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# Unravelling the Phenotypic, Genomic, Reproductive, Behavioral Characteristics and Management of Gayal (*Bos frontalis*) in Bangladesh: A Review

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**Abstract**

GAYAL is remarked as one of Bangladesh's endangered animals. Effective measures should be taken to conserve and develop Gayal by utilizing it as an economic resource. Across the country, the government is working a lot to meet the demand for animal protein. In this regard, we advocate for the advancement of Gayal farming, to foster its growth as an emerging sector, thereby fulfilling the increasing demand for meat within the country. The present study was undertaken due to an immense need for integrated understanding and synthesis of previous research on Gayal (*Bos frontalis*). On Gayal, a lot of relevant titles and abstracts were searched, accounted and considered for organizing and preparing the present review. A comprehensive literature search, screening, and review were performed to identify and investigate factors potentially linked with the farm-to-fork pathway in Bangladesh. The most common factors (n=101) were identified considering the studied parameters of origin, distribution, population, phenotypic and genotypic characteristics, productive and reproductive performances, health status and biosecurity, marketing facilities, development and conservation, etc. The research team aimed to know the existing scenario and the importance of the conservation and development of Gayal in Bangladesh from available secondary sources such as literature, journals, books, thesis reports etc. It also aims to know the physical traits, genetic composition, and behavior of Gayal, along with investigating their productivity and reproductive efficiency, health status, prevalent diseases, and challenges encountered by farmers. It further explores the purposes of Gayal rearing, evaluates their marketing status, and reviews conservation efforts in Bangladesh.

**Keywords:** Gayal, conservation, endangered animal, Genetic Resource.

## Introduction

The Gayal is a Ruminant animal that is available in hilly areas of Bangladesh, especially in Chittagong hill tract areas. The Gayal belongs to the Bovidae family, tribe Bovini, group Bovina, genus Bos, and species *B. frontalis*, and is very much kindred to the Indian Bison. Indian forest dwellers called this species 'Mythun' or 'Mithan'. It's also known as Chattogram Bison because it may be found primarily in the mountainous forested areas of Chattogram [1]. Gayal is available in Northeast India, Myanmar, and Yunnan, China [2]. They are mostly distributed in some hilly areas of Bangladesh, the northeastern part of India, some parts of Myanmar, and Bhutan [3]. Gayals were removed from the list of wild animals and classified as cattle in 1964 [4]. In Bangladesh, the hill tribes collect Gayal from the dense forest and then try to domesticate them. Some researchers and investigators believed that Gayal was domesticated from Gaur [5], but some were concerned about this species being a cross between Gaur and domestic cattle [6]. In Bangladesh, Gayal is reared under a free-range management system in hilly forest areas. They prefer a shady and humid environment and spend the day browsing largely on tree leaves or grasses on hill slopes, summits, and valleys higher than 1,000 meters above sea level. Due to inadequate feed ingredients on slopes throughout the winter, they descended to the hill foot paddy and grass fields. They have a different morphology than domestic cattle. In addition to having white stockings on all four legs, they have featured a bony dorsal ridge on the shoulder [7]. During the day, Gayals typically remain in the forest, but at night, they leave the forest searching for salt and water. The villagers frequently use salt as a trap because salt is one of the animals' favorite foods. In addition, the hill tribes will occasionally gather these animals from the thick forest and domesticate them.

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The physical appearance of Gayal is different from that of domestic cattle, and they possess much bigger bodies than the indigenous cattle of Bangladesh. Males are about 25% heavier and larger than females in the adult stage. A prominent hump of flourished muscle may be seen over the shoulders; this can be the result of elongated spinal processes on the vertebrae [8]. Gayal is medium and large, with the female reaching up to 500 kg and the male weighing up to 700 kg [9]. Gayal is a valuable sacrificial animal regarded as a symbol of the social status of tribal people in Bangladesh and India [5, 10, 11]. In Bhutan, Thrabum (native cattle) is traditionally used for hybridization with Gayal (Mithun), and the produced hybrid is preferred for dairy and draught purposes [12, 13]. Scientists worldwide have been well concerned about the existing diversity, identical characteristics, and the available use of indigenous animal genetic resources in developing countries as the basis for their present and future sustainable utilization. Therefore, various studies were undertaken on Gayal's different parameters. However, the research data were not well accumulated to find out the findings at a glance. In our studies, we focused on the benefits of Gayal farming. We addressed the urgent need to protect the Gayal population from extinction since the population is facing an outrageous situation. It has also been essential to conserve Gayal's genetic resources and conduct more research and extension services to improve this valuable livestock species and their farming system in Bangladesh. So, this study was undertaken with the following objectives- (1) to review Gayal's phenotypic, genotypic, and behavioral characteristics in Bangladesh; (2) to investigate the productive and reproductive performances of Gayal; (3) to understand Gayal's health status and common diseases and the challenges of farmers in Gayal farming; (4) to know about the purpose of Gayal rearing and their marketing status in Bangladesh; (5) to look into available aspects of Gayal and Gayal farming in Bangladesh.

*Data Collection Methods*

*Literature Search in Terms and Strategy*

The purpose of the literature search and screening was to identify data sources for available components of Gayal in Bangladesh. Consequently, the search strings and reference screening were sufficient to meet the objectives of this scoping review yet comprehensive enough to capture the references targeted for this review. The initial search was conducted in January 2024 and was updated in March 2024. All citations were manually exported and de-duplicated from secondary sources such as Google, Wikipedia, Research Gate, Google Scholar, Journals, Books, Articles, and others.

*Scenario Selection*

Review on Gayal is a very broad topic, and the research team targeted selected "scenarios to represent the phenotypic, genotypic, behavioral characteristics of Gayal, their productive and reproductive performances, health status and disease prevalence, seasonal and environmental influences on Gayal farming, purposes of Gayal rearing as well as their demand and marketing facilities in Bangladesh. We also studied the threat responsible for Gayal's extinction and their conservation in Bangladesh. These scenarios were selected after the literature search and before data extraction to streamline the potential results obtained.

*Relevance Screening of Abstract*

Initially, each abstract (or title, where no abstract was available) and full-text articles were screened independently by two reviewers. Studies were included for the scoping review, excluded, or reserved for the study with agreement by two reviewers. In the case of disagreement, the decision to include, exclude, or reserve was based on a review by a third research team member. The purpose of the screening was to define all components of the research objectives.

*Qualitative data extraction*

Primary data extraction focused on the initial scenario selection. Information about other parameter reviews was reserved for future work and is not discussed here. Qualitative data were extracted from each study by a small group of researchers and managed using a pretested electronic spreadsheet program (Microsoft Excel) with oversight by the corresponding author of the research team.

*The Origin and Distribution of Gayal around the World*

In the first description in 1804, Aylmer Bourke Lambert applied the binomial *B. frontalis* to a domestic specimen probably from Chittagong [14]. There were different observations on the origin of the Gayal. [2]. stated that Gayal was directly domesticated from wild gaur and Taurus. Gayal was a hybrid breed, the crossing of wild gaur and domestic cattle, either *B. indicus* or different Bos species [15]. Many taxonomists blunder Gayal as a domesticated type of Indian gaur because of their similar appearance [16]. In 2003, the International Commission on Zoological Nomenclature particulates the first available specific name based on a wild population and the name for this wild species was valid by its being antedated by a name based on a domestic form. Most authors supported the binomial *B. frontalis* for the domestic species as valid for the taxon [17]. Gayal is native to Bangladesh, Bhutan, Cambodia, China, India, Lao PDR, Malaysia (Peninsular Malaysia), Myanmar, Nepal, Thailand, and Vietnam and is regionally extinct in Sri Lanka [18]. Mithun/Gayal was

domesticated more than 8,000 years ago from a wild gaur, *B. gaurus* [19, 20]. The study of [21] considered the gaur, known as the Indian Bison, as the wild ancestor of Mithun due to their similarities in phenotype, habitat, habits, and behavior. The karyotypes of three Bos species of Gayal (*B. frontalis*), yellow cattle (*B. taurus*), and gaur (*B. gaurus*) were analyzed by [22] where they noticed the number, form, and configuration of chromosomes were different among them and their numbers of chromosomes were 58, 60, and 56, respectively. There were no sub-metacentric chromosomes in the eu-chromosomes of yellow cattle, two pairs in Gaur, and one pair in Gayal. However, their sex chromosomes were all sub-metacentric chromosomes. The study of [22] detected that Gayal was neither a domesticated type of gaur nor a descendant of gaur and yellow cattle. An investigation was performed by [23] on restriction fragment length polymorphism of mitochondrial DNA (mtDNA) of 15 Yunnan yellow cattle, two Hesitant cows, and one Gayal where they observed that the restriction type of mtDNA of Gayal was the same as that of zebu, so the maternal origin of Gayal had a close relationship with zebu while Y chromosome of Gayal was the same with gaur. They stated that Gayal might be the descendant of male gaur and female zebu. Cytochrome b (Cyt b) gene partial sequences of 12 Gayals from Yunnan province having thirty-three mutations were analyzed by [16] where they reported that the Maximum Parsimony (MP) methods adopted almost the same topology and observed that Gayal was not a crossbreed descendant, but an independent species of Bos from *B. indicus, B. taurus, and B. gaurus*. Study of [24] conducted a study that analyzed the Cyt b gene entire sequences (1,140 bp) of 11 Gayals in Yunnan China combined with other bovine Cyt b sequences cited in Gene-Bank. The phylogenetic trees of genus Bos were reconstructed by NJ (Neighbor-Joining) and MP methods with *Bubalus bubalis* as an out-group. NJ and MP trees revealed that Gayals were mainly divided into three embranchments: one embranchment clustering *with B. gaurus*, the second group clustering with *B. taurus*, and the last one clustering with *B. indicus*. The result of the phylogenetic analysis exposed that the Gayal might be a domesticated form of Gaur, and a large proportion of the Gayal bloodline in China was afflicted by other bovine species. In the study of [25] analyzed mtDNA control region sequences of 71 samples and SRY gene sequences of 39 samples, together with the available sequences in the Genebank, which exposed that the origin of Yunnan Gayal was the hybridization between male *B. frontalis* and female *B. taurus* or *B. indicus*, and that Yunnan cattle mostly originated from *B. indicus*, also containing some hybrids of male *B. indicus* and female *B. taurus*. Again, [26] conducted a study where they found that the mitochondrial cytb gene of 20 Gayals from Myanmar and 13 from Bhutan were sequenced to trace its maternal origin. These results revealed that the principal maternal origin of Gayal was gaur and reported that it was directly domesticated from gaur. There were various theories on the origin of domestic Gayal, but a recent study has substantially backed the generally held theory that domestic Gayal's ancestors were gaur [27, 28]. Therefore, a different hypothesis was observed with the results reported by [24] and [26] where they mentioned Gayal as an independent bovine species, also stated by [16, 22, 29]. The Gayal was a member of the Bovidae family, specifically the Bovini tribe within the Bovina group, categorized under the Bos genus and *B. frontalis* species. Gayals, also known as mithuns or mithuns, were a rare breed of cattle with a small geographic range that stretched from eastern Bhutan across the state of Arunachal Pradesh in North-east India to the Naga and Chin-Hills-Arakan Yomarange, which marked the borders between Bangladesh, India and Myanmar reported by [30]. Another study was conducted in the Yunan province of China, Bangladesh, Myanmar, and Bhutan, and the Northeastern hilly areas of India were the only places where Gayal was found geographically [27]. In contrast to cattle, Gayal was reared in a small population in mountainous regions and tracts of Myanmar, Bangladesh, China, Bhutan, and India mentioned by [31]. According to the survey by [32], Gayal lived in the deep hilly forest of Bandarban Hill district near the Bangladesh-Myanmar and Bangladesh-Mizoram borders. They were distributed in Royangchhari, Ruma, Thanchi, and Naikhonchhari Upazila of Bandarban Hill district and Bilaichhari Upazila of Rangamati Hill district. However, they were observed in large numbers in Royangchhari, Ruma, and Thanchi, which were the actual home tracts of Gayal nowadays. From that survey, they reported that only the Bawm, Marma, and Mru tribes possessed Gayal in Ruma Upazila. Bawm, Marma, and Tanchonga tribes possessed Gayal, who mainly lived in Royangchhari Upazila. Therefore, the Marma and Mru tribes possessed Gayal in Thanchi. Bawm named Gayal ‘Siya,’ and the Marma called it “Tong Noa,” Mro termed it as ‘Chia nom’.

*The population of Gayal in Asia*

The population of Gayal is mentioned in Table 1, where we focus on the global population of Gayal, especially in the Asian subcontinent. The study of [32] mentioned that the total number of Gayal was less than 1000 (about 850-900) in Bangladesh. They also recorded data from field surveys at three upazila and found 571nos. The gayal population distributed throughout the Bandarban Hill Tract Area where 392nos. were in Ruma upazila, 69nos. in Ruangchhari and 110nos. in Thanchi upazila. According to [20] stated in their study that the Gayal population was 260000nos in India and 3000nos. was in Myanmar, respectively, whereas, the findings of

[33] reported the number of Gayal in China was around 3000. The Gayal population in India is 386,293 Nos, reported by the [34] 30,000 Nos, reported by [35] and 70,000 Nos, by [36] in Myanmar, 3,068 to 3,077 Nos, in China [35] 850 to 900 Nos, in Bangladesh reported by [32] and 418 Nos, according to Bhutan [37]. From this data, the global Gayal population is estimated at 0.500 million Nos. Author [38] reported that the Gayal population in India was 176,893 in 1997 and 246,315 in 2003. India had the biggest Gayal population (~97.57%) in the world (0.38 million) revealed by the Department of Animal Husbandry Dairying & Fisheries [39] New Delhi, India in the 20th Livestock Census, while in Myanmar, Bangladesh, China, and Bhutan accounted for approximately 3000 (0.96%), 1000 (0.32%,), 3000 (0.96%), and 570 (0.18%) respectively where the range of gayal per household were 1 and 25nos., respectively with an average number of 5.01nos. per household, according to the report of [32]. The Gayal population was classified as an endangered species by the International Union for Conservation of Nature and Natural Resources [40].

*Phenotypic Characteristics of Gayal*

According to the study of [32] adult Gayal carried black color skin and those white stockings were quite common. Gayal resembled Bhutanese, Chinese, and Burmese animals regarding body shape and coat color. White was the predominant color of the Gayal in Arunachal, India mentioned by [41, 42]. A study carried out by [43] on the phenotypic characteristics of Captive Gayal (*B. frontalis*). She stated that Gayal possessed a distinctive look like a cross between domestic cattle and wild bison. They had an athletic build, a well-defined hump over the shoulders, and a short, thick tail. Their coat might be any color from dark brown to black, and they occasionally had white markings on their body, legs, and face (Figure 1). One phenotypic trait that stood out was the variety in coat color. Gayal's coat colors change as they age, although the particular alterations might vary from person to person and be impacted by genetics, diet, and environmental factors. She mentioned that Gayals typically had a different coat color at birth than they turned as adults. The calf coat color had distinctive patterns or markings that became frequently lighter. Gayals matured into the typical adult coat color for their breed or population as their coat color darkened with age (Figure 1). From two and a half to three months old, the Gayal calf's coat color changed. A study of [43] also stated that Gayals had brown or black eyes like other cattle. Gayal eyes were not distinct from those of other domesticated cattle species. Although it frequently looked within the spectrum of ordinary cattle eye colors, their eye color varied slightly through individuals, which might be brown or black. Both stout and upwardly curving horns were present on both sexes. Horn size and shape could vary between individuals and horn length and curvature can be influenced by heredity and age. The impressively long horns are usually marked for social interaction and defense. The tail switch color varied from black to white depending on their coat color. Gayals were larger than the majority of domestic cattle breeds. The study of [44] reported that the Gayal was 140-160 cm taller at the shoulder part of the body, which was smaller than the gaur and contained shorter legs. Bulls could weigh a ton and were 20–25% heavier than cows. In Gayal, the shoulder hump was lacking and huge in the gaur, a shorter, wider, and flatter skull, and both sexes possessed horns that protruded from the sides of their heads and were bigger but that horn was shorter than the gaur. A dewlap was well formed at the chin and throat region. Females were brown-black, while bulls were black, and both had white stockings. The study of [7] mentioned that in contrast to domestic cattle, the huge semi-domesticated Gayal had white stockings on all four legs and a bony dorsal ridge on the shoulder. Typically, it was black. Compared to the female, the male Gayal had a darker skin color that turned black or dark brown as its aged. Gayals had larger bodies than Bangladesh's native cattle. Gayal mature males typically weighed 600 to 700 kg, while females typically weighed 400 to 500 kg; [32] stated that at the age of four months, those white stocking began to form in Gayal. The newborn calf's coat was crimson or coffee in color and after four months of age, the calf's coat color changed to black. In the study of [32], they reported that Gayal possessed a typical appearance. Like the common cow, the head and upper part were broad and flat, naked and shrunken towards the nose. The forehead flourished with two horns which were thick, short, horizontal, and smooth; lay closely to the plane of the forehead. The horn of Gayal diverged in an outward direction and turned upwardly with a gentle curve. Horns were thicker and slightly compressed at the bases. Near the head, the neck was much sleazy, at a few distance from the neck a dewlap incipient. Gayal had a sharp ridge at the place of the hump. Near the end, the tail was covered with short hair, an ox/male Gayal which had a bunch like the Male cattle/common oxen. The legs of this Gayal species were thick, especially the forelegs. The hind parts look weaker in comparison to the fore part, owing to the contraction of the belly. In Gayal, stockings were developed in white color at 4 months of age. Initially, the body coat color of the newborn calf seemed red or coffee color, and gradually, it turned black color after 4 months of age, whereas the coat color of adult Gayal was black. In different parts of the body of Gayal white spotting was observed in some adult Gayal. White stocking was marked in the lower parts of the leg of adult Gayal. The5-6 years old Gayal bull's average withers height, length of body and head, forehead breath, and weight were 132.50±1.42 cm, 132.00+1.02 cm, 50.00+0.00 cm, 32.22+ 0.55 cm and 510.00+16.71

kg, where in growing Gayal at 1-2 years old it was 120.75+0.42 cm, 124.50+0.25 cm, 45.50+0.25 cm, 30.00+0.00 cm, and 2.43.33+11.96 kg, respectively mentioned in the findings of [32]. According to the study of [45], we found that Gayal is a large medium-sized animal that has a deep chest, fine legs, and a black coat color usually. The male Gayal was darker in comparison to the female, coat color became dark brown to black at sexual maturity. At birth, the calves had golden to reddish-brown coat with a typical light spot on the back of the legs. The black color disappeared, and after a few months, the reddish-brown coat color returned. The muzzle fat and switch were black, and the legs were white up to the hocks. They typically had short, fine, and smooth hair, and their skin was pigmented. Gayal had broad heads that were short with a flat poll, and their ears were medium-sized and erected. The horn of the male Gayal was large, growing sideways which was then turned upwards and pointed. The male possessed a definite crest and dewlap well developed in both sexes. The female had a poorly developed udder and was covered with hair. The Gayal was reared for meat purposes because they possess beef-type characteristics and they contain well-developed musculature. A study conducted by [46] on '15 Gayal' in the Bandarban districts of Bangladesh and stated that Gayal calves had a coffee coat color at birth with white stockings on four legs. This color gradually changed to brown at 1 to 2 years of age. In adulthood, it turned to black. The hide of an adult Gayal was found to be very thick and oily externally. The Length, breadth, thickness (butt and belly), and weight of a cured hide of an adult male Gayal were 2.33 m, 1.66 m, 9.2 mm, 7.3mm, and 33.0 kg, whereas the hide of domestic cattle were 1.62m, 1.28 m, 3.02 mm, and 2.12 mm and 11.68 kg, respectively. The Gayal hide was much bigger, thicker, and heavier in comparison to domestic cattle reported by [47]. In the study of [3], they mentioned that the length of Gayal body, withers height, length of head, and head width of male were 156.5 cm, 135.0 cm, 49.5 cm, and 23.5 cm, respectively, in Bangladesh Livestock Research Institute's Regional Station. According to the report of [48] the body lengths of both adult male and female Gayal of India were 138.75 cm and 126.75 cm, respectively.

*Genotypic Characteristics and Genome Sequencing of Gayal*

*Genome organization*

A study was conducted by [49] on the genome sequencing of Gayal. They explained that the complete mitochondrial genome of Gayal (*B. frontalis*) was a closed circular and double-stranded molecule which possessed the size of 16,347 bp, bearing 13 PCGs (cox1-3, nad1-6, nad4L, cob, atp6, and atp8), 22 tRNA genes (one gene for each amino acid, except leucine and serine, which each have two genes), 2 rRNA genes (rrnS or 12S and rrnL or 16S) and a significant non-coding region known as the control region (CR). Out of the 37 genes, 28 were encoded by the heavy (H) strand, while the light (L) strand encodes the remaining nad6 gene and 8 tRNAs. As a result, no significant variation was noticed in the length of the protein-coding genes (PCGs), rRNAs, and tRNAs across the mitogenomes of different Bos's species. The finding [49] supported the genome size and gene organization of Bangladeshi *B. frontalis* was consistent with those observed in the mitochondrial genomes of Indian Mithun and Gaur that had been stated by [28, 50, 51]. The mitochondrial genome containing AT and GC was recognized by [49] to be 60.21% and 39.79%, respectively, which pointed out that the composition of nucleotide was overall biased towards adenine and thymine. A similar trend was noticed among the indicated Bos species by [28, 51, 52, 53]. In the research of [49], the positive AT (0.105) and negative GC (-0.322) skewed was exposed by the mitochondrial genome, which revealed the higher content of adenine and cytosine compared to their respective complementary nucleotide's guanine and thymine. There were 5 nucleotides overlapping in the range from 1 to 3 bp, distributed across 3 distinct locations. The most extensive overlapping region (3bp) was identified between the two protein-coding genes NADH dehydrogenase subunit 4L (nad4L) and NADH dehydrogenase subunit 4 (nad4). Additionally, it contained a total of 118 bp of inter-genic spacer (IGS) sequence, which was dispersed across 24 regions across the mitochondrial genome with lengths ranging from 1 to 32 bp. The longest spacer sequence (32bp) was positioned between the two tRNA genes trnN and trnC. The putative control region of the mitochondrial genome was situated between the tRNA-P and tRNA-F, spanning a length of 921 bp. [28] and [51] also observed the same results in Indian Mithun and *B. gaurus*.

*Protein-coding genes (PCGs)*

In the study of [49], they stated that the mitochondrial genome encodes 13 PCGs consisting of a length of 11,268 bp, which accounted for 68.93% of the entire mitochondrial genome. The AT content was 58.92% while GC content was 41.08%, respectively commencing the nucleotide compositional biases towards adenine and thymine in the PCGs. The PCGs were categorized into 7 NADH dehydrogenase subunits (nad1, nad2, nad3, nad4, nad4L, nad5, and nad6), 3 cytochrome c oxidase (cox1, cox2, and cox3), 2 ATPase subunits (atp8 and atp6) and 1 cytochrome b gene (cob). The size of the PCGs varied particularly, with atp8 (150bp) being the smallest and nad5 (1797bp) being the largest. In order of frequency, the most commonly used amino acids in the mitochondrial proteins were proline, threonine, leucine1, asparagine, and serine sequentially. A common gene was identified by [28] in which its position occurring among the four

adjacent pairs of PCGs (atp8-atp6, atp6- cox3, nad4L-nad4, and nad5-nad6). The relative synonymous codon usage (RSCU) was counted and concise after excluding the stop codons, where the RSCU analysis exposed the highest usage of GCU (A), GUA (V), and AAA (K) codons.

*Transfer RNA (tRNAs) and Ribosomal RNA (rRNAs)*

The study by [49] reported that they found a total of 2692bp lengths in 22 tRNA genes in the Gayal (*B. frontalis*) mitogenome, where each size ranged from 60 bp (trnS1) to 75 bp (trnL2). A total of fourteen (14) tRNA genes were encoded by the H-strand (trnF, trnV, trnL2, trnI, trnM, trnW, trnD, trnK, trnG, trnR, trnH, trnS1, trnL1, trnT) while the remaining 8 tRNAs (trnQ, trnA, trnN, trnC, trnY, trnS2, trnE and trnP) genes were encoded by the L-strand. The typical cloverleaf secondary structure was displayed by all tRNA genes except trnS1 and trnK, lacking a stable dihydrouridine arm loop. Similar abnormal structures of tRNA had been reported in Indian Gaur and Mithun [28, 51]. The study by [49] also observed that in addition to the standard Watson-Crick base pairs, there was 9 unmatched base pairs were identified in those tRNAs. 05 (Five) of them were G-A (two) and C-A (three) pairs, forming weak bonds in tRNA secondary structures termed non-canonical pairs. The residual 4 mismatches included one C-U and three U-U pairs.

*Phylogenetic relationship*

According to the study of [49], where they analyzed the phylogenetic relationship among 26 bovine species across 8 closely related or congeneric species like *B. frontalis, B. Taurus, B. javanicus, B. indicus, B. primigenius, B. taurus, B. grunniens* and *B. mutus*. In their research, the sequenced *B. frontalis* species clustered with Mithun and Gaur. That congregation of Bangladeshi *B. frontalis* with Indian Mithun (MK279401.1), Chinese Mithun (MF614103.1), and Cambodian gaur species signified an intense genetic relationship between Mithun and gaur. The close relationship was strongly adapted to the unequivocal concept that Mithun was a direct descendent of gaur. Mithun might be a direct descendent of gaur, which was strengthened by the results of several studies using the Cytochrome b gene [24, 26] 16S rRNA gene [54] SNP genotyping [27], whole mtDNA [55] and Y chromosomal DNA markers [56]. Conversely, one of the Mithuns had clustered with the *B. javanicus* (AB915322.1), named Banteng or Tembadau commonly found in a Southeast Asian cattle species. The sporadic clustering of Banteng with *B. frontalis, B. gaurus* and *B. taurus* respectively reported it's hybrid nature whereas the similar nature was mentioned earlier by [57].In contrast, another Chinese *B. frontalis* (MF959941.1) had ordered with *B. indicus, B. primigenius* and *B. taurus*, which manifested the intense genetic relationship between those species. The observation was consistent with the results attained in the studies of [25, 55].

*Behavioral Characteristics of Gayal*

Geographically, the Mithun inhabits low to high-altitude regions and favors with the temperatures between 20°C and 30°C in cool climates. Gayal spends almost the same time chewing their cud or thinking as they browse and graze. They lie down at night and spend little time walking or standing [7]. They rested in the afternoon under trees near water sources or human settlements. Due to Gayal's complete reliance on the nearby jungle forage supply, extra care should be taken when providing mineral supplements to ensure better performance, as mentioned by [58, 59] in their study, stated that mineral leaching occurred frequently on steep hillsides, especially during the rainy season. Therefore, the soil would be deficient in some significant mineral elements in a particular hilly grazing gradient. In this scenario, a mineral deficiency might result from the vegetation in that region being deficient in some mineral elements. Mineral supplementation was the only way to make things right in this case. From the study of [43], we found less maternal behavior in Gayal cows. However, according to [7, 45], cows expressed maternal behavior during the first week after giving birth and reverted to their prior status. The study of [60] mentioned that Gayals were seen as social animals and lived in herds. A female adult Gayal was seen leading the group, while they roaming. The female Gayals showed aggressive behavior; especially with calves while male Gayals were comparatively less aggressive in the farm. Gayals loved to wet in the rain and swim in water. They didn't like to feed under the hot sun and could less tolerate to hot weather. In the study of [32], they reported that the aborigine of Gayal was situated at hilly areas with an altitude of 800 to 1100 m, which were tunicate by deep forests in Bangladesh. Moreover, [61] stated that Gayal lives in forests having altitudes as low as 150 m and as high as 3000 m, also mentioned by [20] Such identical habitats and ecology were observed for Gayal in India, Bhutan, Myanmar, and China had been mentioned by [5, 11, 26, 34, 62, 63, 64, 65]. Studies by [45] stated that Gayal's becoming very anxious and nervous to see strangers and tried to get away in the dense forest. They liked humid and shady environments and tried to save themselves from extreme heat or direct sunlight. At noon, they were hidden themselves in the deeper forest areas. Male Gayal became more docile with the companion of female Gayal as his. They had studied Gayal's feeding behavior and reported that Gayal mostly likes browsing on hill slopes. They liked to browse 300 to 400 meters above sea level. Gayals were tempted with a piece of rock salt used to following any place as they fond of salt. They searched shard hilly areas

during browsing periods and an open forest with plenty of bamboo leaves they liked most. Gayal always chosen the natural feed, but when they were in stall feeding, they liked salt-added feed staff and concentrates. Their study revealed that Gayal spent about one-third of their time browsing and grazing, whereas the same time was spent ruminating or chewing their cud. They went for lying only at night. The study by [45] also mentioned that Gayal was shown the silent estrus. Male animals were always needed to detect the estrus of Gayal. The male Gayal usually detected the estrus of females by smelling and licking the external genitalia. The female generally accepted the advancement of the male Gayal during estrus. They also reported that the estrus detection of male and female Gayal responded by the domestic native bulls for mating. In the case of Calf-mother behavior [45] observed that the pregnant mother became nervous just before parturition and tried to leave the rest of the herd. To find a hidden place, they went through the forest area. They didn't come back to the stall and stayed in the forest. The newborn calf broke through the amnionic sac after parturition and began breathing; the remains of the amnionic sac and tissues of the newborn calf were licked away by female Gayal. The newborn calf struggled to find the udder to get a meal. The mother Gayal threatened during this period, if a person or other animal approached close to her baby. She browsed and grazed around her newborn baby so that she could keep a sharp watch on her calf. She used to come back to her herd after one or two days. The calves suckled milk 12-15 times daily, it's browsed, played and around her mother. Gayal's mother was careful about the safety of her baby at the first week. Female Gayal gradually became normal after one week, and the calf was moving freely in the herd. The study by [45] also described Gayal's physiological and hematological characteristics. They noticed that the pulse rate, body temperature, and respiration rate range was 47-75 per minute, 37.78-38.88°C, and 20-40 per minute, respectively. Those physiologically important values varied in different age groups, time of the day, and seasonal variation. In hematological features, the mean assumption was RBC 7.01±0.52 million/cu.mm, WBC 14.3±3.69 thousand/cu.mm, hemoglobin concentration 9.81±2.25 gm%, PCV 35.86±3.68%. In differential WBC count neutrophils 28.23±1.75 %, lymphocytes 62±2.05 %, monocytes 4.4±1.34%, eosinophil's 5±2.49% and basophils 0.4±0.51%. Author [32] mentioned that the percent values of packed cell volume were 33.5±5.71% while hemoglobin was 13.43±2.9 g/dl in males and 34.5% and 12.2g/dl in females, respectively.

*Housing and Management System of Gayal*

Farmers raised Gayal in the forest under free-grazing conditions without additional housing or feeding facilities. A study by [20] reported that it was possible to supervise the individual animals in the late evening or early morning and administer more food, drink, and medication. The study of [43] mentioned that Gayal required shelter to defend themselves from adverse conditions such as rain, cold, and heat. It was essential to have a robust and well-ventilated barn or shelter. In the Chittagong division, available housing types were face-out-system conventional barns/stanchion barns, where animals were kept in the face-in and face-out systems. Chittagong division had both intensive and semi-intensive housing systems. She also stated that the floor was easy to clean and provided good drainage to prevent the buildup of moisture and waste. Concrete floors were common in the study area. Floor space for calf was1-2 m², cow/heifer 4-5 m²and for bull 12 m² provided in Chittagong areas. The study by [60] mentioned in his study that along with some wild pure breeds, most of the Gayals were crossbred, and Gayals were reared under a semi-intensive housing system on the farm. To be reared as domestic animals, wild Gayals were carefully trained on the farm. The houses or sheds are made of tin roofs and concrete floors, with well-ventilation facilities for Gayals. The housing system of Gayal was faced with single and double-row systems. A study by [32] found that farmers reared Gayal in an extensive management and production system. The animals moved freely in the forests and also rested at night there. Sometimes, they grazed in an open area or field near the village. No supplemented feed was supplied to them, and they were not kept in confinement. Nevertheless, Gayals were allowed to graze in a determinate area of the forest as the owner fenced around the forest to ensure they could trace the Gayal easily. That system restricted and confined free movement of Gayal's from one hill to another, as had occurred in the previous time.

*Feeding System of Gayal*

According to the study [66], the availability of jungle forages and pasture land were Mithuns' only sources of food. In hilly regions during monsoon season, salt feeding and licking of mineral water sources were common practices to prevent mineral deficiency in these animals. A study by [67] revealed that Yunnan Gayals have distinctive dietary habits, including alfalfa, barley straw, rice straw, bamboo leaves, bamboo twigs, and bamboo stems. In the recent study of [43], she explained that Gayal preferred to browse mostly on inclined slopes around 300 to 400 meters above sea level. During the day, they roamed freely in the forest and returned to the owners' homes at night. Gayals were not used to additional concentrate or silage made from cultivated fodder plants unless they only got a limited amount of natural feed. This animal was extremely fond of salt and would follow him/herself wherever anyone offered them a piece of rock salt. During the browsing time, they looked for open hilly areas and

liked to eat bamboo leaves from open forests. Although Gayal always picked up the natural feed, [43] also observed while Gayals were being fed in a stall, they preferred concentrates and feed with extra salt. Farmers provided grass/straw and occasionally rice polish or wheat bran combined with salt under confined conditions. Author [32] stated that Gayal usually fed the shrubs and grass that grew naturally in the forest. The main feeds of Gayal were the hilly grass and bamboo leaves. They rambled in the hilly forests and moved to browse feeds and drink water from one hill to another. Gayals stayed in the forest most of the time, even at night. They went near a small canal that flew through the hills as a water source. They grazed for feed in the morning and afternoon and drank water from 10 a.m. to 12 p.m. They grazed for feed in the morning and afternoon, and they rested under trees near water holds or nearby human dwellings at night. To feed common salt at weekly or fortnightly intervals, they came to the owner's dwelling.Where the grazing place was away from the owner's dwelling, the owner traveled to feed common salt to Gayal in their aborigine. The natural method for these animals to meet their need for minerals was to lick salt and drink mineral water from sources in the hills, as reported by [59] the study by [60] revealed that Gayals were provided straw, wheat bran, rice polish, soybean meal, salt, grasses, and so on as feed the farm. They were allowed to roam freely in the hilly environment and returned to the farm in time. Interestingly, they observed that Gayals were very much fond of salt and they returned to the farm in the early evening only to get salt. Thus, they used to capture and brought to the shed. Usually, calves start to feed naturally grown grasses from 3-4 months of age. Gayals normally ate wild grasses, shrubs, and herbs etc. during free-ranging condition when grown in the hilly environment. Gayals were released in a hilly area besides the farm environment.

*Growth Performance of Gayal*

Gayal is a rapidly growing animal. The growth performance of Gayal was better than that of Cattle and the Boss spp. Gayal's growth performance is mentioned in Table 2. According to [68], the average birth weights of the male Gayals were 24.30±6.99 kg and 20.20±4.08 kg for females, respectively. In contrast, [32] mentioned that the average birth weight of the male Gayals was 21.67±0.15 kg and 19.63±0.21 kg in females respectively. According to the study of [68] where they stated that Gayal calves were weaned at 6 months. Gayal's weaning weight was 83.9±17.7 kg (dry season). The study of [60] mentioned that the average Birth weight of males was 24kg and females 20kg, respectively. In the study of [43], the male Gayal's (37-72 months or 4-6 years) average body length, height at the whither, head length, and weight were 55.67±1.85 inch, 54.72±1.60 inch, and 20.50±1.10 inch and 596.63±69.42 kg, respectively. Study by [43] also mentioned in her report that Gayal's average body weight at first estrous was 227.32±44.38 kg. Research by [32] reported the male Gayal's (5-6 years) average body length, height at the whither, head length, and body weight were 132.00±1.02 cm, 132.50±1.42 cm, and 50.00±00 cm and 510.00±16.71 kg respectively where the adult male and female Gayals in India possessed the body lengths of 138.75 cm and 126.75 cm, respectively mentioned by [48]. According to [69, 70, 71, 72] this animal grows between 300 and 600 gm per day with sufficient nutrition, comparable to the cattle and buffalo rates. However, Gayal had a much higher concentration of (30-90 ng/ml) plasma growth hormone compared to other domesticated animals. The study by [46] revealed the weight of Gayal at first estrus was 247.2±20.53 kg, whereas [73] reported that the average body weight in Gayal at first estrus ranges from 205 kg to 330 kg. Gayal was efficient in converting forest biomass into high-quality meat. Gayal meat was softer and better than other meat sources. Gayal meat was healthy because it contained low fat. Indigenous tribes had a strong preference for Gayal meat. It is always best to slaughter Gayal at the age of 4-5 years to get the most meat. In general, the dressing percentage in Gayal was 58-62% stated by [20]. Gayal mature males typically weighted about 600 to 700 kg, while females typically weighed 400 to 500 kg where the daily average milk output of Gayal's was reported to be 305±30.5 mL/d [7]. A report by [7] stated that the average body weight of Gayal was 247.8±35.1 kg; the weight was between 205 kg to 330 kg. Due to their durability and high quality, Gayal hides. Skin was more valuable than cow leather in the tanning business and used to make items such as footwear, clothing, bags, coats, purses, appealing ornaments, furniture covers, etc. as reported in the study of [66]. According to [43], on average, male Gayal calves could be born weighing 25 to 30 kilograms, while female Gayal calves could be born weighing 20 to 30 kilos. The calf's weaning weight was 40-60kg, and the weight gain after weaning was 0.5-1kg/day. Male Gayals were heavier than female Gayals, with mature male Gayals weighing 700-800 kg and adult female Gayals weighing 400-600 kg. Author [32] accounted those calves had an average birth weight of 20.85+0.24 kg and the growth rate was 256 gm/day, which was quite high. In the study of [46], they mentioned that the average birth weight of male Gayal calves was recorded as 19.0 kg while the female was 20.0 kg with the maximum growth rate at birth to 6-months of age was 554g/animal/day. A study by [74] mentioned that the weight of Gayal at the weaning stage was 84.0kg in males where and 81.80 kg respectively, in females. The average daily weight gain of Gayal was 404.60, 306.80, 315.20, and 312.20 gm/day at 3, 6, 9 and 12 months of age, respectively.

*Reproductive and Productive Traits of Gayal with Their Reproductive Management*

Gayal's reproductive and productive performance was extracted from different literature and presented in Table 3. A study by [75] mentioned that Gayals produced about 1-1.5 kg of milk per day per animal, drinking Gayal milk was not a common habit. Gayal milk was exceptional from a nutritional standpoint and was utilized to make various delectable milk products since it contained 3.4–17% fat, 4.4–9.8% protein and 6.8–22.2% Solid not fat (SNF) The duration of lactation 116.7±8.1 days, Milk production/lactation 35.7± 6.2 kg, and daily milk output 305±30.5 ml/days was observed in Gayal respectively [7]. Several studies by [20, 76] revealed that the female Gayal hybrids were shown to be an excellent milk producer and were widely employed in Bhutan and the north-eastern mountainous regions of India. However, in Bangladesh, such hybrids could not provide any positive outcomes stated by [68]. A study by [7] indicated that the average first estrous age and conception was 598.2±168.4 and 723.9±169.9 days. The age of puberty of females and males was 12-24 months (average 547.5 days) and 36-48 months (average 1277.5 days). Estrus could last anywhere between 36 and 72 hours. However, the standing estrus lasted about 12 to 18 hours on average. The estrous cycle length in Gayal cow was 19-21 days. Gayal didn't display any signs of estrus stated by [77, 78]. The best estrus indicator was the Gayal bull mounting an estrus cow, where the estrus cow standing to be mounted by the Gayal bull. In female Gayal, vulvar mucous membrane congestion and vulva swelling were the major indicators of heat detection. However, other symptoms such as mucous discharge, agitation and alertness, tail rising and moving, frequent urination, and loss of appetite were less noticeable for estrus detection in Gayal cows mentioned by [77]. The Gayal estrous cycle was observed to have a mean duration of 21.2±0.3 days (19–24 days) reported by [38]. Healthy Gayal bulls should be used instead of healthy ones to detect heat. According to [79] ovulation occurs in the Gayal population between 20 and 31 hours after the onset of estrus. In a semi-captive system, it was possible to detect the heat cycle in a female before she was paired with a high-quality bull for breeding, either through natural mating or artificial insemination, as narrated by [20]. Gayal had a rather high reproductive performance, according to the earlier report of [38]. A study by [32] revealed that the average gestation length was around 296.25±0.77days and the calving interval was approximately 402.85 days. He also reported that the average estrous cycle lasted 20 days, and the average heat period was 52 hours. According to [7], the average gestation duration of Gayal was 296.1±3.9 days. The average age at first calving and postpartum estrous was 1,014.4±266.3 days and 96.2±24.1 days, respectively reported by [7]. According to the findings of [20], the average calving interval of Gayal was 1 year (360-400 days). Moreover, [68] revealed that the calving interval of Gayal in ex-situ conditions was 553 days in Bangladesh. The study by [7] mentioned that the number of services per conception (natural) was 1.4. The birth weight of Gayal male calves was higher (19.67 kg) than females (15.58 kg) in the first lactation. Birth weight increased in 2$^{nd}$ to 3rd lactation in contrast to 1$^{st}$ lactation in both sexes. In the winter season, the highest conception rate was observed. When service was given within 21-30 hours of estrous70.60% successful conceptions occurred. Most of the herds of female Gayal come in estrous in winter season and calved in the monsoon and autumn seasons. A study of [43] observed that Gayal's gestation period lasts between 280 and 290 days. Female Gayal gives birth to their first calf at 3-3.5 years. Naturally, Gayal came into estrous within 45-60 days after calving. Calving difficulties were less visible in Gayal. A study by [78] reported that Gayal cows had a high reproductive efficiency and could have one calf per year. The Gayal productive life span was 16 to 18 years. Gayal was a polyestrous mammal, like cattle. Unless she was pregnant, the healthy adult Gayal exhibits repeated estrus cycles every 19 to 24 days. Estrus could last anywhere from 36 to 72 hours; however, standing estrus was usually about 12 to 18 hours. Bulls sniffed the vulva and stood to be mounted by bulls/other herd members 91.30% of the time. In 82.61% of females during estrus, the urine frequency increased when the male's chin rested on the buttock. For some Gayal females with estrus, only 65.22% showed signs of restlessness; in 8.70% of cases, this restlessness was severe, while it was not in 56.52%. A study by [80] mentioned that 56.52% of Gayal cows exhibited shouting, which was rare in 17.39% of the Gayal cows but common in 39.13%. Contrary to cows, Gayal exhibits less overt homosexual behavior during estrus. Most Gayal females in estrus (56.52%) were seen anxiously scanning the outside for other animals. Only 26.09% of females were found to be mounting herd mates during estrus, while 47.83% were shown to lick the bodies of other animals during the period. Among Gayal females in estrus, only 8.70% reduced food intake or appetite loss, as reported by [81]. The vaginal mucosa of female Gayals exhibited varying shades of pinkness during estrus, with 34.78% having a pronounced reddish-pink color, 43.48% displaying a moderate pink hue, and 21.74% showing a slight pinkish tinge. Among the female Gayals in estrus, 82.61% of females had vulvar edema, of which 21.74 and 60.87% had pronounced edema, while the remaining 60.87% had minor edema. Only 78.26% of Gayal females in estrus have had their vaginal mucous spontaneously discharged, and even then, it was not always the case. Rectal palpation was required before the mucus was expelled spontaneously in 39.13% of the animals. 34.78,

43.48, and 21.74% of the females were found to have profuse, little, or no vaginal mucous, respectively. Three distinct hues of vaginal mucous were observed translucent in 61.11% of instances, metallic blue in 22.22%, and white in 16.67% of cases. Vaginal mucus varied in thickness, being thin in 55.56% of cases and thick in 44.44%. Author [82] observed that froth was seen in the lips of 30.43% of the animals. The cow would not show behavioral signals of estrus in this scenario, but the physiological symptoms of estrus occurred. The sexual activity of cattle and buffaloes is nearly identical, the intensity of this behavior to express estrus in Gayal was less pronounced. Since there is no behavioral indicator of heat, such as bellowing, the heat is referred to as silent. Additionally, the behavioral indications of estrus such as mounting to other animals and permitting mounting by others might be present with considerably less intensity. Gayal's estrus could be identified by parading a teaser bull and/or by trained personnel keeping constant watch in the morning and evening. In herds that were under stress and kept on a low diet level, silent heat was shown to occur more frequently, as reported by [78]. In contrast to cattle, more right horn pregnancies had been recorded (60%) by [83]. After 6 months of pregnancy, the fetus was balloted in 74% of pregnancies or its movement was visible through the abdominal wall, as observed by [38] and [83]. The majority of calving in Gayal took place at night. Restlessness, a rise in urination at intervals of 2 to 5 minutes, and an increase in walking were all indicators of impending parturition in Gayal. Gayal cows gave birth while lying down, as stated by [38]. Gayal cows began to lick the calf immediately after birth. About 22 minutes after birth, the calf rose 30 minutes later, it took its first colostrum sucking. The Gayal mother made a great effort to ensure the security of her young during the first week. One week later, she progressively reverted to her previous state, and the calf was observed roaming freely within the herd mentioned by [7]. According to [60], Gayals were Polyoestrous animals that showed silent heat, so a breeding bull was needed to detect heat. Male Gayals usually detect the estrus of female Gayal by smelling and licking the vulva. He also recorded the age of sexual maturity of Gayal where the females come in sexual maturity at 2-3 years of age and males at 3-4 years of age; the average interval of calving and gestation length were 402 days and 296 ± 5 days. Their study also observed that all the female Gayal were inseminated through natural mating. The study of [46] revealed the different reproductive status of Gayal. The age at first estrus in Gayal females is 16.73±1.8 months, age at first calving 28.3±1.11 months, estrous cycle 24.5±3.08 days, gestation period 282.5±4.5 days calving intervals 16.65±1.65 months and postpartum estrus period 126.5±14.5 days which were much lower than our native cattle. In the study of [73], Researcher described Gayal's daily average milk yield305±30 ml/day, production per lactation 35±2 kg, and lactation length 110-115 days respectively. A study by [73] also recorded that the average age at first estrous and age of first conception for Gayal was between 750-800 days. Average length of estrous cycle in Gayal was 21 days and estrus duration were 40- 45 hours. The average 2.70% number of services required for a successful pregnancy in natural insemination. Conception have successfully occurred when natural service was practiced within 21-30h (mid-estrous) of heat. The average gestation period of Gayal was 300±5 days.

*Infectious Disease of Gayal*

Like other domesticated livestock, Gayal is affected by various infectious diseases revealed in Table 4**.** According to [84, 85], the most common illnesses were non-specific diarrhea, conjunctivitis, skin conditions, non-specific fever, and mastitis. The proportion of Foot and mouth disease (FMD) cases during the winter, or 27.38% of all cases, was the highest. Throughout the year, non-specific diarrhea, skin conditions, gastrointestinal disorders, and external parasite infestations were recorded. The study of [85] described that Gayal reared in semi-intensive systems were susceptible to various infectious diseases like Brucellosis, FMD, Paratuberculosis, Bovine viral diarrhea (BVD), Tuberculosis (TB), and Infectious Bovine Rhinotracheitis (IBR). These illnesses had a significant negative impact on profitable Mithun husbandry practices. Author [43] reported that due to a scarcity of green grass, Gayal occasionally grazed in the ditch when they descended the hill during the summer. Fasciola infection was observed to be spread by these water grasses in the ditch, and the monsoon season showed a high incidence. Throughout the year, gastrointestinal nematodes were prevalent in Gayal of the hilly areas. *Rhipicephalus microplus*, *Rhipicephalus appendiculatus*, *Haemaphysalis bispinosa*, and *Amblyomma testudinarium* are common cow ticks that were also found in Gayal round the year. A study by [74] stated that FMD, Diarrhea, Conjunctivitis, and Parasitic infection (Fasciolosis, Ticks, Gastrointestinal parasitic infestation) were commonly seen in Gayal. They also reported that 24% calf mortality was seen in Gayal. Fasciolosis and FMD were highly prevalent in the winter and rainy seasons, whereas tick infestation was observed in the winter and summer. A study of [84] accounted those various infectious diseases of Gayal were FMD 32.14% (FMD diseases were higher in winter (27.38%) followed by the monsoon season), non-specific diarrhea 19.05%, conjunctivitis 17.86%, skin disease 15.48%, non-specific fever 11.90% and metritis 3.57%. Fascioliasis was seen to be the highest (38.89%) in monsoons and winter but low in summer. Non-specific diarrhea and skin diseases were commonly appeared in Gayal all over the year.

However, during summer (8.33% in each case) incidence was observed which was higher in compare to other season. In the hill tract areas of Bangladesh, there were shortage of water in summer/dry season. Lack of drinking and bathing/ body washing water, non-specific diarrhea and skin disease might be highest in summer. Conjunctivitis and non-specific fever were seen in all seasons except in winter. Conjunctivitis was found to be higher (13.10%) in monsoon. Only Conjunctivitis was observed in Gayal during the study by [32]. Gayal was habituated to browsing on hill slopes, hilly areas covered with plenty of leafy bush during monsoon season. A higher incidence of conjunctivitis was found because of mechanical injury by the leaf or thorn of hill plants. [60] carried out a study at Rangunia Chattogram, and diagnosed a large number of (89) Gayal were affected by the Foot and Mouth Disease virus where about 3.4% of calves Gayal died, and few numbers of Gayals were injured during grazing in the forest.

*Reproductive Disease of Gayal*

Gayal shows different reproductive disorders during their life cycle, which are mentioned in Table 5. In the case of bovine species, dystocia was a frequent cause of prenatal calf mortality. In Gayal, dystocia caused by feto-maternal disproportion was uncommon, where neonates usually appear anteriorly during calving. The cow was more likely to experience dystocia or difficult calving when the irregular, misshapen, or narrow pelvic canal results from maternal factors [86]. According to [43], reproduction-related issues and disorders had hardly ever been seen in Gayal. The reproductive disorders metritis and cervicitis were more common in Gayal. Nonetheless, there had been recorded instances of reproductive irregularities in Gayal, including the absence of a consistent estrous cycle, uterine infections, challenging calving experiences, difficulties in expelling the placenta, and behaviors such as placentophagia or postpartum estrus absence as stated by [86] and [32]. On semi-intensive Gayal farms in Bangladesh, the most frequently observed reproductive problems were uterine infections (16.7%), sporadic heat cycles (25.0%) and absence of regular estrus cycles (8.3%); abortion (16.7%), repeat breeding syndrome (8.3%), infections in the cervix (25%), where mortality of calf was 24% as reported by [68]. A study by [84] mentioned that the reproductive diseases of Gayal including irregular estrus cycle, and cervix infection were recorded higher (25%) in contrast to metritis and abortion. After the introduction of Artificial insemination cervicitis and metritis were seen which were not recorded before starting of artificial insemination. Irregular heat, anestrus, and repeat breeding were also recorded in their studies. The study by [7] reported that very common reproductive infection and problem of Gayal were cervicitis and irregular estrus followed by metritis, abortion, anestrous, and repeat-breeding.

*Health and Bio-security Practices in Gayal*

In the report of [43], he stated that Gayals are susceptible to FMD, Anthrax, LSD, Black Quarter, mastitis, parasitic infestations, and Diarrhoea. For disease prevention, farmers often provide an FMD vaccine at the age of 6 months, followed by a booster at a one-year interval. Deworming was done to prevent parasite illnesses initially at the age of 6 months, then at 6-month intervals thereafter. Gayals possessed great immunity and were less prone to sickness. When Gayals were unwell, they tend to graze freely outside of the farm. According to farmers, Gayal consumes medicinal plant leaves from the forest when they are unwell and recover quickly. According to scientists' recommendations in the relevant sector, necessary remedies were given for particular disorders. The same set of experts used clinical history, symptoms, and lab tests to pinpoint reproductive issues as emphasized in the study [7]. The study of [60] observed the vaccination against FMD, Anthrax, Black Quarter (BQ), Haemorrhagic septicemia (HS) and at the farm level in Chittagong. Deworming of calves was done before grazing exposure and then deworming practice was repeated every 3 months intervals. Ivermectin or a combination of Levamisole and Triclabendazole were applied as anthelmintics of Gayal. The poor treatment facilities of Gayal, where some village unqualified doctors provided veterinary service to the livestock and the service was not always available due to a difficult communication system reported by [32].

*Purposes and Use of Gayal*

In ethnic society, Gayal meat was frequently served at weddings, neighborhood feasts, and other significant social events. In the studies of [2, 69, 70, 71, 72, 77, 79, 81, 87, 88,89,90, 91, 92] the robust hill animal of Southeast Asia was significant to the socio-economic and cultural life of the locals. Compared to meat from other species, Gayal meat was regarded as being more delicate and better in Bangladesh. This animal was mostly utilized in Bangladesh as a sacrifice animal during religious festivals in exchange for a high price reported by [45]. The study by [93] revealed that Gayal meat was a significant component of wedding and Christmas celebrations. Live Gayal was given as gifts during weddings and other social and cultural rituals, according to the findings of authors [94]. They also reported that Gayal's offerings brought a renowned, god's favor and protection and also soothed god's house. As a result, animals were slaughtered at religious festivals, and the meat of slaughtered animals was highly valued, as stated by [7]. According to the study of [95] the information generated from the research indicated that Gayal was

a ritual animal that was important to the social, cultural, and economic elements of the lives of the ethnic communities in Bangladesh's Bandarban hillside and Chattogram areas. Author [32] also reported that Gayal milking practice was not usually seen anywhere. Calves suckled the udder of the dam for complete milking. Gayal (both male and female) was only used as a meat animal. They were not used for draught purposes. Gayals were important as sacrificial animals in Naga and Chin hills and were the symbol of social for them stated by [5]. On the other hand, [20] narrated that there was an opportunity to obtain superior-quality leather from Mithun skin.

*Market demand and marketing facilities*

In the report of [43], she found no marketing facilities for selling or buying Gayal in the Bandarban Hill district. She observed that a healthy female Gayal or calf by the owners was not sold during that study period. The owners mainly sold their mature male Gayal and culled female Gayal. They sold Gayal bull from December to February. They were subsequently utilized as sacrificial offerings during the Muslim religious festival called "Oros," which was arranged by a Muslim spiritual leader known as a "peer." The price that farmers received and the Gayal that was sold in "Oros" varied greatly. One adult bull was sold at the home plot for between BDT. 1,20000 (1008 USD) and BDT. 1,50000 (1260 USD). Gayal was sold up to BDT. 3,00000 in the “Oros” place. The second set of middlemen bought the Gayal from the first middleman and transported it to Chittagong or the nearest area of Chittagong. The third group of middlemen bought the Gayal from the second middleman. This marketing chaneel were mainly seen in Chattogram or its nearby areas before those Gayal were sold to final man/ customers during “Oros” also mentioned in the study of [32]. Author [1] reported that Gayal sold during Eid-ul-adha, with 2-3.5 lakh BDT. prices. Gayal prices mostly varied depending on the region and their availability near the locality. Author [43] mentioned that the average selling price of Gayal meat was 1000 BDT. per kilogram. Gayal's pricing system depended on the animal's size, location, availability, and transport system. A pricing system was available in Bangladesh according to the size of the animal which was determined by a small 2-2.5lakh BDT. medium 3-4 lakh BDT. and large animals 6-7 lakh BDT. All of the Gayals were sold except selective breeding bulls. The price rate of breeding bulls remained higher than the others.

*The reason behind Gayal is endangered animal*

IUCN considered the wild Gaur species under *Bos gaurus* as a domestic animal form (Mythun, Mithan, or Gayal) as *B. frontalis*. Gaur was considered as an extinct species in Bangladesh [96]. But there were few species of Gayal in Bangladesh. Inbreeding could happen due to a declining population size, which would then affect reproductive fitness, as stated by [97] including the fertility and survivorship mentioned by [98]. Furthermore, the current free-ranging Gayal raising strategy allowed for limited grazing in selected hillside area with restricted movement in different sites, which caused significant inbreeding in that Gayal genetic resources. Population vitality and flexibility in responding to environmental change were improved when genetic variety was preserved or increased. A few tribal families raised Gayal with native cattle and their cross-offspring; there was a high chance of natural mating, which was occasionally available in the neighborhood market by the name “Tang gaur”. Authors [99] mentioned that the Gayal was considered one of the endangered animal genetic resources in Bangladesh, where the size of the Gayal gradually decreased according to the opinions of Gayal owners. Continuous inbreeding within the herd and lack of awareness about the planned breeding program had resulted in a gradual decrease in the size of Gayal. The number of Gayal had been reduced extremely due to deforestation and converting the forest land into a fruit garden and the pressure of human settlement where the total number was reported below1000 (about 850-900). So, Gayal was an endangered livestock species in Bangladesh. A study by [95] reported that the gradual use of salt to trap Gayal reduced the population. Human interactions, deforestation, changes, and manipulation of biodiversity affected the habitats of Gayals. These various challenges forced Gayal to migrate into deeper forests, especially in the country's south-eastern border.

*Conservation and improvement measures*

In the study of [68], they reported that the Bangladesh Livestock Research Institute (BLRI) had undertaken Gayal's ex-situ conservation and improvement program in 1990. A projet regarding Gayal [100] mentioned that the Integrated Development Foundation (IDF) had been implementing the “Breed conservation, development of Gayal breed (*B. frontalis*) & poverty alleviation by rearing at the farm level” project under the program “Learning and Innovative Fund to test new ideas (LIFT)” of Palli Karma-Sahayak Foundation (PKSF) since 01 March 2020. A Chattogram based on this project had been assigned for the last 3 years. Their main goals were i) the conservation of endangered Gayal species from extinction, ii) the Development of the Gayal breed, iii) the improvement of Gayal domestication, iv) the Increasing popularity of Gayal, v) the Alleviation of poverty by rearing Gayal at the farm level. Project on Gayal by [101] described that Mamata Bangladesh had also involved in a project titled, “Poverty alleviation through the conservation, development, and rearing of Gayal (*B. frontalis*) at

the farm level" with the goal of Conservation and development of Gayal through farming. The Gayal project was launched in July 2020 and financially supported by PKSF for initially 3 years (2020-21 to 2022-23). For the long-term conservation and development of Gayal, the government and NGOs should work on it to save it from the threat of extinction.

## Conclusion

In this study, a comprehensive search on a literature review is resource intensive. This study is necessary for improving, curating, and conserving Gayal data resources to facilitate and support the synthesis research, which will help and guide the researcher to undertake future research and surveillance on Gayal. From this review study, we selected previous research and activities related to Gayal, specially connected with distribution, characteristics, productive and reproductive performance, health and biosecurity, and the importance of conservation and development of the Gayal population available in Bangladesh. From this study, we also identified some factors related to the popularization of Gayal farming and enhancing the marketing facilities commercially, which require further research and aggregated effects on livestock production. There were a lot of gaps and poor knowledge among the Gayal-rearing farmers about the importance of some management programs such as scheduled vaccine programs, deworming, balanced nutrient supply, planned breeding programs, scientific housing and management, etc. Research investigations on these factors and the introduction of suitable technologies in the Gayal-prone area as well as other widespread developmental activities implementation will be helpful in further resource generation at farmer's levels and in the extension process to upward the overall livestock food chain. To addressing those research gaps and Gayal farming practices from this review, requires routine communication, training, extension work, and collaboration among the researcher, policy maker, stakeholders, and commodity farmer groups to identify the problems with practical and effective interventions to recommend possible solutions to conserve and mitigate the threat of extinction of this valuable genetic resource.

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*Conflict of interest*

There is no conflict of interest regarding this article.

*Authors' contributions*

Author SI and SS conceptualized and designed the study and wrote the protocol and manuscript. Authors SI and SS wrote the methodology, completed the formal analysis, and wrote the manuscript. Author MAI, MZA wrote the manuscript and reviewed it. Authors SI, MAI, and MZA reviewed and edited the manuscript for final submission. Author RK provided guidelines for writing the manuscript and financial support for the manuscript. All authors read and agreed to the published version of the manuscript.

**TABLE 1. Distribution and yearly trend of the Gayal population**

| Year | Year wise Gayal Population in Asian countries | | | | |
|---|---|---|---|---|---|
| | **Bangladesh** | **India** | **Myanmar** | **Bhutan** | **China** |
| 1997 | - | 176,893[(1)] | - | - | - |
| 2003 | - | 246,315[(1)] | - | - | - |
| 2006 | 850-900 [(10)] | | - | - | - |
| 2007 | - | 257,478[(2)] | 30,000[(9)] | 1,643[(3)] | - |
| 2011 | - | - | - | - | 3000[(7)] |
| 2012 | - | 297,289[(2)] | - | - | - |
| 2014 | - | 260000[(6)] | 3000[(6)] | - | 3,000[(6)] |
| 2015 | 850-900[(5)] | - | - | - | |
| 2016 | | - | - | - | 3,068-3,077[(9)] |
| 2019 | 1000[(8)] | 386,293[(2)] | 3000[(8)] | 418[(3)] - 570[(8)] | 3000[(8)] |
| 2020 | - | - | 70,000[(4)] | - | - |
| References | [(1)] [38], [(2)] [34], [(3)] [37], [(4)] [36], [(5)] [32]; [(6)] [20], [(7)] [33], [(8)] [39], [(9)] [35], [(10)] [83] | | | | |

**TABLE 2. Growth Performance of Gayal**

| Average Growth Parameter | Male | Female | References |
|---|---|---|---|
| Birth weight (kg) | 24.30±6.99, 21.67±0.15 25-30, 19.0, 24 | 20.20±4.08, 19.63±0.21, 20-30, 20.0, 20 | [32, 43, 46, 60, 68] |
| Weaning weight (kg) | 84.0 | 81.80 | [43, 68] |
| | Average 83.9±17.7, 40-60 | | |
| Heifer weight at 1st estrus (kg) | - | 227.32±44.38, 205-330, 247.2±20.53. | [43, 46, 73] |
| Mature body weight (kg) | 600-700, 700-800 | 400-500, 400-600 | [7, 43] |
| Average daily gain (kg) | 0.30-0.60, 0.256 | | [32,69,70,71,72,87] |
| Average daily gain after weaning (kg) | 0.50-1.00 | | [43] |
| ADG at 6, 9, 12months (kg) | 404.60, 306.80, 315.20, 312.20 | | [68] |
| ADG at 6 months (kg) | 0.554 | | [46] |
| Dressing percentage (%) | 48-54 | | **[100]** |

**TABLE 3. Reproductive and Productive Traits of Gayal**

| Reproductive Traits | Length (days) | References |
|---|---|---|
| Age of puberty in male | 36-48 months, 3-4 years, | [7, 60] |
| Age of puberty in female | 12-24 months, 2-3 years, | [7, 60] |
| Age of first Estrous | 598.2±168.4 days | [7] |
| Age of first conception | 723.9±169.9 days | [7] |
| Estrous Cycle | (19–24 days), 19-21 days, 20 days, 24.5±3.08 days, 21 days | [7, 38, 43, 46, 73,78] |
| Estrous period | 12-18 hours, 52 hours, 20-31 hours. 36-72 hours, 40-50 hours | [7, 43, 78, 73, 79] |
| Postpartum estrus | 45-60days, 96.2±24.1 days, 126.5±14.5 days | [7, 43, 46] |
| Age at 1st calving | 1,014.4±266.3days, 3-3.5 years, 28.3±1.11 months | [32, 43, 46] |
| Gestation length | 296.25days, 280-290 days, 296 ± 5 days, 282.5±4.5days, 300±5 days. | [32, 43, 46, 60, 73] |
| Calving interval | 402.85days, 402 days, 16.65±1.65 months, 465±80.48 days | [7, 32, 46, 60] |
| Reproductive life span | 16-18 years | [78] |
| Lactation length | 116.7±8.1days, 110-115 days | [7, 73] |
| Milk Production/day | 1-1.5kg 305±30.5 ml, 305±30 ml/day | [7, 73, 75] |
| Lactation yield | 35.7± 6.2 kg, 35±2 kg/lactation | [7, 73] |

**TABLE 4. Infectious disease of Gayal**

| Infectious diseases and their prevalence | References |
|---|---|
| FMD 32.14%, non-specific diarrhea 19.05%, conjunctivitis 17.86%, skin disease 15.48%, non-specific fever 11.90% and Fascioliasis (38.89%) | [84] |
| FMD | [60] |
| Fasciola infection, gastrointestinal nematodes infection, tick infection | [43] |
| FMD, Diarrhea, Conjunctivitis, and Parasitic infection (Fasciolosis, Ticks, Gastro-intestinal parasitic infestation) | [74] |
| Brucellosis, Tuberculosis, Para-tuberculosis, Foot and mouth disease (FMD), Bovine viral diarrhea and Infectious bovine rhinotracheitis | [85] |

**TABLE 5. Reproductive disease of Gayal**

| Reproductive disease | References |
|---|---|
| Absence of a consistent estrous cycle, uterine infections, Dystocia, difficulties in expelling the placenta, placentophagia, and postpartum estrus absence | [32, 86] |
| Metritis and cervicitis | [43] |
| Uterine infections (16.7%), sporadic heat cycles (25.0%) and absence of regular estrus cycles (8.3%), repeat breeding syndrome (8.3%), abortion (16.7%), cervix infections (25%), | [68] |
| Irregular heat and cervicitis (25%) followed by metritis (3.57%), anestrus, and repeat breeding | [84] |
| Irregular heat and cervicitis followed by metritis, abortion, anestrus, and repeat breeding | [7] |

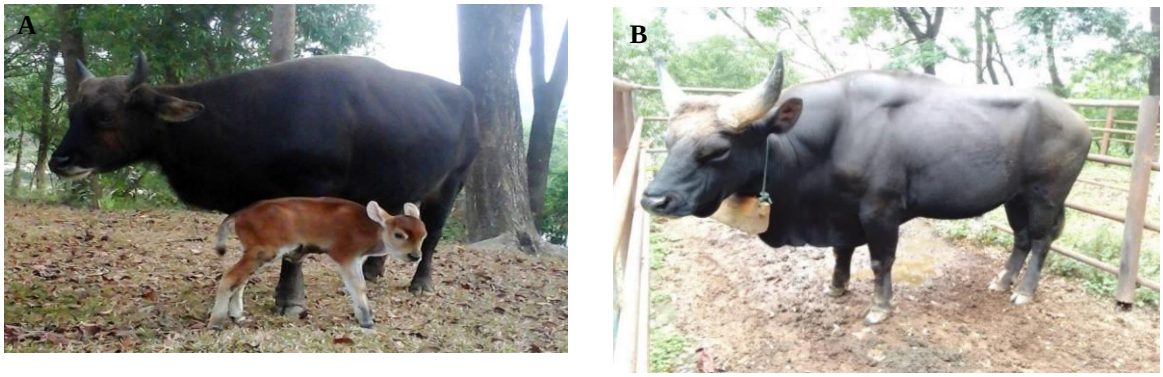


**Fig. 1. Gayal in different ages, (a) Gayal calf with mother, (b) adult male Gayal.**

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