Buffalo: Asia☆

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Introduction

Tropical Asia is the homeland for slightly more than 169.4 million of the total world population of 178.2 million domestic buffaloes (*Bubalus bubalis*) estimated in 2006. Domestic buffaloes in Asia are of two types: the swamp type for draught in the eastern half of Asia and the river type for milk in the western half of Asia. The river-type buffaloes, the once-neglected farm species, currently produce about 73.2 million tonnes of milk annually from some of the world's best buffalo breeds in India and Pakistan. They breed throughout the year, conceive at 250–275 kg body weight, calve for the first time at 3–5 years of age following a gestation period of 305–320 days, and produce two calves every 3 years. Lactating animals are fed mainly on straw, crop residues, and mineral supplements such as urea–molasses–mineral block (UMMB). In most rural areas, animals are hand-milked twice daily and the calf is used to stimulate milk letdown. The lactation period is 200–300 days with first lactation milk yields of 1500–800 kg. Breeding females are retained in the herd until about the ninth lactation (16 years of age) with reasonable economic returns. River buffaloes are vulnerable to most infectious and metabolic diseases affecting cattle. In India and Pakistan, milk is marketed through a network of milk cooperatives, which guarantee a stable price throughout the year for the farmer. Buffalo milk contains twice as much butterfat as cow milk. Besides ghee, several other products are manufactured from buffalo milk, such as butter, cheese, full cream milk powder, skim milk powder, and infant milk powder. Thus, the domestic buffalo is emerging as an alternative source for the manufacture of dairy products worldwide.

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Buffalo Species, Types, Population

The term 'buffalo' refers to three species in the family Bovidae. The African buffalo (*Syncerus caffer*) and the North American buffalo (*Bison bison*) have yet to be domesticated. On the contrary, the Asian buffalo (*B. bubalis*) was domesticated around the same time in history as cattle for draft power, milk, and meat (Figure 1). The domestic buffalo is also known as the 'water buffalo' because of its fondness to cool itself in water (Figure 2).

The two types of domesticated water buffaloes found in Asia, that is, the river and the swamp type, differ in their wallowing habits, chromosome numbers, and physical features (Table 1). The river buffalo makes up nearly 75% of the buffalo population in Asia. The dairy breeds of river buffaloes are the Murrah, Nili-Ravi, and Surti in India and the Nili-Ravi and Kundi in Pakistan.

Figure 1 Buffaloes plowing in a paddy field–Myanmar.

Figure 2 Wallowing behavior of the river and swamp buffaloes.

Table 1 Some characteristics of swamp and river buffaloes

Characteristics	*Swamp buffalo*	*River buffalo*
Location	Eastern half of Asia	Western half of Asia
Countries	Burma, China, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam	India, Pakistan, Iran, Iraq, Nepal, Sri Lanka, and Bangladesh
Horns	Grow outward and curve in a semicircle but remain on the plane of the forehead	Grow downward and backward
Breed(s)	Single breed	Seven recognized breeds, for example, Murrah, Nili-Ravi, and Surti
Wallowing habits	Swamps	Clean running water, for example, rivers or streams
Chromosome number (2n)	48	50
Purposes	Draft and meat	Milk and meat

Breeding Management

Buffaloes are polyestrus, breeding throughout the year, but the calving pattern is influenced by rainfall, feed supply, ambient temperature, and photoperiod. In India and Pakistan, most buffaloes calve between November and March. Although natural mating is the most common method of breeding, artificial insemination (AI) is also practiced.

Puberty

The buffalo attains puberty between 1.5 and 3.0 years of age. On recommended levels of nutrition, most conceptions occur when the female weighs 250–275 kg, which is usually achieved at 24–36 months of age. In the male, viable spermatozoa appear at about 24 months of age.

Estrous Cycle

The estrous cycle length is about 21 days with estrus lasting 12–30 h and ovulation occurring spontaneously after the end of estrus (Table 2). However, factors such as climate, temperature, photoperiod, and nutrition have been shown to influence the length of estrous cycle and also the extent of estrus manifestation.

Unlike cattle, overt signs of estrus are not pronounced. In most smallholder farms, a male buffalo may not be available for estrus detection. Homosexual behavior or standing to be mounted by another female is observed only occasionally in the buffalo. As a result, most inseminations are based on less-reliable signs such as clear vulval discharge, restlessness, frequent urination, vocalization, and reduction in milk. Estrus commences toward late evening with peak sexual activity at night.

Artificial Insemination

Since the early 1950s, AI has been practiced in the river buffalo in the Indian subcontinent, but its progress has been very slow because of the difficulty in detecting estrus and low conception rates in smallholder farms.

Buffalo semen is routinely collected in AI centers using an artificial vagina (AV), similar in design to that of cattle. Ejaculate volume and concentration of semen are lower in buffalo than in cattle. Techniques of semen evaluation, processing, and cryopreservation are as in cattle with minor modifications.

AI centers in India and Pakistan provide an AI service with either chilled or frozen semen. In Pakistan, an AI network consisting of more than 140 main centers and about 400 subcenters provides more than three million inseminations annually.

Most inseminations are usually performed between 12 and 24 h from the onset of estrus. At this time, the cervix is sufficiently dilated for the deposition of semen in the uterine body with the same insemination equipment as for cattle.

Both India and Pakistan export frozen semen to upgrade or crossbreed indigenous buffaloes in Thailand, China, and the Philippines.

Embryo Transfer Technology

Several countries are engaged in developing embryo transfer (ET) technology in the buffalo. The basic principles of ET technology in cattle are applicable to buffalo except that embryos are collected from the uterus on day 5 of the cycle instead of on day 7 or 8 adopted in cattle. Also the pregnancy rates have been less than 10% in Bulgaria and India, as compared with 50–70% in dairy cattle. Previous studies have shown that the superovulatory response to gonadotropins is comparable to that of cattle. However, low embryo recovery rates were not necessarily due to poor superovulatory responses, but instead due to failure of oocytes to enter the oviduct and/or impairment of embryo transport in the reproductive tract.

Table 2 Reproductive parameters of buffalo and cattle

Parameter	*River buffalo*	*Cattle*
Sexual season	Polyestrus	Polyestrus
Age at puberty (months)	15–36	10–24
Estrous cycle		
Length (days)	18–22	14–29
Estrus (h)	12–30	17–24
Gestation length (days)	305–320	278–293
Age at first calving (months)	36–56	24–36
Calving intervals (months)	15–21	12–14
Ejaculate volume (ml)	3–6	4–10
Sperm concentration ($10^6 ml^{-1}$)	300–1500	800–2000
First-service conception rate (frozen semen) (%)	10–50	45–75

Reproduced from Jainudeen, M.R., Hafez, E.S.E., 2000. Cattle and buffalo. In: Hafez, B., Hafez, E.S.E., (Eds.), Reproduction in Farm Animals, seventh ed. Lippincott Williams & Wilkins, Baltimore, pp. 159–171.

In vitro fertilization (IVF) of buffalo oocytes is an alternative to superovulation. Several laboratories have produced buffalo embryos by IVF. In 1997, the first IVF buffalo calf was born in India. Since oocytes can be collected at slaughter from high-producing buffaloes at the end of their lactation (see section Feeding the Lactating Buffalo), IVF has potential applications in Pakistan and India.

Gestation

Gestation is longer in buffalo than in cattle, varying from 305 to 320 days for the river buffalo and from 320 to 340 days for the swamp buffalo. Pregnancy is routinely diagnosed by rectal palpation of the uterus from about 40 to 45 days following insemination. Transrectal real-time ultrasound scanning to determine early-stage pregnancy and fetometry have also been used.

Parturition

The birth process is similar to that of cattle. The fetus is delivered in anterior presentation with fully extended limbs, and fetal membranes are expelled 4–5 h later. Twinning is rare, and the incidence is less than 1 per 1000 births. Birth weights range from 26 to 35 kg, with male calves weighing 2–3 kg heavier than female calves.

Postpartum Period

After calving, the first estrus and ovulation occur at about 60 and 90 days, respectively, in well-managed herds. Postpartum anestrus or failure to resume estrous cycles after calving remains a major problem contributing to long calving intervals.

Fertility

Conception rates based on the nonreturn rates to AI are inaccurate, because of the inherent difficulty in detecting estrus (see section Artificial Insemination). Pregnancy rates, based on rectal palpation, usually range from 50% to 60% with chilled semen, 25–45% with frozen semen, and more than 60% for hand matings.

A buffalo usually produces, on average, two calves every 3 years. However, in well-managed herds, calving intervals of 14–15 months have been achieved.

Several southeast Asian countries have embarked upon crossbreeding the indigenous swamp buffalo with the river buffalo. The F1 crossbreds (river x swamp) and F2 offspring possess an intermediate karyotype of $2n = 49$. Unlike other mammalian hybrids possessing chromosome complements differing from their parents, both male and female hybrids are fertile. As a matter of fact, the F1 crossbreds had improved body growth, larger body size, and better draft power and milk yield (4.0 kg day^{-1}) than the local buffaloes.

Reproductive Management

As mentioned previously, seasonal calving patterns in buffaloes have been attributed to ambient temperature, photoperiod, and feed supply. In India and Pakistan, buffaloes calving in summer or fall resume ovarian cyclicity earlier than those calving in winter or spring. Perhaps decreasing day length and cooler ambient temperatures favor cyclicity.

In the past, ’silent estrus’–ovulation not preceded by estrus–was believed to be a major problem in buffalo breeding, but recent hormonal studies have revealed that it is due to the farmer’s inability to detect estrus.

Improvements in nutrition could increase growth rates and hasten the onset of puberty. Similarly, early weaning, induction of estrus with prostaglandin (PG)- or progesterone-releasing intravaginal devices, and better nutrition have hastened the resumption of early postpartum ovarian activity and reduced the calving-to-conception intervals. Induction of estrus with synthetic analogues of PG_{2a} and fixed-time insemination with frozen semen may prove useful in restricting mating seasons so that calving occurs when water and green feed are abundant.

Male buffaloes show marked seasonal fluctuations in libido and semen quality, which may be overcome by providing cooling facilities during the hot season. In addition, females could be inseminated with semen collected and cryopreserved during the cooler months.

Most reproductive management programs adopted for cattle can be effectively applied for the buffalo, but the commercial and smallholder farmers have not realized the benefits of such programs.

Feeding Management

Many Asian countries have limited feed resources for feeding their buffaloes. The available resources are essentially tropical pastures (both green and mature), straw, and crop residues, which are generally low in protein.

Feeding the Calf

Two systems are practiced for rearing buffalo calves. In smallholder farms, calves are allowed to suckle their dams to stimulate milk letdown and then allowed to suck 1–2 l of milk. As they grow older, suckling time is gradually reduced and replaced by grass and small quantities of concentrate. Beyond 4–6 weeks of age, the calf is used only for milk letdown. In commercial farms, calves are weaned at birth and managed as for dairy calves. Often male calves are neglected and die of starvation.

Feeding the Lactating Buffalo

Feeding systems of buffaloes for milk can be broadly classified as (1) extensive, (2) semi-intensive, and (3) the intensive system. The second system is most common, with animals tethered in the farmer's backyard and fed mainly on cut fodder and crop residues. Lactating animals receive 0.5 kg concentrate mixture per liter of milk produced.

Large herds of high-producing buffaloes are located near big cities in India and Pakistan. These animals, purchased from the villages immediately after calving, are transported to cities where they are confined in large holding areas and fed with dry fodder and large quantities of discarded bread and other preparations made of flour. 'Dry' animals are sent to the abattoir since it is uneconomical to transport them back to their original villages.

Nutritional Requirements

The energy and protein requirements have been established for maintenance and milk production for the river buffalo (Table 3). There is no physiological need for concentrate feed to maintain butterfat content that is about twice as much as cow milk. Feeding concentrates increases milk fat content as high as 15%, since the buffalo releases unwanted fat into the milk and stores only a minimum in body tissues.

Utilization of Crop Residues

Several physiological and physical factors contribute to the buffalo's ability to utilize poor quality roughage and crop residues. Among these factors are the large rumen volume, high rate of salivation, slower rate of passage of digesta through the reticulorumen, slow rumen motility, and higher cellular activity.

The dry matter intake and digestibility of roughage can be improved by supplementing with a mixture of urea-molasses. The mixture is available as a block lick–UMMB. This block supplies fermentable energy, bypass protein, and macro- and microminerals to make the rumen microflora and microfauna more efficient in digesting roughages. Buffaloes fed these supplements show better body condition, shorter calving intervals, and higher milk yields.

Milk Harvesting and Storage

The annual production of buffalo milk in the Asia–Pacific region exceeds 55 million tonnes (see Table 4), with India and Pakistan contributing more than 50 million tonnes (Figure 3). Almost all the milk is produced in smallholder farms.

Milking Technique

Milk letdown is slower in buffalo than in cattle. The presence of the calf initiates the milk letdown reflex. In most smallholder farms, animals are hand-milked and the calf is used to stimulate milk letdown, whereas in big herds in India and Pakistan, they are machine-milked as for cattle. Normally, buffaloes are milked twice a day.

Milk Yield

The lactation length is about 300 days in the Murrah breed and about 320 days in the Nili-Ravi breed. Milk yields range from 1500 to 1800 kg for the first lactation with a steady increase to a peak in the fourth lactation, and are then maintained at peak levels until the ninth lactation. Thus, a buffalo could be retained in the herd up to about the ninth lactation (16 years of age) with reasonable economic returns.

Table 3 Metabolizable energy and digestible crude protein (DCP) requirements for maintenance and milk production of the river buffalo

Parameter	*Measured values*
Metabolizable energy	
Dry and lactating buffalo (kcal kg $W^{-0.75}$)	97.8–188.8
Milk production (kcal kg $W^{-0.75}$ 4% fat-corrected milk (FCM))	1171–1863
Digestible crude protein	
Dry and lactating animals (g kg $W^{-0.75}$)	1.28–3.48
Milk production (g per100 g of protein in milk)	126.6–166.34

Reproduced from Mudgal, V.D., 1988. Energy and protein requirements for dairy buffaloes. In: Nagarcenkar, R., (Ed.), A Compendium of Latest Research Based on Indian Studies. Indian Council of Agriculture Research, New Delhi, pp. 130–141; Ranjhan, S.K., 1998. Text Book on Buffalo Production, fourth ed. Vikas Publishing House, New Delhi, 397 pp.

Table 4 The domestic buffalo's contribution to milk and meat production in Asia

Country	*Nos. (10^6)*	*Milk (10^6 MT)*	*Meat (10^6 MT)*
River type			
Bangladesh	0.854	0.022	0.004
India	92.090	35.340	1.403
Iran	0.465	0.169	0.011
Iraq	0.065	0.190	0.001
Nepal	3.419	0.729	0.117
Pakistan	21.213	16.456	0.603
Sri Lanka	0.721	0.067	0.005
Swamp type			
Cambodia	0.694		0.013
China[a]	20.818	2.300	0.242
Indonesia	3.145		0.053
Laos	1.286		0.016
Malaysia	0.150	0.010	0.004
Myanmar	2.379	0.104	0.020
Philippines	3.006	0.018	0.051
Thailand	4.200		0.061
Vietnam	3.000	0.031	0.105
Asia	158.032	55.356	2.713
World	163.134	57.353	2.933

[a]China has a population of about 150 000 crossbred buffaloes (river x swamp buffalo).
Reproduced from FAOSTAT, 1999. Food and Agricultural Commodities Production. Countries by Commodities. http://faostat.fao.org/site/339/default.aspx.

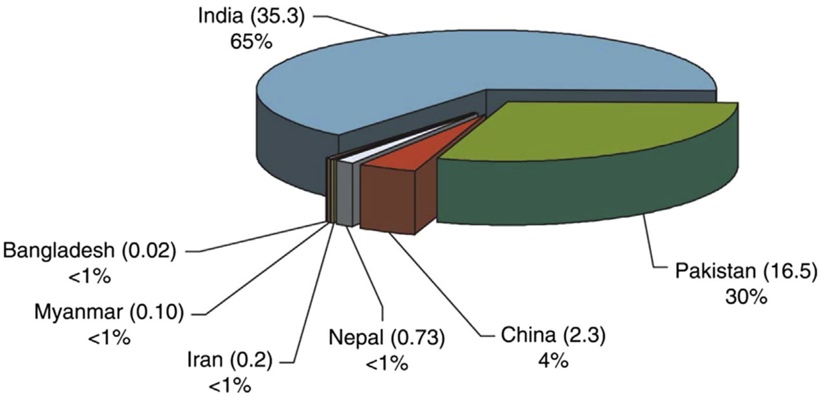

Figure 3 Major producers of buffalo milk in Asia (in million MT). Reproduced from FAOSTAT, 1999. Food and Agricultural Commodities Production. Countries by Commodities. http://faostat.fao.org/site/339/default.aspx.

With selective breeding, improved management, and the establishment of more dairy herds, milk yields are increasing. The individual 3000-l-per-lactation female, considered a record 30 years ago, is now common. There are many that yield 40 00 l in a lactation period of 300 days–some have even attained 50 00 l.

Most Asians consume buffalo milk in liquid form. Surplus milk is processed into butter, ghee, condensed milk, curd, and cheese. Dairy products, made from cow's milk, are also produced from buffalo milk in modern dairy plants.

The dairy industry has grown from small creameries to large dairy plants supported by thousands of small farmers who supply between 5 and 10 l of milk per day.

Milk Marketing

The rapid expansion of the buffalo dairy industry in the past two decades can be attributed to the Cooperative Milk Marketing model, first developed in Gujarat, India (Table 5), and then adopted by other states in India and Pakistan. In this model, the smallholder farmer is guaranteed a stable price for milk throughout the year, eliminating the middleman from the profits. In addition, these cooperatives provide loans to farmers to purchase superior animals, sell animal feed, and provide a routine veterinary and AI service. Their extension programs help producers to increase production and reduce costs.

Table 5 Some statistics of the buffalo dairy industry in Gujarat, India (1999–2000)

Members: District Cooperative Milk producers' Union	12
No. of producer members	211 755
No. of village societies	10 411
Daily milk handling capacity (10^6 l)	6.7
Total milk collection (1999–2000) (10^6 l)	1586
Average daily milk collection (10^6 l)	43.46
Milk drying capacity (tonnes per day)	450
Feed manufacturing capacity (tonnes per day)	1450
Sales turnover (US$ million)	500

Reproduced from Gujarat Cooperative Milk Marketing Federation, Anand, India.

Composition and Nutritive Value

Few differences exist between buffalo and cattle in the nutritive value of milk and milk products. The milk of the buffalo is healthy as it is richer in saturated fatty acids. The lower water and higher fat contents make buffalo milk better suited for the manufacture of fat-based and solid non-fat (SNF)-based milk products, such as cheese, butterfat, many kinds of traditional pastries, candies as well as ice cream, ghee, and milk powder (Table 6). In fact, swamp buffalo milk has higher fat (9–15%), protein (7.1%), lactose (4.9%), and ash (0.89%) contents. In general, calcium, iron, and phosphorus contents are higher in buffalo milk than in cow milk. The lower cholesterol content in buffalo milk should make it more popular than cow milk in the health-conscious public.

Unlike the cow, the buffalo converts the yellow pigment beta-carotene into vitamin A, which is colorless, and is passed on to milk. Therefore, buffalo milk is distinctively whiter than cow milk; not only cow milk is pale creamish-yellow but also the milk fat is golden yellow.

Proteins of buffalo milk, particularly the whey proteins, are more resistant to heat denaturation than those of cow milk. Dried milk products prepared from buffalo milk exhibit higher levels of undenatured proteins when processed under similar conditions.

Ultra-heat-treated (UHT)-processed buffalo milk and cream are intrinsically whiter and more viscous than their cow milk counterparts, because greater levels of calcium and phosphorus are converted into the colloidal form.

Milk Products

Ghee accounts for about 45% of the total milk produced in India. Ghee is clarified butterfat and contains about 99% of milk fat. Ghee from buffalo milk has no color, unlike ghee from cattle, which is golden yellow due to the presence of carotenoids as stated earlier. Ghee is the only source of animal fat in the vegetarian diet of the human population in India.

Cheese made from buffalo milk displays typical body and textural characteristics. For the manufacture of Mozzarella cheese, buffalo milk is preferred to cow milk. Certain traditional cheese varieties, such as paneer in India or pickled cheeses from the Middle East countries, are best made from buffalo milk.

Amul is a cooperative factory in Gujarat that produces a range of milk products exclusively manufactured from buffalo milk. The products include butter, full cream milk powder, skim milk powder, ghee, infant milk powder, cheese, chocolates, ice cream, and nutramul. Amul products are exported to the United States, New Zealand, and the Gulf states. The sale figures for Amul's butter have increased from 1000 tonnes a year in 1966 to more than 25 000 tonnes a year in 1997.

Table 6 Composition of milk (g l^{-1}) of river buffalo and cow

Constituent	*Buffalo milk*	*Cow milk*
Water	820	870
Total solids	172	125
Lactose	55	46
Proteins	44	33
Fat	75	36
Cholesterol (mg g^{-1})	0.65	3.14

Reproduced from Rajorhia, G.S., 1988. Dairy technology applied to buffalo milk. In: Bhatt, P.N., (Ed.), Invited Papers and Special Lectures Proceedings, vol. II, pp. 624–640. Part II. Indian Council of Agriculture Research, New Delhi; Ganguli, N.C., 1992. Milk processing and marketing. In: Tulloh, N.M., Holmes, J.H.G., (Eds.), Buffalo Production in Subseries: Production–System Approach World Animal Science C6. Elsevier, London, pp. 393–411.

Table 7 Common diseases/disorders of the domestic buffalo in Asia

Etiology	*Diseases/disorders*
Viral	Rinderpest, foot-and-mouth disease, malignant catarrhal fever
Bacterial	Hemorrhagic septicemia (*Pasteurella multocida*), Johne's disease (*Mycobacterium paratuberculosis*), tuberculosis (Mycobacterium bovis), *mastitis* (Staphylococcus *and Streptococcus* spp., *Escherichia coli*, *Corynebacterium pyogenes*)
Parasitic	Hemoprotozoan: *Anaplasma*, *Babesia*, *Theileria*, *Trypanosoma*, and *Schistosoma* species Gastrointestinal nematodes: *Haemonchus contortus*, *Toxocara vitulorum*, liver fluke *Fasciola gigantica*, *F. hepatica* Ectoparasites: Tick infestation (*Boophilus microplus*, *B. annulata*), mange (*Sarcoptes scabiei*, *Psoroptes* sp.)
Metabolic disorders	Hypocalcemia (milk fever), hypoglycemia (ketosis), hypomagnesemia, hypophosphatemia, selenium toxicity, bracken fern poisoning
Abortion, retention of fetal membranes, repeat breeding	Brucellosis (*Brucella abortus*), vibriosis (*Campylobacter fetus*), trichomoniasis (*Trichomonas fetus*), leptospirosis (*Leptospirosis pomona* and *L. hardjo*)
Vaginal, uterine, and ovarian disorders	Prepartum vaginal prolapse, postpartum uterine prolapse, puerperal metritis, endometritis, cystic ovaries, delayed resumption of ovarian cycles

Reproduced from Adlakha, S.C., Sharma, S.N., 1992. Infectious diseases. In: Tulloh, N.M., Holmes, J.H.G., (Eds.), Buffalo Production in Subseries: Production–System Approach World Animal Science C6. Elsevier, London, pp. 271–303.

Health Management

Contrary to the popular belief that domestic buffaloes thrive in the harsh, humid conditions in the tropics, they are susceptible to thermal stress, infectious diseases, and disorders similar to cattle.

Thermal Stress

With less than one-tenth the density of sweat glands of cattle, the domestic buffalo's ability to sweat and lose heat through evaporative cooling is significantly diminished. In addition, their dark body coat promotes heat absorption from the direct rays of the sun, whereas the thick epidermal layer prevents heat dissipation through conduction and radiation. Thus, the domestic buffalo is more sensitive than cattle to direct solar radiation and high ambient temperatures during the summer months.

Thermal stress may lead to higher calf mortality, lower milk yields, slow growth, and depressed signs of estrus. Thermal stress can be reduced by providing cooling facilities such as shade and wallows and sprinkling water on to the skin during the hotter part of the day, and feeding roughage during the night.

Infectious Diseases

River buffaloes are susceptible to most diseases affecting cattle (Table 7). Compared with cattle, buffaloes show greater resistance to foot-and-mouth disease (FMD) and brucellosis but have a higher incidence of parasitic diseases because of their wallowing habits.

The dairy buffalo is as susceptible to mastitis as the dairy cow. Bacteria causing mastitis and their treatment and control are similar to those for cattle.

There is a high incidence of calf mortality caused by *Toxocara vitulorum*, virulent strains of *Escherichia coli*, and rota and corona viruses. Larvae of *T. vitulorum* are transmitted from the dam to the calf through the milk during the first month of life.

Puerperal metritis and retained fetal membranes occur in the buffalo. The high incidence of metritis and other genital infections has been partly attributed to the unhygienic practice of dilating the vagina either by inserting objects or by blowing air for stimulating milk letdown.

Metabolic Disorders

High-milk-producing river buffaloes are as susceptible to metabolic disorders as dairy cows. Apparently, the etiology is similar because affected buffaloes respond to therapy and control the same way as dairy cows.

Further Reading

Ahmed, H., Andrabi, S.M., Anwar, M., Jahan, S., July 12, 2016. Use of post-thaw semen quality parameters to predict fertility of water buffalo (*Bubalus bubalis*) bull during peak breeding season. Andrologia. http://dx.doi.org/10.1111/and.12639 [Epub ahead of print].

Ali, A., Fahmy, S., 2008. Ultrasonographic fetometry and determination of fetal sex in buffaloes (*Bubalus bubalis*). Animal Reprod. Sci. 106, 90–99.

Fagiolo, A., Roncoroni, C., Lai, O., Borghese, A., 2005. Buffalo pathologies. In: Buffalo Production and Research, FAO Inter-regional Cooperative Research Network on Buffalo Food and Agriculture Organization of the United Nations, Rome.

FAO 2005–2006. FAO Statistical Yearbook (2005/6) vol. 1/2 Issue 1 2005–2006 WEB edition. http://www.fao.org/economic/ess/publications-studies/statistical-yearbook/fao-statisticalyearbook-2005-2006/en/.

FAO, 2005–2006. FAO Statistical Yearbook (2005/6) vol. 2/2 Issue 2 2005–2006 Country Profiles – WEB edition. http://www.fao.org/economic/ess/publications-studies/statistical-yearbook/fao-statisticalyearbook-2005-2006/en/.

FAOSTAT, 1999. FAOSTAT Food and Agricultural Commodities Production Countries by Commodities 1999. http://faostat.fao.org/site/339/default.aspx.

Jainudeen, M.R., Hafez, E.S.E., 2000. Cattle and buffalo. In: Hafez, B., Hafez, E.S.E. (Eds.), Reproduction in Farm Animals, seventh ed. Lippincott Williams & Wilkins, Baltimore, pp. 159–171.

Jamuna, V., Chakravarty, A.K., 2016. Evaluation of fertility in relation to milk production and productivity of Murrah buffaloes. Animal Reprod. Sci. 171, 72–80.

Kumar, S., Kanawjia, S.K., Kumar, S., 2015. Incorporation of Lactobacillus adjuncts culture to improve the quality of Feta-type cheese made using buffalo milk. J. Food Sci. Technol. 52 (8), 5021–5029.

Mudgal, V.D., 1992. River buffalo production systems in Asia. In: Tulloh, N.M., Holmes, J.H.G. (Eds.), Buffalo Production in Subseries: Production – System Approach World Animal Science C6. Elsevier, London, pp. 377–392.

Nanda, A.S., Nakao, T., 2003. Role of buffalo in the socioeconomic development of rural Asia: current status and future prospectus. Animal Sci. J. 74, 443–455.

Rajorhia, G.S., 1988. Dairy technology applied to buffalo milk. In: Bhatt, P.N. (Ed.), Invited Papers and Special Lectures Proceedings, vol. II. Indian Council of Agriculture Research, New Delhi, pp. 624–640. Part II.

Ranjhan, S.K., 1988. Text Book on Buffalo Production, fourth ed. Vikas Publishing House, New Delhi. 397 pp.

Santillo, A., Caroprese, M., Marino, R., Sevi, A., Albenzio, M., 2016. Quality of buffalo milk as affected by dietary protein level and flaxseed supplementation. J. Dairy Sci. 99 (10), 7725–7732.

Thomas, C.S., 2008. Efficient Dairy Buffalo Production. Milking DeLaval International AB, Tumba, Sweden. http://www.delaval.com/Global/PDF/Efficient-dairy-buffalo-production.pdf.

Zade, S., Mani, V., Sarma Deka, R., Kumar, M., Kaur, H., Kewalramani, N.J., Kumar Tyagi, A., 2014. Energy metabolites, lipid variables and lactation performance of periparturient Murrah buffaloes (*Bubalus bubalis*) fed on diet supplemented with Inorganic Chromium. Biol. Trace Elem. Res. 159 (1–3), 115–127.

Zicarelli, L., 2010. Enhancing reproductive performance in domestic dairy water buffalo (*Bubalus bubalis*). Soc. Reprod. Fertil. 67, 443–455.