

A direct exploration study conducted in buffalo production units in southeastern Mexico reported weaning ages of nine months at average weights of 245 kg. The onset of puberty was recorded at 15 months at a mean weight of 300 kg, while the first service took place at 23 months and an approximate weight of 360 kg. Gestation was about 300 days, with the animals reaching a weight of 520 kg at first calving
at the age of 33 months. Lactation lasted an average of 270 days, the calving/pregnancy interval was three months, and the calving interval was 390 days (Figure 3).

Thermoregulation

As endothermic animals, buffaloes and cattle are capable of controlling their body temperature by regulating their basal metabolic rate through the mechanism of thermoregulation in which the energy produced by cellular metabolism (catabolism, anabolism) can be partially dissipated by irradiating heat by the organism itself [23, 63]. However, if heat loss is deficient, the animal can suffer heat stress. It is well-known that feedlot cattle are highly sensitive to heat stress because they consume a high-energy diet [64] and are raised in environments that lack adequate shade. Dairy cattle have been bred primarily in temperate zones, but in environmental conditions in the tropics, they are exposed to stressful climatic conditions that compromise both their productivity and welfare. For this reason, cross-breeding is common between Bos taurus and Bos indicus to decrease the metabolic rate, foster heat loss by sweating and increase tolerance for ambient heat. However, this comes with a lower efficiency in milk production [65]. In contrast, river buffaloes raised in tropical regions have an inefficient thermoregulating system under extreme heat conditions. Though this is similar to dairy and feedlot cattle (Bos Taurus), the buffalo possesses certain advantages: scarcer hair and a thicker layer of surface skin (epidermis) with a high quantity of melanin that absorbs heat and gives the characteristic black coloration [66]. Melanin particles trap ultraviolet rays (UV) to prevent them from penetrating the dermis into internal tissue layers, while simultaneously blocking solar radiation from reaching the core of the animal’s body. UV rays are abundant in the solar radiation of tropical and sub-tropical regions, so excessive exposure of the skin can be harmful [23, 66-68]. Another advantageous characteristic of the buffalo is the number of hair follicles: only 135-145/cm² compared to 3,000/cm² in normal zebus-Bos indicus cattle. This feature exerts a double effect on river buffaloes: first, it facilitates heat dissipation; second, it exposes more skin to the direct action of solar radiation [49]. Buffaloes also have a lower density of sweat glands (168 vs. 1680 glands/cm²), though theirs are commonly larger than in cattle and provide greater thermoregulation capacity [16, 49]. These traits explain why buffaloes require shade, flood zones, and wetlands as additional preferential mechanisms of thermoregulation (Figure 4). The body heat of buffaloes in environments with high temperatures can only be kept normal if the animals have shade, ponds, swamps or mud available, or frequent application of water, preferably with a wind current for drying [68], it dissipates body heat, and maintain comfort levels [23]. See Figure 4 [69, 70].

Mammary Gland

Concerning dairy production, there are anatomical-physiological differences between buffalo and dairy cows. However, mammary glands of both species reside in the inguinal region and consist of four quarters that are close to one another and form an
udder [71]. The cistern, located in the ventral part of the gland, functions as a milk storage area that allows the synthetization of diverse quantities of milk depending on its size [71]. The udder of buffalo cow can store 92-95% of the milk in the alveolar compartment, the rest (around 5%) is stored in the cistern. Dairy cows, in contrast, store 20% of their milk in the cistern. The fraction of cisternal milk is available for either milking or nursing the calf before the myoepithelial cells contract in response to the oxytocin that triggers milk ejection [72, 73]. Alveolar milk, however, is available only if it is ejected actively [73]. Unlike buffalo cows, dairy cows have shown more significant development of the udder such that they can synthetize more massive amounts of milk. In addition, they have highly-elastic connective tissue that runs from the abdominal tunic –known as the suspensory system– and allows these cows to store the milk produced by the mammary glands [71]. Meanwhile, dairy buffalo cows are characterized by lower milk production and a less-developed suspensory ligament than dairy cows (Figure 5).

According to Espinosa et al. [74], a related aspect is the morpho-biometry of the teats. Those authors

Figure 4: The effect of heat dissipation in swampy areas can be appreciated using infrared thermography. The puddled water in the swamp and the dry mud help buffaloes lower their body temperature by approximately 6 °C, as shown in these thermograms and digital photographs. a. River buffalo exposed directly to the sun in a tropical region. The surface temperature exceeds 39 °C, over 95% of the body surface (red). b. Buffalo with mud on 85% of its body. An average surface temperature of 30.2 °C is seen in yellow. The areas without mud are visible in red color. c. A buffalo inside the swamp area. Its surface temperature in the yellow regions drops to an average of 29.1 °C. Infrared thermography is a technique used in both veterinary and human medicine to quantify the surface temperature of the skin through visualizations of thermographic changes [69, 70].
analyzed buffalo cows of different breeds, finding that most of those animals (56.46%) had conical-shaped teats with an average length of 6.90 cm. Riera-Nieves et al. [75] examined Holstein dairy cows, and their results show predominantly cylindrical-shaped teats (48.30%) that averaged 5.90 cm in length. Buffalo cows thus have longer, thicker teats with a narrower canal and a tighter sphincter than dairy cows, suggesting a lower predisposition to mastitis but also a possible more difficult milk ejection [72, 74]. Due to the different anatomy and physiology of the buffalo mammary gland, as compared to dairy cattle, numerous authors suggest adapting the milking routine (e.g., vacuum level, pulsation rate, and ratio) to the specific characteristics of these animals (e.g., Caria et al. [76]. Genetic selection means dairy cows now have certain physiological and anatomical characteristics that allow them to produce larger amounts of milk than buffalo cows. Their suspensory ligament and more-developed cistern will enable them to synthesize, transport, and store such quantities of milk, while the shape and size of their teats facilitate the use of milking machines. However, dairy buffalo cows show greater resistance to microorganisms that could predispose them to mastitis. Although the quantity of milk produced is less than in dairy cows, it has a higher dry matter content [76,77].

Allosucking

Allosucking is understood as an infant's action that ingests milk from a female distinct from its genetic mother [78]. This behavior has often been reported in several ungulates, including pigs [79], reindeer [80], cattle, and buffaloes [81] sheep and red deer, among others [82]. See Figure 6 [7, 81]. Many hypotheses have been tested concerning the causes and consequences of this behavior. Roulin [83], for example, postulated that the female that allows the sucking of foreign calves' benefits because she can increase or maintain her prolactin concentration once her own offspring cease to stimulate her teats sufficiently while sucking. This may improve her immunity and resistance to pathogenic microorganisms. Víchová and Bartoš [82] found that allosucking in domestic cattle calves could be a compensatory behavior in case of low-weight births or a means of counteracting nutritional deficiencies. Their studies also showed a higher frequency of allosuckling in female offspring and beef calves compared to males and calves of cross-bred species. Another observation is that sucking decreases in older calves, though a study by Paranhos da Costa et al. [84] did not report allosuckling behavior in the calves of two zebu breeds.
It seems that both buffalo and cattle may express allosucking as a consequence of insufficient calf nutrition [85, 86]. For many years, it was believed that allosucking was a costly behavior that, moreover, entailed the risk that the cow could manifest aggression towards the foreign calf that tried to ingest her milk [83], and/or the transmission of pathogenic microorganisms through milk—as in the case of Johne’s disease—since allosucking and communal nursing are considered risk factors for paratuberculosis in buffaloes [87]. But allosucking can also have positive consequences, such as reinforcing the calf’s immune system through the ingestion of antibodies from a non-biological mother. It is important to emphasize that the monitoring of buffaloes over ten months by Andriolo et al. [88] showed that when maternal lactation of foreign offspring is allowed, the mother does not neglect her own offspring. Those authors further determined that allowing allosucking depends more on individual tolerance than group behavior by dams during lactation. Thus, allosucking has an individual component that reinforces calves’ attempts to nurse.
3. IMMUNE SYSTEM AND DISEASE RESISTANCE

The selection of disease-resistant species or breeds in production units is an ongoing enterprise around the world whose objective is to improve the health, welfare, and productivity of animals [89]. Cattle-breeders are attentive to this because of the economic losses caused by diseases, their treatment, and the culling of animals that fail to satisfy productive and/or reproductive parameters due to sub-clinical conditions [90]. Therefore, it is important to determine the degree of resistance or susceptibility to the most frequent diseases that impact the livestock industry.

Disease prevalence in cattle tends to result in significant economic losses. Animals in tropical areas are especially subject to high incidences of hoof diseases, mastitis, and ectoparasitic infections. River buffaloes, in contrast, manifest high resistance to these types of diseases because their habits and morphophysiology give them low susceptibility. The species-specific thermoregulation habit of wallowing, to give one example, can interrupt the life-cycle of ectoparasites. One consequence of this resistance is that mortality rates in adult buffalo are negligible [24]. Torres [25] sustains that buffaloes suffer lower incidences of mastitis because their anatomical and physiological characteristics generate barriers to the penetration of microorganisms into the cistern of the mammary gland, prevent occlusions of the orifice of the teat, and generate higher keratin levels (which has bactericide and bacteriostatic action) in the teat canal. Moreover, in natural environments with high humidity, this species shows low susceptibility to bacterial and fungal infections of the hooves [22].

Mastitis

In today’s world, the health of the udders of milk-producing animals is important not only for dairy producers but also for consumers who are now more concerned with being informed about the measures taken to ensure the welfare of dairy-producing animals [91]. In the production chain of dairy products in general, mastitis in dairy cattle and buffaloes is a clinical condition that causes significant economic losses. It is considered one of the most serious limitations for this industry worldwide [26, 92, 93]. Reports indicate that *Staphylococcus aureus* (S. aureus) is one of the most important causal agents of this infection and is responsible for contagious intramammary infections in dairy herds [94]. These bacteria cause clinical and sub-clinical mastitis in dairy cattle and buffaloes and pose a potential health problem for humans as well [93]. El-Ashker *et al.* [93] detected the *Staphylococci* in 21.1% of the milk samples drawn from dairy and buffalo cows. The results of a study by El-Ashker *et al.* [95] that analyzed samples from Holstein-Friesian bovines and Murrah buffaloes, for example, detected more samples that carried *Staphylococcus aureus* in conventional bovines as compared with buffaloes.

It appears, then, that dairy buffalo cows have lower incidences of mastitis than dairy cows, a condition attributed to morphophysiological differences in the former, which function as barriers that impede and/or prevent the access of the microorganisms that cause mastitides, such as *Staphylococcus aureus* and *Clostridium perfringens*. The characteristics that provide this marked resistance to the colonization of microorganisms include,

- A higher concentration of melanin pigments;
- A teat canal with a keratin epithelium thicker (than the one in cows);
- The thicker muscle layer of the sphincter around the teat canal (which has more tone, blood vessels, and nerve fibers).

Finally, the teat canal lumen is lower than in dairy cows [73, 96].

Ectoparasites

A study by Ybañez *et al.* [97] detected diverse ectoparasites in dairy bovines (Holstein) and river buffaloes (Murrah). *Haematopinus spp* and *Rhipicephalus spp* (lice and ticks, respectively) were identified, both known to be potential vectors of Mycoplasma spp. All the bovines were found to have ticks, but lice were absent; in contrast, the buffaloes had lice, but only one was found to have ticks. This difference could be due to the river buffalo’s wallowing behavior in mud and the survival mechanism of lice, that is, the ability to close respiratory orifices underwater. These findings concur with the research by Benitez [98], who conducted an assay with infection by the tick *Rhipicephalus*, which is considered the ectoparasite with the most significant negative impact worldwide on dairy cattle. This study used a Mediterranean buffalo calf and a Holstein calf of the same age under identical environmental conditions. Findings showed that the number of mature ticks on these animals corresponded, respectively, to 5.4% and
12% of the initial larvae detected, indicating resistance levels of 94.5% in buffaloes and 88% in cattle, respectively. Observations also found a marked inflammatory reaction in the adherence area of the ticks in the buffalo, a process not seen in the bovine because the buffalo’s immune system was more reactive to the allergenic components in the saliva of the *Rhipicephalus* [98]. Another possible explanation could be that the buffalo’s thicker skin limits the tick’s capacity to anchor its hypostome.

**Reproductive Pathologies**

Motta-Giraldo *et al.* [99] carried out a study that identified reproductive pathologies in buffalo cows and Holstein-Friesian cows in Colombia. Two management systems were examined: simple (one species per farm) and mixed (buffaloes and cattle kept together). The prevalence of reproductive pathologies in the mixed herds was 15.5% in buffalo cows and 55.8% in dairy cows, while the figures for the simple herds were 24.4% and 46.7%, respectively. In both cases, significant between-species differences were found. This study also analyzed zootechnical indicators, where the buffalo cows showed a higher reproductive performance than the cows, expressed in a higher natality rate (84% for buffaloes vs. 72% for bovines), shorter calving intervals and open days, and a lower age at the time of the first birth, as the buffalo cows were more precocious (34.8 months) than the dairy cows (38.59). This occurred regardless of the type of herd but was more marked in the mixed herds than the simple ones [99].

**Lameness**

Cattle lameness is one of the most significant welfare and productivity issues in dairy farming, after mastitis. Lameness is an affection that generates significant economic losses in bovine production units. In the United States, these losses are estimated at around US$21 per dairy cow with clinical lameness [100]. The main direct consequences are decreased productivity, high treatment costs, and deterioration of the body condition, but indirect impacts include the cost of eliminating animals and the loss of milk and derived products due to the therapeutic medications [101]. Reports on buffaloes, in contrast, suggest that this animal is more resistant to these problems, as indicated by De Rosa *et al.* [50] in a study conducted on 42 buffalo farms. They found that lameness with symptoms of limping was virtually non-existent in those animals. Limping is an important problem for the welfare of dairy cattle, usually associated with long-term pain and discomfort. The low incidence of limping in buffaloes could, once again, be due to certain morphological characteristics, since these animals have large hooves, elastic hocks, and thicker limbs that allow them to move in swampy, uneven terrain, and submerge for long periods in water [22]. Another explanation may be the fact that the dietary regimen of buffaloes is low in concentrates [5], compared to that of dairy cows since observations show that diets low in fiber content (<18%) and with a high percentage of carbohydrates and proteins can be responsible for lameness in dairy cows [102]. It is important to note that another factor that may provide resistance to lameness in buffaloes involves the differences in their metabolism compared to cattle [5].

**4. LEVEL OF MILK PRODUCTION ACCORDING TO THE PRODUCTION SYSTEM**

Buffaloes are raised for two purposes simultaneously: producing milk and meat, though a third function may complement this since they can also work as draft animals. Worldwide, they are recognized, especially for their milk production and typical dairy products such as yogurt and mozzarella cheese. It is important to emphasize that buffaloes currently provide 13% of global milk production [6-8]. However, their contribution to the Americas remains low due to its recent introduction and a slow response by producers [103]. Much remains to be learned about the river buffalo. Virtually all aspects of production and its potential for generating products that can be inserted into markets for milk, meat, and their derivatives [103], especially where this species has been introduced recently into settings where it was not traditionally reared. For this reason, it is important to document the advantages and challenges that this species presents since these data could play a key role in promoting the political will required to support buffalo farming, and in convincing farmers to evaluate this species for their agricultural activities [9]. The academic sector must also assume responsibility for disseminating this information by analyzing options for developing the river buffalo as a potential alternative source of income and supporting the development of tropical regions where this species currently receives little attention [104].

Different production systems exist for buffalo cows and dairy cows, but the most common types are called intensive, semi-intensive, and extensive. Intensive systems predominate in temperate climate zones, while
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semi-intensive and extensive production units are more frequent in tropical zones, mainly in the form of double-purpose systems. The main features that differentiate among these systems include the manner of exploiting the area, technological levels, zootechnical orientation, the species of cattle raised, and commercialization of products [105-107]. Because of their rustic nature, river buffaloes are associated with tropical regions characterized by swampy areas, high temperatures, high humidity, and low-to-medium quality forage [103]), but buffalo production systems have evolved, and today there is a wide variety of farming systems that reflects differences in the regions of the world where buffalo-raising has been introduced [50].

Intensive Systems

Cattle breeds specialized in milk production are more common in temperate zones where intensive production systems predominate. In these systems, animals remain housed most of the time, and nutritional supplementation allows them to achieve high production [50, 108]. Cosmopolitan cattle breeds are, however, also being raised in tropical zones. Besides, the cross-breeding of Bos taurus and Bos indicus has been conducted to achieve greater resistance to tropical climate conditions and tick infections while simultaneously favoring milk production [15]. See Figure 7 [26].

Extensive Systems

The river buffalo, which has been raised principally in tropical climates with a double purpose (i.e., milk and meat production), has been adapted to temperate climates with intensification levels similar to those typically used with species specialized in milk production. These systems rely on forage as the primary feeding source with minimal supplementation [109, 110] and reduced environmental impact [111] (Figures 8, 9).

As shown in Figure 5, the udders of buffalo and dairy cows present anatomical differences; however, the sensory stimuli provided by the calf and the
application of exogenic oxytocin can produce similar physiological responses in both species [73,74].

5. PERSPECTIVES

The ever increasing demand for food requires research into alternative products for human consumption but also calls for implementing production systems that are more efficient and sustainable than traditional schemes. It is in this context that the studies mentioned above show that introducing the river buffalo is a viable option since this animal can fulfill the functions of producing meat and milk, particularly in tropical areas with availability of water for wallowing. This requires, however, becoming familiar with these animals' characteristics and obtaining a thorough understanding of their particularities, advantages, and challenges. Once this knowledge has been acquired, it will be possible to effectively assess whether the buffalo can potentially replace other farm species. Likewise, it is important to understand the biological aspects associated with the health of these animals in terms of susceptibility to certain harmful agents, such as ticks in tropical areas. Finally, the decision to replace cattle or zebus with buffaloes in individual production units depends on specific economic aspects affecting farm profitability.

6. APPLICATIONS AND CONCLUSIONS

This review has shown that although river buffaloes and domestic bovines belong to the same Bovidae family and seem quite similar, awareness of the anatomical, physiological, and behavioral differences among Bos taurus, Bos indicus, and the buffalo will make it possible to:

1. Select the animal species that best adapt to the environmental conditions of the diverse livestock production systems.

2. Adapt the installations of production units and develop appropriate technologies for milking equipment specifically-adapted to the buffalo's anatomical characteristics instead of using the same equipment as with dairy cows.
3. Avoid making the same errors that marked the development of highly-specialized dairy production, which brought such consequences as a higher predisposition to infectious and metabolic diseases than rustic animals like the river buffalo.

4. Implement production strategies that do not compromise animal welfare.

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Figure 9: Importance of the calf in milk ejection. Milk ejection can be induced by various stimuli that facilitate the emptying of the mammary gland. Using calves as a tactile sensory stimulus is very frequent. This stimulus is transmitted through the spinal cord to the hypothalamus and neurohypophysis, where oxytocin is synthesized and released to contract the myoepithelial cells that surround the alveolus, thus inducing milk ejection.
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