

VETERINARY SCIENCES 1.0:

TECHNOLOGY, SUSTAINABILITY
AND INNOVATION

Editors:

**Dr. D. P. S. Badwal
Dr. Sushila Hooda**



JUST VETERINARY PUBLICATIONS

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PREFACE

It gives us immense pleasure to present the book entitled “**Veterinary Sciences 1.0: Technology, Sustainability and Innovation**”, which reflects the emerging advancements, scientific innovations, and sustainable approaches shaping the future of Veterinary and Animal Husbandry Sciences. This book has been prepared with the vision of providing a comprehensive platform for academicians, veterinarians, scientists, researchers, students and industry professionals to explore contemporary developments and future - perspectives in the field.

The veterinary and livestock sector plays a crucial role in ensuring animal health, food security, public health, rural livelihoods, and sustainable agricultural development. In recent years, rapid technological advancements, increasing environmental concerns, emerging diseases, and changing global demands have transformed the landscape of veterinary sciences. The integration of modern technologies such as biotechnology, genomics, artificial intelligence, precision livestock farming, and digital healthcare systems has opened new avenues for improving livestock productivity, disease prevention, animal welfare, and sustainable management practices.

This book encompasses a collection of scholarly chapters contributed by experts and researchers from diverse disciplines of Veterinary and Animal Husbandry Sciences. The chapters included in this volume address important themes such as animal health management, emerging and re-emerging diseases, genomic innovations, climate-resilient livestock systems, sustainable farming approaches, automation in livestock management, holistic animal healthcare practices, and environmental challenges affecting animal production systems.

The primary objective of this publication is to encourage scientific dialogue, promote innovative research, and bridge the gap between research findings and practical applications. It is hoped that this book will serve as a valuable academic resource for students, researchers, policymakers, extension workers, and professionals working in veterinary, livestock, and allied sectors. We express our sincere gratitude to all authors for their valuable contributions, dedication, and scholarly efforts in making this publication possible. We also acknowledge the support and encouragement provided by the organizing institutions, reviewers, collaborators, and members of the editorial team.

We believe that “Veterinary Sciences 1.0: Technology, Sustainability and Innovation” will contribute significantly towards advancing knowledge, fostering innovation, and promoting sustainable development in Veterinary and Animal Husbandry Sciences.

Editors

Veterinary Sciences 1.0: Technology, Sustainability and Innovation

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VETERINARIANS: GUARDIANS OF FOOD AND HEALTH

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1. Introduction

Veterinarians play a pivotal and evolving role in modern society, extending far beyond the traditional perception of animal healthcare providers. They operate at the crucial intersection of animal health, human health, and environmental sustainability, forming the backbone of the globally recognized *One Health* approach. In an era marked by rapid population growth, emerging infectious diseases, and increasing demand for safe food, veterinarians have become indispensable to public health systems. The growing interdependence between humans and animals has heightened the importance of veterinary science. Approximately 60% of human infectious diseases originate from animals, emphasizing the need for strong veterinary surveillance and intervention systems. Thus, veterinarians are not merely clinicians but guardians of food safety, disease control, and global health security.

2. Role of Veterinarians in Food Safety

2.1 Farm-to-Fork Approach

Veterinarians ensure food safety through a comprehensive farm-to-fork strategy, which includes:

- Monitoring animal health at the farm level
- Ensuring hygienic slaughter and processing
- Inspecting meat, milk, and other animal products

Their involvement guarantees that food reaching consumers is safe, nutritious, and free from contamination.

2.2 Residue Monitoring and Quality Control

Veterinary professionals regulate the use of drugs in animals by:

- Enforcing withdrawal periods
- Monitoring antibiotic and chemical residues
- Ensuring compliance with food safety standards

This helps prevent health risks such as allergic reactions, toxicity, and antimicrobial resistance in humans.



Veterinarians: Guardians of Food and Health

2.3 Control of Foodborne Pathogens

Veterinarians play a key role in controlling pathogens like:

- *Salmonella*
- *E. coli*
- *Listeria*

Through surveillance and laboratory diagnostics, they minimize foodborne outbreaks and protect public health.

3. Zoonotic Disease Surveillance and Prevention

Zoonotic diseases represent a major global health threat. Veterinarians serve as the first line of defense against such diseases through:

- Early detection and reporting
- Disease surveillance in livestock and wildlife
- Implementation of vaccination programs

Diseases such as rabies, avian influenza, brucellosis, and COVID-19-related infections highlight the importance of veterinary intervention. Their role in epidemiology and outbreak control ensures that diseases are contained at their source, preventing large-scale public health crises.

4. Antimicrobial Resistance (AMR) and Veterinary Responsibility

Antimicrobial resistance is one of the most pressing global health challenges. Veterinarians contribute significantly to its control by:

- Promoting rational use of antibiotics
- Avoiding misuse in livestock production
- Encouraging preventive healthcare practices
- Participating in AMR surveillance programs

By adopting these measures, veterinarians help preserve the effectiveness of life-saving drugs and protect both animal and human health.

5. One Health Approach: Integrating Systems

The *One Health* concept recognizes that human, animal, and environmental health are interconnected. Veterinarians play a central role in implementing this approach by:

- Collaborating with medical and environmental professionals
- Participating in interdisciplinary research
- Supporting policy-making and disease control strategies

This integrated approach is essential for addressing complex challenges such as pandemics, climate change, and ecosystem degradation.

6. Contribution to Food Security and Rural Development

Livestock plays a crucial role in ensuring food and nutritional security, particularly in developing countries. Veterinarians contribute by:

- Improving livestock productivity
- Preventing and controlling diseases
- Supporting sustainable farming practices

Their efforts enhance:

- Farmer income
- Rural employment
- National economic growth

Thus, veterinary services are vital for both food security and socio-economic development.

7. Environmental Health and Sustainability

Veterinarians also contribute to environmental conservation by:

- Monitoring wildlife diseases
- Promoting biodiversity conservation
- Addressing climate change impacts on livestock

They help maintain ecological balance and ensure sustainable use of natural resources, reinforcing the idea that healthy ecosystems support healthy populations.

8. Role in Crisis and Disaster Management

During disease outbreaks and natural disasters, veterinarians play a critical role in:

- Emergency disease control
- Animal rescue and rehabilitation
- Preventing disease spread during crises

Their expertise ensures rapid response and minimizes economic and health losses.

9. Challenges and Future Perspectives

Despite their crucial role, veterinarians face several challenges:

- Emerging and re-emerging diseases
- Increasing antimicrobial resistance
- Climate change impacts
- Limited infrastructure and workforce

Future strategies should focus on:

- Strengthening veterinary education and infrastructure
- Promoting One Health policies
- Enhancing research and innovation
- Increasing public awareness

10. Conclusion

Veterinarians are integral to ensuring safe food, healthy animals, and healthy human populations. Their contributions span across food safety, disease prevention, environmental health, and global health security. Recognizing and strengthening the veterinary profession is essential for building resilient health systems.

Veterinarians are not just animal healers—they are true guardians of food, health, and the future of humanity.

AUTOMATION IN HORSE MANAGEMENT

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Introduction

Automatic control or automation refers to the use of various control systems to operate equipment such as machinery, processes in factories, boilers, heat treating ovens, telephone networks switching system, steering and navigation systems with minimal or reduced human intervention. While it significantly reduces labour, automation also enhances energy efficiency, material usage, accuracy quality and precision. The term “*automation*”, derived by the earlier word “*automatic*” and ultimately form “*automation*” came into prominent use around 1947, when Ford Motor Company established a department of automation. This era saw the widespread adoption of feedback controllers, originally introduced in the 1930s. In the fast paced, competitive industrial environment of today, flexibility, cost-effectiveness and operational efficiency are essential. As a result, industrial automation systems have become indispensable in improving speed, reliability and productivity. Automation goes beyond mechanization by minimizing not only muscular but also sensory and mental input from humans. Automation involves the use of computers and mechatronics in the manufacturing of products and services.

It is generally divided into

- ❖ service automation
- ❖ manufacturing automation

Types of Automation

➤ Fixed automation

- ❖ It consists of special purpose equipment specifically designed to automate operations in a definite sequence.
- ❖ It provides high production rates, but less flexibility in product design.

Automation in Horse Management

➤ Programmable automation

- ❖ Equipments are designed to accommodate a specific class of product variations.
- ❖ Suitable for medium volume batch production.

➤ Flexible automation

- ❖ This allows for the manufacturing of a variety of products or parts.
- ❖ It is deal for rates of low production and variable product design and demands.

➤ Programmable automation

- ❖ Programmable looms
- ❖ Musical instruments
- ❖ Weaving
- ❖ Batch-processed products such as hinges, brackets, locks and door knobs

Reasons for Automation

- ❖ Shortage of labor: For example, the USA projected a 2:1 worker-to-retiree ratio in 2000.

High cost of labor

- ❖ Setting up plants in countries with low labor costs may not always make sense

Increased productivity

- ❖ Increased productivity per individual per hour
- ❖ Reduced operational costs
- ❖ Lower rate of scrap and in-process inventory
- ❖ Superior and consistent product quality
- ❖ Shorter and compact production lines
- ❖ Shorter manufacturing lead times
- ❖ Rapid adaptability to design changes and consumer demands

Efficient Watering Systems for Horses

Horses require consistent access to fresh, clean water with the average horse consuming about ten (10) gallons daily. Dehydration can lead to serious health issues like impaction colic. Factors like size, weather, diet, activity level and health condition influence water needs. Automatic horse waterers are designed to ensure efficient hydration with minimal effort. While traditional buckets and troughs suffice for some, automatic systems are more labour-efficient and consistent.

Key features to consider:

- ❖ Fully automatic with insulated design for energy efficiency
- ❖ Self-activated or manually flowing water
- ❖ Good tasting water – free from contaminants

- ❖ Horse – safe and low maintenance design
- ❖ No risk of electrical shock
- ❖ Made up of durable and infestation free materials like stainless steel
- ❖ Prevents mosquito infestation
- ❖ Easy to clean
- ❖ Practical and energy efficient - if you live in an area that gets plenty of sunlight consider a solar powered watering machine

Rule out labor-intensive waterers and those that are uninviting to horses. Choosing the right waterers save time, money and labour while ensuring horse health.



(Source: Equi Med Staff, 2010)

Stable Grazer Automatic Hay Feeders

These types of feeders are designed to assist horse keepers in the everyday care and maintenance of their horses. These feeders simulate natural grazing behavior by offering multiple times feedings. These batteries – powered feeders dispense pellets, flake hay, grain and dry supplement up to six times daily.

Benefits:

1. Promotes digestive health and prevents vices like cribbing and wood chewing
2. Provides feeding flexibility for busy owners
3. Improves overall horse health
4. Timer – activated and suitable for most locations

Feeding robot

Feeding robots offer precise portion control, customizable feeding programs (1-4 feedings) and save time. Robots are compact and maneuverable; they can operate in tight spaces with a 50 cm turning angle. Safety features include adjustable friction gearing and rail slides.

Automatic Feeder Chart

Most automatic feeders are powered by electricity or batteries, some with solar chargers.

Features include:

1. Programmable feed schedule and quantities
2. Backup power systems



Credit: feed-device

(Source: Horse Journal; 2014)

Automation in Horse Management

3. Malfunction alarms and feed shut – off valves
4. Indicators for battery replacement
5. Capacity from 23 – 50 lbs, expandable with hopper extensions

Only dry feed or pellets under 1" are generally suitable. Moist or molasses – rich feeds many cause clogs or damage.

Automatic feeders

Automatic feeder benefits both horses and owners, especially in large facilities or for horses requiring frequent feeding. By mimicking natural eating patterns, they help to prevent gastrointestinal issues like ulcers and colic.

Advantages:

1. Reduces boredom and vices
2. Prevents feed waste
3. Save time and money

Challenges:

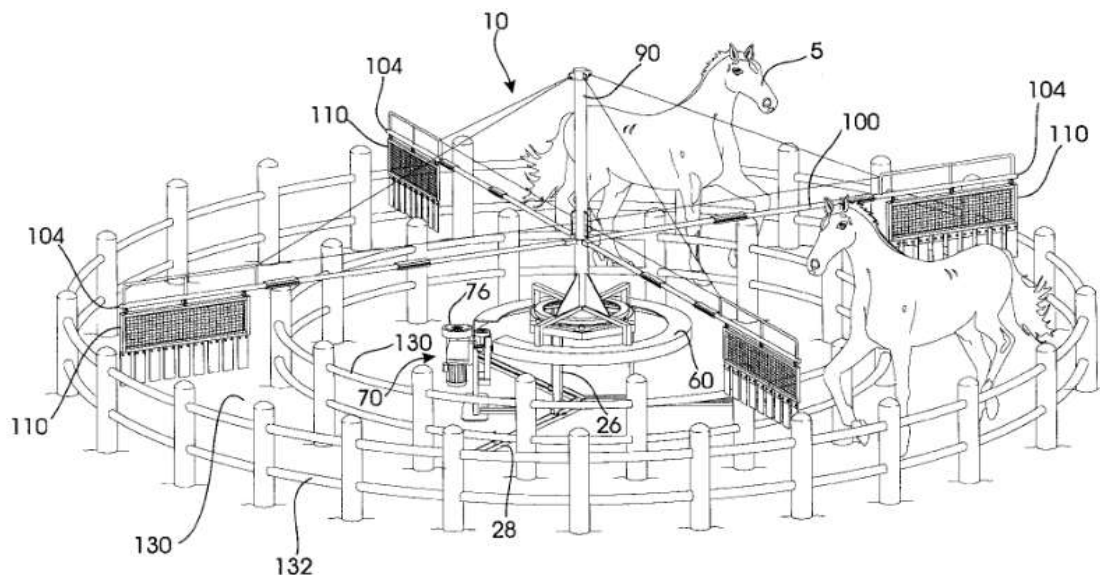
1. Risk of malfunction or tampering by horses
2. Feed clogs and power failure

Feeder Construction:

Feeder models like AgPro, ProFeeder are rodent, weather proof and made of galvanized steel and can be used both in outdoor and indoor.

Automatic Horse Walker

Horse trainers often utilize horse walkers to encourage a horse to walk during a ‘cool down’ phase following a race, helping to prevent muscle stiffness and respiratory issues. They are also used for training and acclimating a young horse to harness or halter.



(Horse Journal; 2014)

Objectives of Automatic Horse Walker

- ❖ Provide enough encouragement to the horse to keep moving in the forward direction.
- ❖ Providing a mechanical horse walker that does not pull the horse by the rope.
- ❖ To create a mechanical horse walker that allows the horse to move its head freely while in use.
- ❖ To design a mechanical horse walker that does not limit the horse's movement to the length of a tether.

Historically, a horse Walker was a person who exercised the horse by guiding it with reins. In modern times, various mechanical devices have been created to encourage a horse to move at a walking pace. For example, Profughi (U.S. Pat. No. 3,773,018) describes a horse Walker device featuring spokes attached to a rotating central hub. A horse is tied to a spoke and is moved along as the hub turns. The mechanical horse Walkers described in previous inventions demonstrates the application of a tether that pulls a horse in a circular motion using a rotating arm.

Conclusion:

Automation in horse management offers significant advantages in efficiency, labour reduction and animal welfare. From automatic waterers and feeders to robotic walkers, these technologies align with horses' natural behaviours while making management easier for owners. As technology continues to evolve automation will play an even greater role in advancing equine care and productivity.

COMMONLY OCCURRING EMERGING AND RE-EMERGING DISEASES IN RUMINANTS

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Introduction

Emerging diseases are those that have either appeared for the first time or are now expanding quickly in terms of incidence or geographical distribution over the previous 20 years. On the other hand, re-emergence diseases are those that were once considered public health issues and decreased and now again incidence is rising and becoming major health problem. Wildlife is the source of most newly discovered diseases. A survey found that zoonotic diseases are more likely to be caused by organisms that cause emerging and re-emerging diseases (Taylor *et al.*, 2001). According to Taylor *et al.* (2001), over half of human illnesses are zoonotic, and they are mostly brought on by increased animal-human contact (Heymann *et al.*, 2013). One of the primary causes has been identified as ecological changes. The ecological factors that cause diseases to emerge and re-emerge include agricultural growth, climatic change, food handling techniques, changes in water ecosystems, food handling methods, and deforestation and reforestation (Morens *et al.*, 2013). Climate change mostly affects vector borne and food/water-borne diseases (Cisse *et al.*, 2019). Shared environment and interaction between human and animal can also be source of diseases (WHO, 2020). Urbanization is another factor for emerging and re-emerging diseases. Slums are created inside cities because of rapid urbanization, subpar home building, and dense populations. Tuberculosis in Dhaka, Bangladesh (Banu *et al.*, 2013) because of inadequate sanitation, overcrowding, and infrastructure. Overcrowding and substandard housing can further fuel the spread of vectors. Changes in biological, environmental, and social factors brought about by globalization raise the under subfamily the of the burden of infections (WHO, 2020). Major epidemics and diseases are brought in by an increase in international trade and travel (Vignier *et al.*, 2018). Other factors for re-emergence of diseases can be due to rise in antimicrobial resistance and host susceptibility.

Commonly Occurring Emerging and Re-Emerging Diseases

1. PPR

Synonyms: Goat Plague, Erosive Stomatitis, Stomatitis-Pneumo-enteritis complex.

Peste des Petits Ruminants (PPR), a re-emerging disease in India, it is an acute, highly contagious viral disease of goats and sheep characterized by fever, anorexia, lymphopenia, erosive stomatitis, diarrhea, oculo-nasal discharge and respiratory distress. It's a Rinderpest like disease, highly more severe in goats than sheep with a morbidity & mortality of 50-90%. It is caused by Morbillivirus, a negative sense single-stranded RNA virus, Paramyxoviridae family.

Transmission occurs mainly through aerosols and direct contact with ocular, nasal, oral secretions, and feces of infected animals (Abubakar *et al.*, 2012), while contaminated feed, water, or pasture can also spread the virus (Baron *et al.*, 2016). Clinical signs include conjunctivitis, erosive lesions in the mouth and gastrointestinal tract, Broncho interstitial pneumonia, diarrhoea, weight loss, and labored breathing, often progressing to death in severe cases (Kumar *et al.*, 2004).

Gross lesions: extensive areas of erosions, necrosis & ulcers in the oral mucosa, pharynx & upper esophagus., sometimes even in abomasum & intestines. Hemorrhagic ulcers in ileocecal junction, colon & rectum with Zebra markings. Mucopurulent exudate in the respiratory tract from nostrils to larynx, presence of froth in trachea & bronchi. Lungs show interstitial pneumonia in uncomplicated cases while bronchopneumonia if complicated by secondary bacterial infections.

Prevention and control

Effective methods of disease control include mass vaccination, mobility control for sheep and goats, immunization monitoring, and disease surveillance. An attenuated vaccine is available which provide immunity for 1 year. The vaccinated animal produce antibodies against F, N and H proteins. The affected animals should be promptly treated with antibiotics to stop secondary bacterial infections, anti-histamine and multi-vitamins and minerals supplements as supportive measures.

2.FMD

- Foot-and-Mouth Disease (FMD), a re-emerging disease in India, is a highly contagious, viral disease of domestic cloven-hoofed and many wild animals characterized by fever, lameness, vesicles in the mucosa membrane of the mouth and hooves and teats. Although adult mortality is low, young animals up to 6 months of age, is very high may die due to viral myocarditis. The disease is caused by Foot-and-Mouth Disease Virus (FMDV), a member of the Aphtho virus genus in the Picornaviridae family, with seven

identified serotypes—A, O, C, Asia1, and SAT-1, 2, 3; of which serotypes O, A, and Asia1 are currently circulating in India (Paton *et al.*, 2021; Dahiya *et al.*, 2021).

- **India:** O, A, C & Asia-1 are prevalent. Strain 'O' is the most predominant followed by Asia-1
- **Transmission** Mainly air borne infection & the virus is highly contagious & extremely infectious. Virus is carried mechanically on humans, animals & fomites. Direct contact-Inhalation-Ingestion are the major routes of transmission. Clinically, the disease presents with fever followed by vesicle formation, especially on the tongue and feet; pigs primarily develop foot lesions, and myocarditis can be fatal in young animals.
- **Gross lesions** Vesicles on the mucosa of lips, dorsum of tongue and palate in cattle and in coronet, udder and teat, Lesions also seen – Rumen, Reticulum and Omasum, Haemorrhage and diffuse oedema in mucosa of abomasum and small intestine Death may be due to gastroenteritis and myocardial lesions in young calves - "Tigroid heart".
- **Prevention and control**

Restriction of animal movement should be made. Polyvalent vaccines containing serotypes O, A, C and Asia 1 are available. Primary vaccination should be done at 4 months of age followed by booster after 2-4 weeks and then revaccination should be done at every 6 months. Sprinkling of lime powder within premises should be done. In India, FMDCP (FMD Control Program) started in 2003-04 covering 54 districts and now has expanded to entire nation. The affected animals should be promptly treated with antibiotics to stop secondary bacterial infections, anti-histamine and multi-vitamins and minerals supplements.

3.Hemorrhagic Septicemia It is an acute, septicemic with high fever, respiratory distress, diarrhea primarily affecting cattle and buffalo caused by specific serotypes of *Pasteurella multocida*, a Gram-negative coccobacillus commonly found as a commensal in the nasopharynx of animals, HS is especially prevalent in Asia and Africa.

- **Transmission** occurs via direct contact with infected animals or contaminated fomites, and the bacteria typically enter the host through inhalation or ingestion. Carriers are common in endemic areas, and outbreaks are often associated with environmental stress, overcrowding, poor nutrition, and the rainy season. The bacterium can survive in moist soil or water for days but typically does not persist beyond 2–3 weeks (Shivachandra *et al.*, 2011). Typical clinical signs of HS appear suddenly and include high temperature, dullness, dyspnoea, hot painful swelling – head, dewlap and neck

with Inflammatory exudate in the subcutaneous tissues, salivation, and serous nasal discharge. Affected animals quickly develop respiratory distress and often die within 6–24 hours of symptom onset, though some may survive up to five days. The disease most commonly affects young adult animals and older calves in endemic zones (Shivachandra *et al.*, 2011).

- **Gross lesions:** Petechiae on all serous and mucous membranes especially on epicardium, myocardium, pleura, peritoneum and Gastrointestinal tract, Lymph glands- Swollen and haemorrhagic, G.I tract is severely inflamed with contents mixed with blood.
- **Prevention and control:** Three types of inactivated vaccines are used: formalin-inactivated bacterins, dense bacterins mixed with either oil adjuvant or alum adjuvant, and alum adjuvant bacterins, which are believed to offer protection for four to six months and up to a year, respectively. The effectiveness of the immunization in calves is hampered by maternal antibodies. Since 1989, Myanmar has employed a live HS vaccine, administered by intranasal aerosol spray, to prevent the disease in cattle and buffaloes older than six months. The affected animal should be treated with antibiotics like sulphonamides, tetracyclines, penicillin, gentamicin, ceftiofur or enrofloxacin.

4. Tuberculosis

Bovine tuberculosis is a chronic, zoonotic re-emerging disease caused mainly by *Mycobacterium bovis*, a member of the *Mycobacterium tuberculosis* complex, The name ‘tuberculosis’ comes from the nodules called ‘tubercles’, which form in the lymph nodes and other tissues of affected animals. The bacterium is aerobic, acid-fast, and possesses a lipid-rich cell wall dominated by mycolic acids, making it resistant to standard Gram staining (Markey *et al.*, 2013).

- **Transmission** occurs predominantly through inhalation of aerosolized droplets from infected animals, but can also occur via ingestion of contaminated milk, pasture, or water, and more rarely, through vertical or sexual transmission (Constable *et al.*, 2016). The disease is often subclinical in cattle, with overt signs appearing only in advanced stages. Clinical manifestations depend on factors like infection route, immune status of the host, and the infectious dose (Pollock *et al.*, 2002). Pulmonary involvement commonly leads to chronic cough, respiratory distress, and auscultatory abnormalities, while lymph node enlargement—especially retropharyngeal and mediastinal—can result in dysphagia or ruminal tympany (Constable *et al.*, 2016). Reproductive forms of TB may present as orchitis, metritis, or tuberculous mastitis, the latter posing significant public health risk due to shedding of *M. bovis* in milk. bovine TB is a zoonotic disease

it can infect humans, primarily through consumption of unpasteurized milk or direct contact with infected animals. Although diarrhea is rare, generalized emaciation and intermittent fever can also be seen in disseminated forms of the disease (Belinda & Erin, 2018).

- **Gross lesions:** characterized by the formation of tubercles which are avascular granuloma. These lesions typically found in lungs, lymph nodes, liver, intestine and kidney. The cellular composition of granuloma macrophages, epithelioid cell, giant cells and lymphocytes.
- **Prevention and control** post mortem meat inspection (looking for tubercles in the lungs, lymph nodes, intestines, liver, spleen, pleura, and peritoneum), for detection of infected animals and herds, intensive surveillance including on-farm visits, systematic individual testing of cattle, removal of infected and in-contact animals, adequate local legislation, effective movement controls, individual animal identification.

Detecting infected animals prevents unsafe meat from entering the food chain and allows Veterinary Services to trace-back to the herd of origin of the infected animal which can then be tested and eliminated if needed. Pasteurization or heat treatment of milk from potentially infected animals to a temperature sufficient to kill the bacteria has proven effective for preventing the spread of disease to humans.

Bacillus Calmette Guerin (BCG) was shown to be very effective when given to newborns in several recent experimental experiments conducted on cattle (Liao et al., 2019).

5. Paratuberculosis

Paratuberculosis, commonly known as Johne's feverless disease, is a re-emerging and chronic wasting illness of ruminants with prolonged course, recurrent diarrhoea, dehydration, emaciation. Gut is the main target organ. It is caused by *Mycobacterium avium* subspecies paratuberculosis, which belongs to the *Mycobacterium avium* complex.

- **Transmission** of Paratuberculosis typically occurs via the fecal-oral route, with infected animals shedding the organism through feces, milk, or colostrum. Calves can become infected through contaminated feed, water, teats, or milk, and intrauterine transmission is also possible, especially in clinically or sub clinically infected pregnant animals (Field *et al.*, 2022; Biemans *et al.*, 2021). The disease progresses in four stages: silent infection (Stage I), subclinical infection (Stage II), clinical disease (Stage III), and advanced clinical disease (Stage IV). Clinical signs become evident usually in animals older than two years and include chronic watery green diarrhea, progressive

weight loss, reduced milk yield, and submandibular oedema (bottle jaw) due to hypoproteinemia (Peek *et al.*, 2018). Terminal stages often result in cachexia and death, with necropsy findings including thickened intestinal walls, pale mucosa, and calcified or caseous lymph nodes (Elze *et al.*, 2013).

- **Gross lesions:** Carcass – Emaciation with gelatinous fat, Terminal part of ileum – Wall thickened and oedematous, the mucosa is folded and showed Transverse corrugation or rugae (like cerebral convolution).
- **Prevention and control:** strict biosecurity practices—like separating infected from uninfected groups and avoiding contaminated pastures—are essential for disease control (Garvey, 2020).

Additionally, young animals must be managed under optimal hygienic conditions to minimize the risk of infection.

6. Bovine Viral Diarrhoea

Bovine Viral Diarrhoea (BVD), an emerging disease, is a globally significant disease in cattle, caused by the Bovine Viral Diarrhoea Virus (BVDV), a Pestivirus within the Flaviviridae family.

- **Transmission** occurs through direct contact with infected animals or secretions, vertical transmission from infected dams to fetuses, and iatrogenic means such as contaminated equipment. Persistently infected (PI) animals are key reservoirs, shedding large quantities of the virus throughout their lives. Clinical signs of BVD vary depending on viral strain, immune status of the host, and stage of infection. Acute infections may present with fever, diarrhea, nasal and ocular discharge, oral ulcers, and reduced milk yield. Reproductive consequences include infertility, abortions, and congenital abnormalities like cerebellar hypoplasia. PI animals may appear clinically normal but are often immunosuppressed and stunted. In some PI animals, infection with a cytopathic strain can lead to mucosal disease, which is typically fatal, marked by severe diarrhea and ulceration of mucosal surfaces (Walz *et al.*, 2010).
- **Gross lesions:** GIT: sharply demarcated, irregular shaped ulcers on dental pad, palate, tongue, cheek, nuzzle, pharynx & larynx.
Esophagus: coalescing, elongate ulcers with necrotic debris. Petechial hemorrhages, erosions & ulcers on abomasum, omasum, SI, caecum, colon.
- **Prevention and control**
Biosecurity: Testing new animals before introduction, quarantine protocols, avoid shared needles, equipment, or untested biological products. Vaccination: Modified-live

and inactivated vaccines are available, should include both BVDV-1 and BVDV-2 strains, timing is crucial, especially in breeding animals to prevent fatal infections. Testing and culling: Identify and remove Persistently infected animals through antigen-capture ELISA or PCR on ear notches, blood, or milk, routine testing in youngstock and breeding herds.

7. Babesiosis

Babesiosis is an economically important tick-borne disease caused by protozoan parasites of the genus *Babesia*, which infect red blood cells of domestic and wild animals. The disease is endemic in tropical and subtropical regions, including India, and leads to high morbidity and potential mortality, particularly in cattle and companion animals. Clinical signs include high fever, anemia, jaundice, hemoglobinuria, and reproductive issues such as abortion and infertility. In severe cases, particularly with *Babesia bovis*, nervous signs and death may occur due to cerebral involvement (Solano Gallego *et al.*, 2016; Constable *et al.*, 2017). The disease is primarily transmitted by hard ticks, especially *Rhipicephalus* spp. Incidence is rising due to expanding tick populations and climate change (Sivakumar *et al.*, 2020). Major losses occur through reduced milk and meat production, decreased fertility, and increased veterinary care costs.

Prevention and control

The keystone of babesiosis control in veterinary medicine is effective tick management. This involves regular use of acaricides (e.g., deltamethrin, flumethrin), environmental de-ticking, pasture rotation, and strategic treatment. Chemotherapy includes diminazen aceturate (3.5 mg/kg IM once) or imidocarb dipropionate (1.2–3.0 mg/kg SC, repeated after 2 weeks), depending on the species and *Babesia* strain. Supportive therapy such as IV fluids, blood transfusions, anti-inflammatory drugs, and hematinic is critical in severe cases. Prophylactic use of imidocarb may reduce relapse risk in endemic areas. Although commercial vaccines exist in some countries (e.g., Australia, South America), India currently lacks an approved babesiosis vaccine, though experimental efforts are underway (FAO, 2011; Kumar *et al.*, 2021).

8. Lumpy Skin Disease

Lumpy Skin Disease (LSD) is a contagious re-emerging viral disease affecting cattle, caused by the Lumpy Skin Disease Virus (LSDV), a double stranded DNA virus within the *Capripoxvirus* genus of the *Poxviridae* family. LSDV is closely related to Sheep Pox and Goat Pox viruses. It has a strong affinity for dermal tissues, vascular endothelium, and lymphatics. The virus causes vasculitis, thrombosis, and necrosis of the skin and subcutaneous tissues.

- **Transmission:** Insect vectors – flies play a major role in transmission. The disease is vector-borne, transmitted primarily through blood-feeding insects such as biting flies (e.g. *Stomoxys calcitrans*), mosquitoes, and ticks, though direct and indirect transmission via contaminated equipment, feed, and water is also possible. Outbreaks are more common during the monsoon season due to high vector activity. Clinically, LSD is characterized by high fever, enlarged lymph nodes, and firm, appearance of nodules (2-5 cm in diameter) on all parts of the skin. that may ulcerate and scab. Additional signs include nasal discharge, conjunctivitis, reduced milk production, infertility, abortion, mastitis, and in severe cases, necrosis and secondary infections. The disease typically has an incubation period of 4–14 days and can last 2–6 weeks or longer, depending on the animal’s immune status and management practices (Constable *et al.*, 2017; OIE, 2021). Initially endemic to sub-Saharan Africa, LSD has become a significant transboundary disease, emerging in Asia, the Middle East, and Europe, with outbreaks reported in India since 2019 (Sudhakar *et al.*, 2023).
- **Gross lesions:** Lesions generally involve epidermis & dermis but may extend to subcutis & muscles also. Acanthosis (thickening of epidermis), parakeratosis (thickening & keratinization of stratum corneum with pyknotic nuclei) and hyperkeratosis (thickened stratum corneum layer of epidermis) are the major microscopic changes seen.

Prevention and control

Control of LSD is achieved through vaccination, vector control, movement restriction, and biosecurity. Vaccination is the most effective strategy. In India, heterologous vaccines such as the sheep pox vaccine were initially used but had variable efficacy. In response to recent outbreaks, India developed its indigenous vaccine “Lumpi-ProVacInd” in 2022, showing high efficacy against LSDV (ICAR-NRCE, 2022). Vector control includes the application of insect repellents, insecticide sprays, and environmental sanitation to reduce breeding sites of flies and mosquitoes. Movement control, including quarantine of affected farms and restriction of cattle transport, is essential to limit spread. Symptomatic treatment includes use of antipyretics, anti-inflammatory drugs, wound management, and antibiotics for secondary infections. Severely affected animals may require fluid therapy and nutritional support. There are no antiviral drugs for LSDV (OIE, 2021; ICAR NRCE, 2022).

Conclusion

Emerging and Re-emerging diseases in animals poses significant threats to animal health, human health and the economy. Understanding the dynamics of these diseases is crucial for

developing effective prevention and control strategies. For control of the diseases, we should focus on enhancing disease surveillance and reporting systems; developing new diagnostic tools and treatments, making and implementing policies.

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GENOMIC INNOVATIONS FOR ENHANCING LIVESTOCK HEALTH AND DISEASE RESISTANCE

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Abstract: Genomic advancements leverage our understanding of the livestock health and its management by enabling precise, data driven approaches to improve animal health, productivity, disease resistance, reproduction, and adaptability. This chapter presents an outline of the transformative impact of genomic innovations on livestock health and disease resistance and various aspects of livestock improvement. Diseases represent a significant challenge in the livestock sector, not only directly affecting the economic benefits of the industry but also posing potential risks to human health. Modern Tools such as genome-wide association studies (GWAS), genomic selection, and cutting-edge gene editing methods like CRISPR/Cas9 have made it possible to identify and target specific genetic markers linked to immunity and resilience. In addition, advancements such as whole genome sequencing, transcriptomic and epigenomic analyses, and metagenomics have greatly deepened our understanding of how livestock interact with pathogens, both at the genetic level and within their microbial environments.

Keywords: CRISPR, GWAS, Next-Generation Sequencing, Genomic Selection.

1.0 Introduction: As the global population continues to grow, the demand for livestock, whether as a source of food, animal products, or other agricultural resources, is also rising. This increasing demand highlights the critical need for advanced technologies to improve animal health and enhance disease resistance, ensuring sustainable and efficient livestock production. Disease resistance of an animal is its natural ability to keep invading germs in check, rooted in a dynamic interplay between its immune system, genetic makeup, and the traits of the invading pathogen. Precision farming (sensors, wearables, AI, data analytics), diagnostics (molecular tests, point-of-care testing devices), vaccines & alternatives (mRNA-based vaccines, heat resistant vaccines, antimicrobial alternatives), use of robotics, drones, smart housing and many more cutting-edge technologies are being used for enhancing livestock health and disease resistance.

These technologies are essential but the innovations in genomic technologies have offered a more precise, faster, healthier, higher performing livestock as compared to the traditional tools. The use of genomic tools has made it possible to bring out the change by altering the root cause at the genetic level.

2.0 CRISPR-Cas9: Biology is changing as a result of the easy genome engineering of plants and animals using the bacterial RNA-guided CRISPR-Cas9 system. CRISPR, which stands for clustered regularly interspaced short palindromic repeats, has also proven to be a revolutionary tool in the field of livestock genetics and breeding. Clustered regularly interspaced palindromic repeats (CRISPR)/Cas9 is a gene-editing technology causing a major upheaval in biomedical research allowing the precise and targeted changing of DNA in living organisms. Originally it was discovered as a part of the bacterial immune system. Bacteria and archaea have an adaptive immune system called CRISPR. It is made up of functional genes, short regularly clustered repeat sequences, the Cas9 protein, and similarly long spacer DNA sequences arranged from 5' to 3', which effectively defend preventing the destruction of genetic information and preventing the invasion of exogenous viral DNA. Among these the three main components of the CRISPR system are Endonuclease (Cas9), CRISPR RNA (crRNA) and trans-activating crRNA (tracrRNA). Cas (CRISPR-associated proteins) are the proteins that have been encoded using CRISPR.

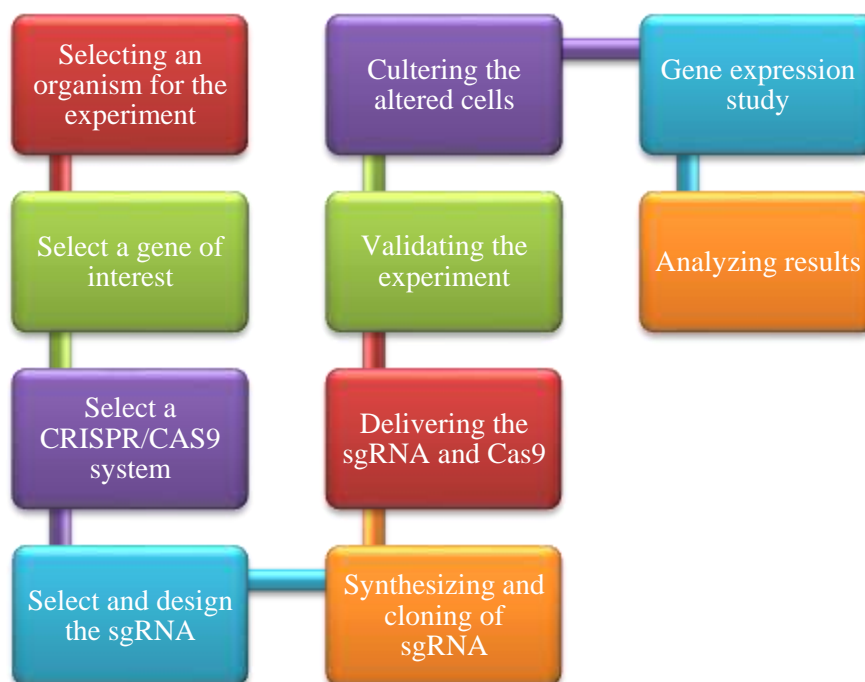


Fig. 1 Procedures of CRISPR/CAS9 modification system.

The Cas9 endonuclease, a key component of the Type II CRISPR/Cas9 system, which creates double stranded breaks in specific locations of genome, is guided to target DNA sequences

with the help of two types of RNA molecules. The first is the crRNA, which directs Cas9 to the correct target site in the genome. The second is the tracrRNA, which acts as a scaffold that connects the crRNA to Cas9 and also plays a role in processing crRNA into its mature form. Together, these two RNAs can be combined into a single molecule called the guide RNA (gRNA) or single guide RNA (sgRNA), which simplifies and streamlines the targeting process. The cell then uses its own natural repair systems to fix this break, which can be harnessed to add, delete, or edit specific genes. Eukaryotic cells mainly repair double stranded breaks by any one of the two mechanisms: Non-Homologous End Joining (NHEJ) or Homologous Recombination (HR) (Charpentier *et al.*, 2013; Doudna *et al.*, 2014).

2.1 Applications of CRISPR-Cas9 for enhancing livestock health and disease resistance:

Due to its ability to introduce precise genetic modifications, its specificity and its efficiency, it has been used in livestock to enhance disease resistance, increase tolerance to diseases, improve productivity and introduce desirable traits. Gao *et al.*, (2017) demonstrated natural resistance-associated macrophage protein-1 (*NRAMP1*) gene-inserted cows through the Cas9 strategy with increased resistance to tuberculosis. By using CRISPR/Cas9-assisted genome editing, Ikeda *et al.*, (2017) substituted a single mutated nucleotide with the appropriate nucleotide in the IARS (Isoleucyl-tRNA synthetase) gene, which is responsible for IARS syndrome-a recessive disease of Japanese Black cattle caused by a single nucleotide substitution. On a study done by He *et al.*, (2018) MSTN KO (Myostatin Knockout) goats with double-muscled phenotype were successfully generated by targeting the exon3 of MSTN using CRISPR/Cas9 system which resulted in the increase in average BWG per day of MSTN KO goats in comparison to that of WT (wild-type) goats. Other study was performed on sheep by Guo *et al.*, (2023) and they found out that *MSTN*-KO Hu sheep (an indigenous breed in China known for its high fecundity) showed a double-muscled phenotype, characterized by a higher body weight at 3 and 4 months old, prominent muscular protrusion, clearly visible intermuscular grooves, and muscle hypertrophy. Xie *et al.*, (2020) performed study on RSAD2 gene which exhibits antiviral activity against various DNA and RNA viruses. They successfully produced a pRSAD2-KI pig that constitutively overexpressed the pRSAD2 and viral challenge results indicated that fibroblasts isolated from the pRSAD2-KI pig showed reduced CSFV (classical swine fever virus) infection. Hübner *et al.*, (2018) showed that targeting the ASFV (African swine fever virus) p30 gene using CRISPR-Cas9 is a legitimate method of delivering resistance against ASF infection, which can also be used in its native animal host. On a study done by Senevirathne *et al.*, (2021) genetic interference exerted by salmonella delivered CRISPR/Cas9 significantly reduced the pathological burden caused by Marek's disease virus in chickens.

3.0 Genome-Wide Association Studies (GWAS): A genome-wide association study examines vast numbers of genetic differences across multiple genomes, aiming to identify variants that are statistically linked to a certain trait or illness. It is a favored method for finding genetic variants that increase disease risk. GWAS offers the advantage of accurately pinpointing mutation sites and directly utilizing SNP/LD (single nucleotide polymorphism/linkage disequilibrium) identification within genes or at the individual level (without lineage specificity) to identify new single genes and oligogenic disease genes. SNPs are used as molecular genetic markers in genome-wide association studies to identify links with specific traits. Currently predominantly used molecular markers in GWA studies are the SNP markers. This approach is based on the principles of Linkage Disequilibrium (LD) to explore the relationship between genetic variations and traits in populations. The GWAS technology’s high throughput and comprehensiveness are what give it an advantage. The first successful genome-wide association study was published by Klein *et al.*, (2005), which explored the polymorphisms of age-related macular degeneration (AMD) gene, the gene majorly responsible for blindness in elderly person. Since then, it has gained popularity in livestock also, by enabling the mapping of QTL (quantitative trait loci) of the traits of economic importance like milk yield, fat percentage, egg production, meat quality etc., to mention a few. In livestock industry, the diseases have always been a serious problem being capable of causing significant economic losses.

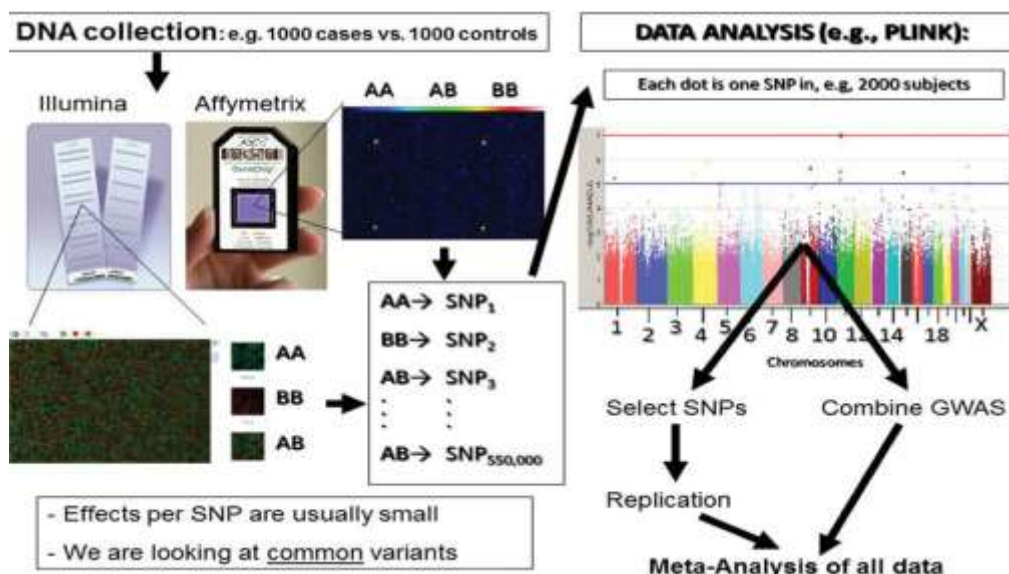


Fig. 2 Schematic representation of the various steps in a genome-wide association study (GWAS) (Uitterlinden *et al.*, 2016)

Health of the animal and its disease resistance have always been crucial for the production of better quality and quantity of livestock products. By utilizing identified genetic markers for disease resistance, selective breeding can rapidly improve the disease resistance of livestock

and poultry. Thus, it is possible to reduce disease incidence, while maintaining other desirable traits, improve the overall health level of livestock and poultry, reduce breeding risks, and enhance the sustainable development of the breeding industry.

3.1 Applications of GWAS for enhancing livestock health and disease resistance: GWASs have been very successful in the discovery of SNPs and candidate genes associated with tick resistance in variety of cattle breeds from diverse backgrounds. On a study done by Otto *et al.*, (2018) using GWAS they were able to identify candidate genes for tick resistance in Gir × Holstein crossbreds in both rainy and dry seasons (e.g., *TREM1*, *TREM2*, *TREML1*, *CD83*, *MYO5A*, and *PRSS16*). Uemoto *et al.*, (2021) performed GWAS for a total of 22 production, respiratory disease, and immune-related traits in MPS (Mycoplasmal pneumonia of swine) selected Landrace pigs and found a total of six significant QTLs for these traits and most of these detected QTL regions were novel regions. The high-density genome-wide association analysis by Murdoch *et al.*, (2011) identified a SNP on bovine chromosome 1 at 29.15 Mb that was significantly associated with BSE (Bovine spongiform encephalopathy) disease which will enable us to gain a better understanding of the pathobiology of prion diseases and may also provide insight towards development of effective gene-specific treatments of Prion related diseases. Finlay *et al.* found a genomic region on BTA 22 (*Bos taurus* chromosome 22) which was suggestively associated with tuberculosis susceptibility, it contains the taurine transporter gene *SLC6A6*, or *TauT*, which is known to function in the immune system but has not previously been investigated for its role in tuberculosis infection.

4.0 Genomic Selection: A new technology called genomic selection is revolutionizing livestock breeding. Genomic selection is a kind of marker-assisted selection where all quantitative trait loci are in linkage disequilibrium with at least one marker using genetic markers that span the entire genome. Genomic selection refers to selection decisions based on genomic breeding values (GEBV). To calculate the genomic estimated breeding value (GEBV), first a predictive equation based on high density single nucleotide polymorphisms (SNPs) is derived. The genome is divided into many small segments, and the effect of each segment is estimated by analyzing a reference population that has both genotype and phenotype data. In this way, the contributions of all genetic loci to the genetic variability, even those with very subtle effects are captured. Then, in subsequent generations, animals may or may not be phenotyped but are always genotyped to determine which chromosome segments they possess, and after summation of the estimated effects of those segments across the genome, the GEBV is predicted. This breeding value is termed as the GEBV.

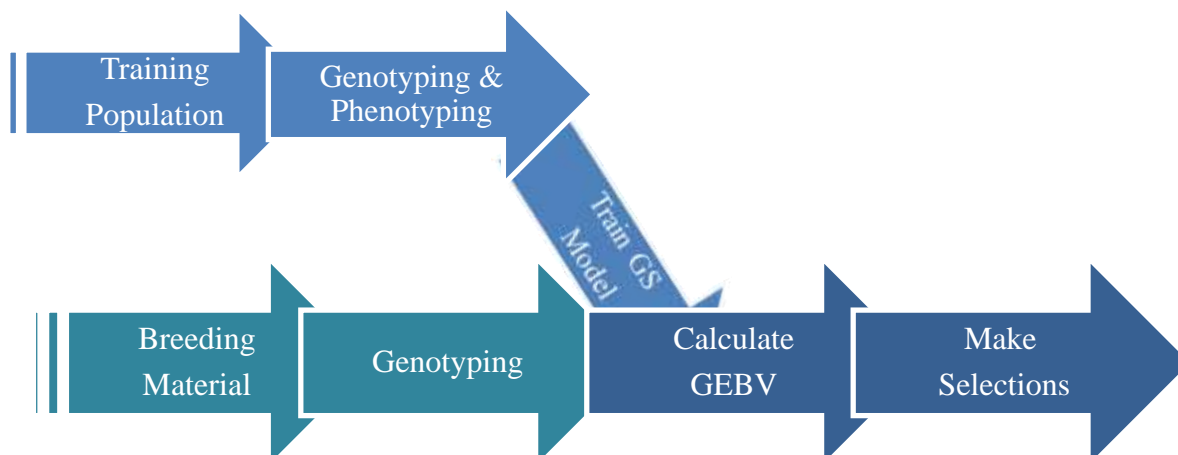


Fig. 3 Schematic diagram of the genomic selection (GS) process (Heffner *et al.*, 2009)

In their landmark study, Meuwissen *et al.*, (2001) first proposed the concept of genomic selection- a technique that enables the prediction of breeding values of individuals without phenotypes but that have been genotyped using high density marker panel. Since then, Genomic selection has profoundly affected the genetic improvement of livestock. The benefits of genomic selection were initially noted for dairy cattle, and it has greatly improved the technical and financial efficiency of animal breeding programs. These anticipated benefits are typically brought about by shorter generation intervals, higher EBV accuracy of bulls for milk production, and lower progeny testing expenses.

4.1 Applications of Genomic selection for enhancing livestock health and disease resistance: Genomic selection in livestock disease prevention is completely transforming the way the industry approaches the herd health and disease management. It has become possible by integration of genomic selection with genome-wide association studies, next generation sequencing etc. to identify the individuals with higher resistance to particular diseases. Genomic selection uses DNA markers to find animals with superior disease resistance traits. This method works especially well for diseases like tick borne infections that have complicated genetic basis. For example, genomic research has identified particular genetic variants linked to the inherent resistance to ticks exhibited by *Bos indicus* cattle. These markers can now be used by selective breeding programs to increase tick resistance in offspring, decreasing the need for chemical treatments and enhancing animal wellbeing. Vera *et al.*, (2025) with the integration of genomic data enhanced the genomic selection of Australian Merino sheep to improve resistance to gastrointestinal parasites. Zhang *et al.*, (2025) used Genomic Selection for Economically Important Traits in Dual-Purpose Simmental Cattle and observed the feasibility of applying the ssGBLUP method in breeding programs for dual-purpose Simmental cattle populations. Ruban *et al.*, (2023) observed that use of genomic

selection in breeding of dairy cattle in Ukraine can substantially increase genetic progress by means of shortening generation intervals and it is possible to increase the level of genetic progress in milk yield from 100.1 kg up to 180.0 kg, i.e., by 80%.

5.0 Next Generation Sequencing: The advent of next-generation sequencing technologies has revolutionized the way genomes are sequenced, including those of farm animals. NGS offers a high-throughput option for DNA sequencing compared to traditional Sanger sequencing and Maxam and Gilbert sequencing. NGS has enabled the researchers to generate cost effective large amounts of genomic data often without the need of DNA amplification. NGS technologies encompass various modern sequencing methods, with the most commonly used platforms being Illumina (Solexa), Roche/454, Ion Torrent, the Applied Biosystems SOLiD™ System, Pacific Biosciences and Oxford Nanopore. NGS platforms can be classified into second and third generation sequencing technologies, depending on when they were developed. Among the NGS technologies mentioned, the last two (Pacific Biosciences and Oxford Nanopore) are the most recently developed NGS technologies and can be called as third generation sequencing technologies, whereas the others fall under second generation sequencing. Second generation NGS platforms depend upon PCR to generate clusters from a given DNA template, which was one of their limitations. While third generation NGS platforms operate with a concept of sequencing individual DNA molecules without a prior amplification step.

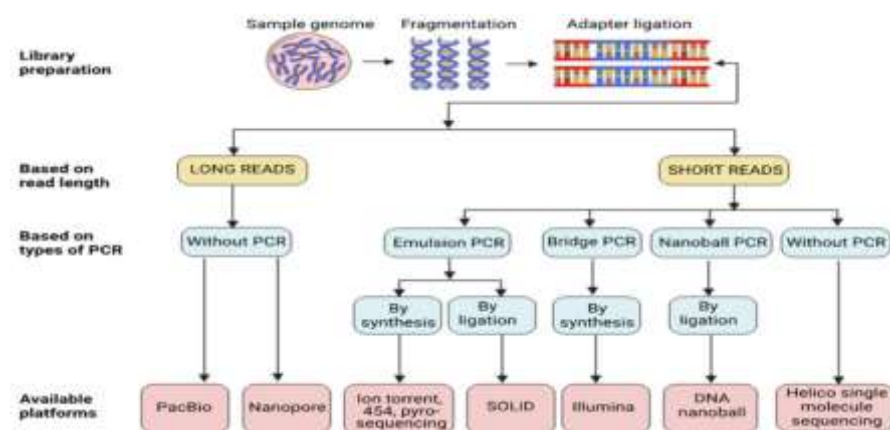


Fig. 4 Schematic diagram of various NGS technologies with different platforms and principles. (Satam *et al.*, 2023)

Next Generation Sequencing has made it possible to characterize and quantify various types of “omics”, including genomics, transcriptomics, epigenomics and metagenomics (Horgan *et al.*, 2011). Genomic research utilizing NGS conducts DNA analysis through various methods, including whole-genome sequencing, whole-exome sequencing and targeted sequencing. Whole-genome sequencing (WGS) is a highly effective and comprehensive method of genomic

analysis that involves determining the entire DNA sequence of an individual's genome, thus providing the blueprint of an individual's genetic makeup, encompassing all the genes, regulatory regions, and non-coding elements present in their genome. Whole-exome sequencing (WES) is application of the next-generation technology to determine the variations of all coding regions, or exons, of known genes. While targeted sequencing panels focus on a particular cluster of genomic regions and have fewer data burdens with the level of bioinformatics or computational demand. The transcriptome is the total mRNA (including messenger RNA, transfer RNA, ribosomal RNA, and other non-coding RNAs) in a cell or organism and the template for protein synthesis in a process called translation, while transcriptomics is the study of the mRNA within a cell or organism. Transcriptome analysis enables us to understand the genome expression at the transcription level, which provides information on gene structure, regulation of gene expression, functions of the gene product, and the overall genome dynamics. Epigenomics is the study of how chromatin structure affects a cells genetic material or epigenome. This includes higher order chromatin folding and attachment to the nuclear matrix, DNA packaging around nucleosomes, covalent modifications of histone tails (acetylation, methylation, phosphorylation, ubiquitination), and DNA methylation.

Metagenomics is the direct genetic analysis of genomes of uncultured microorganisms included in an environmental sample. Cloning environmental DNA is the first step in the field, is then followed by functional expression screening. Our understanding of the microbial world is growing and changing as a result of faster, less expensive sequencing technologies and the capacity to sequence uncultured microorganisms taken straight from their environments.

5.1 Applications of NGS for enhancing livestock health and disease resistance: The development of Next-Generation Sequencing (NGS) has made a big impact on research. With the help of NGS scientists can identify and study known as well as novel genetic variations that lead to disease. Patel *et al.*, (2015) studied single nucleotide variations (SNP/SNV) and haplotype structure in innate immune genes viz *CHGA*, *CHGB*, *CHGC*, *NRAMP1*, *NRAMP2*, *DEFB1*, *BNBD4*, *BNBD5*, *TAP* AND *LAP* in Gir cattle and Murrah buffalo and a large number of genetic variations were observed in 7 out of 10 candidate genes. These variations in specific gene will contribute to the design of markers related to specific health related traits in bovine. Transcriptomics data can facilitate the functional studies where high and low producing animals can be compared and differentially expressed genes could be identified. Chaorattanakawee *et al.*, (2022) analyzed whole blood samples from 243 livestock in Mongolia (cattle=38, camel=11, goat=85, horse=22, sheep=87) with 16S metagenomics next-generation

sequencing (NGS) to screen for tick-borne bacterial pathogens and found high prevalence of *Anaplasma* in livestock, with sheep experiencing the highest burden of infection.

6.0 Conclusion: Recent advances in genomic livestock improvement are increasingly focusing on precision breeding and data-driven decision-making. Studying innate immune responses in indigenous, exotic, and crossbred animals of the same species can provide valuable insights into the genetic factors that influence resistance to economically important infectious diseases. Technologies like CRISPR have seen widespread use in recent years, but there is still much to explore to fully realize their potential. Expanding the application of CRISPR/Cas9 will require improving its efficiency by increasing gene correction rates, minimizing off-target effects, and developing more effective delivery methods. Genomic selection is also changing the way we prevent disease in livestock, using precise data and methods to better manage health and enhance resistance to common infections. Similarly, GWAS, which examines large-scale SNPs, has proven effective in identifying genetic variations linked to complex traits in livestock. Next-generation sequencing has further transformed our understanding of animal infectious diseases, offering veterinarians valuable tools to develop new vaccines and treatments. Overall, innovations in genomics are making it possible to perform tasks faster, more accurately and at a lower cost than earlier technologies, opening up new possibilities for livestock breeding and health management.

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CARING BEYOND CURE- HOLISTIC PRACTICES IN ANIMAL HEALTH

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Abstract

Holistic animal care means looking after an animal's whole well-being which involves the treatment of whole animal, including physical, behavioral, environmental and nutritional factors alongside conventional modern measures. It's like caring for a family member, not just fixing them when they are sick. The idea of holistic animal health care practices aligns closely with WHO concept of one health which recognizes the interconnectedness of animal, human, and environmental health. Holistic animal healthcare approach includes complementary and alternative veterinary medicine which is based on acupuncture, herbal medicine, homeopathy, physiotherapy and ethno-veterinary practices- which involves the use of traditional knowledge using plant based remedies and indigenous practices, which leads to low cost and less use of medicines and more natural, responsible animal farming, particularly essential for livestock healthcare in remote regions. also animal nutrition, plays a central role in holistic animal health, with the help of balanced diets, use of probiotics and mineral supplementation helps in improving the immunity and reduced disease incidence. Stress reduction, improved housing and hygiene and environmental enrichment, enhances the productivity and animal welfare, especially in dairy and poultry systems. Holistic care improves the psychological well-being of animals as well as prepare an important role in achieving the goal of one health program through prevention and control of diseases. Holistic animal healthcare contribute to sustainability in several ways- which includes reduced antibiotic resistance, by using herbal and natural therapies, environmental protection and by biodiversity conservation. Complementary and alternative veterinary medicine includes therapies such as Chiropractic care, Aromatherapy, Laser therapy, hydrotherapy. Despite many advantages, several barriers limit the promotion of holistic animal healthcare, which includes lack of scientific validation because many therapies lack strong clinical evidence and standardized testing, also the dose differences. Even the veterinary professionals often lack formal education in holistic approach and the lack of policies. The risk of misuse of relying a lot on alternative therapies may delay essential medical treatment.



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To promote the holistic animal healthcare practices, clinical trials should be conducted to validate the therapies by integrating traditional knowledge with modern science and by developing standard treatment protocols, promoting interdisciplinary research and including alternative veterinary medicine in veterinary education and training. With the help of these approaches, holistic animal healthcare offer a promising approach to improving animal health, welfare and sustainability.

Keywords: One health, WHO, sustainable livestock production, animal nutrition, antimicrobial resistance, alternative veterinary medicine.

Introduction

Long before modern veterinary science emerged, people relied on integrated, observation based systems that resemble what we now call “holistic” care. In ancient India, animal care was closely connected to Ayurveda. Early texts like shalihotra samhita focused on horses and recommended proper diet, herbal remedies, surgery and attention to behavior. The goal was to keep the animal body in balance. In china, Traditional Chinese medicine {TCM} was also used for animals, techniques such as acupuncture and herbal treatments were common. In Egypt, animals were both useful and sacred .Records show that people used plant –based medicines, treated wounds, and performed spiritual rituals to keep the animals healthy. A key idea in Ayurveda is balance between the three *energies, or doshas*- Vata meaning movement, Pitta means heat and metabolism and Kapha means structure and stability .when these are balanced, the animal stays healthy; when disturbed, illness can occur. So the holistic animal health care just means taking care of an animal in a complete way-not only when it gets sick, but all the time. Instead of focusing only on medicine, it looks at everything that affects the animal. In simple words if an animal eats well, lives in a good place, and is cared for properly, it is less likely to fall sick.

Need for maintaining good animal health

Animal health is essential for maintaining productivity and ensuring overall agricultural sustainability. The health of animal plays an essential role in supporting food security and economic development. Proper animal health management is crucial for enhancing livestock performance and preventing disease transmission. Maintaining good animal health is fundamental to animal welfare and public health protection.

Holistic animal healthcare practices meaning.

Holistic animal health care means taking care of animals in a complete way by focusing on their nutrition, environment, welfare, and disease prevention together.

According to Temple Grandin (2014). Proper housing, reduced stress, and humane handling significantly improve animal welfare and productivity.



Source: <https://www.myfurrries.com/blog/building-a-pet-animal-health-ecosystem-why-collaboration-is-key/>

Similarly, Calvin W Schwabe (1984). Introduced the concept of “One Medicine”, highlighting the interconnectedness of animal and human health, which forms the basis of holistic care. Research by Delia Grace et al. (2015) indicates that improving animal health through better nutrition, hygiene, and disease prevention contributes directly to food safety and public health. According to Bernard vallat (2011). Preventive measures such as vaccination, biosecurity, and welfare friendly management are essential for sustainable livestock production. The goal of holistic veterinary medicine is to treat the "whole animal," which includes environmental, behavioral, and physiological aspects. Holistic care, attempts to support entire body balance and long-term health while addressing the underlying cause of illness.

This approach has gained attention due to increasing concerns about:

- Overuse of antibiotics
- Drug side effects
- Animal welfare and sustainability.

Core Principles

- Individualized treatment
- Balance and homeostasis
- Minimal use of synthetic drugs
- Natural and sustainable therapies
- Preventive healthcare focus

Essential Elements of Holistic Practices

1. **Whole-Body Method:** - An animal's diet, way of life, emotional well-being, and surroundings are all evaluated in holistic treatment.
2. **Prevention Rather Than Treatment:** - Disease prevention through healthy eating, good cleanliness, and stress management is emphasized.
3. **Customized Care:** - Every animal is given individualized treatment based on its particular physiology and living circumstances.
4. **Combining Therapies:** - In order to provide balanced and efficient care, alternative therapies are used in conjunction with conventional medicine rather than in its place.

Typical Holistic Approaches: - Veterinary holistic approaches use a variety of treatments, such as Immune system support, pain relief, and improved circulation are all benefits of acupuncture.

Herbal medicine lessens medication side effects and supports organ function.

Enhances mobility and lowers stress with massage therapy

Supplemental nutrition can aid in healing and stop the progression of illness.

Enhancing Musculoskeletal Health with Chiropractic Care These treatments aim to preserve equilibrium and encourage the body's natural healing processes.

Components of holistic animal health

Ethno-Veterinary Medicine with Special Reference to Jammu and Kashmir

Traditional methods of treating animals that make use of local resources and indigenous knowledge are referred to as ethno veterinary medicine. Ethno veterinary medicine is an offshoot of ethno botany associated with the usage of traditional methods of medication of animals *Dutta et al. 2021a, Singh et al. 2021*. Due to insufficient or limited accessibility of allopathic medicines in several parts of the country, most livestock holders and farmers are still using the ancient plant-based traditional knowledge for the treatment of livestock ailments *Bhat et al. 2021*.

One of the most crucial prevailing systems in the Himalayan region where modern veterinary healthcare facilities are scarce or in extremely bad condition is the traditional method of treatment. The folk knowledge of ethno-veterinary medicine has its significance in the treatment of livestock diseases in remote and rural areas of the J&K. The seminomadic and nomadic tribes of the Indian Himalayan region in general and the Gujjar and Bakerwal tribes of J&K, in particular, still possess a rich heritage of traditional healthcare systems. In our literature survey, it was found that plant species documented during the present study possess biological activities owing to the presence of various biologically active phytochemicals. Thus, more studies of the biological activities of ethno-veterinary plants can provide clues of

promising leads for the isolation and identification of useful compounds that may be developed into pharmaceuticals. Further, there is recurrently an overlap between medicinal plants used to alleviate animals and humans. Thus, ethno-veterinary medicines can function as leads for drug development, but probably a more practical and lucrative exercise would be to develop a preferred preparation by pharmacological research, and the ensuing medication can be returned to the society with extra impact. However, this valuable knowledge-base has become obsolete due to industrialization, urbanization and, above all, lack of recognition by the younger generations. Therefore, there is a dire need to review, document and authenticate the valuable traditional knowledge of ethno-medicinal plants for the human welfare. This study could be a pilot to document the sustainable utilization of frequently used bio resources by understanding the traditional knowledge systems, and will provide important leads for the formulation of novel drugs and medicine *Wani, Z.A. et al. 2022.*

With the increase in demand for organic farming products and controlled use of synthetic antimicrobials as growth promoters in the plant, ethno veterinary medicine is the pre-eminent and fitting alternative approach McGawetal (2020).

Herbal Therapy- Herbal Medicine (Phytotherapy) Herbal medicine is widely used in holistic veterinary care. The World Health Organization (WHO) defines traditional medicine (herbal medicine) as “the sum total of the knowledge, skills, and practices based on the theories, beliefs, and experiences indigenous to different cultures, whether explicable or not, used in the maintenance of health as well as in the prevention, diagnosis, improvement or treatment of physical and mental illness”.

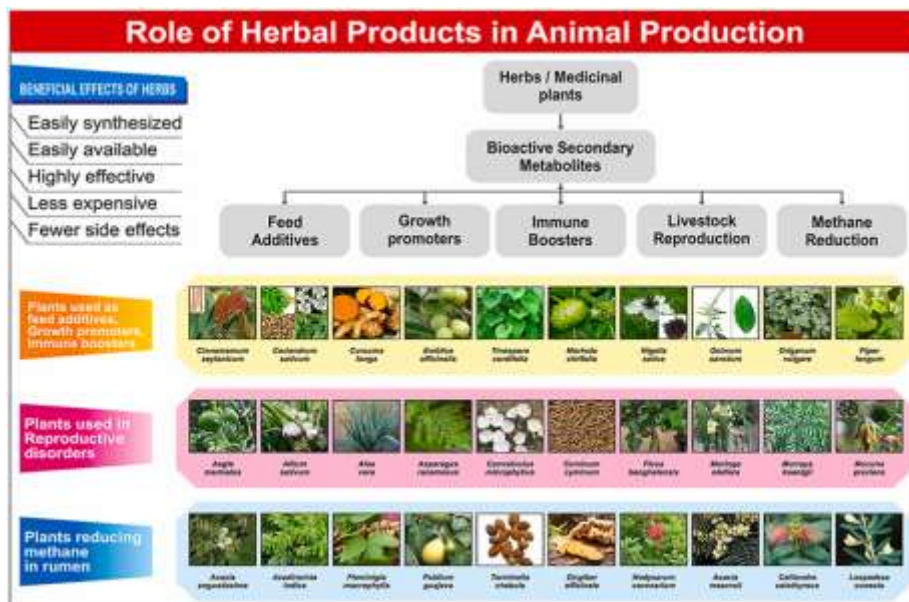
Source- who.int. World Health Organization

Herbal medicine is one of the oldest forms of animal treatment. Plants have been used for centuries to manage:

- Skin diseases
- Wounds
- Digestive disorders

Medicinal plants can play an important role in treating dermatological conditions and supporting healing.

- Uses plant-based formulations for treatment.
- Supports organ function and tissue healing
- Eco-friendly and sustainable
- Minimal side effects Common-Uses:



Source- https://ars.els-cdn.com/content/image/1-s2.0-S0378874121004736-ga1_lrg.jpg

- Neem (*Azadirachta indica*) – antimicrobial
- Turmeric (*Curcuma longa*) – anti-inflammatory
- Aloe vera – wound healing Uses highly diluted substances.

Standardization of veterinary herbal medicines (crude drugs/extracts) is necessary to establish their quality, consistency, and reproducibility to ensure that one or more of the veterinary herbal medicine's key phytochemical ingredients or other ingredients are present in a defined amount. It is also necessary to implement quality control for batch-wise consistency, uniformity of dosage, stability, and for the detection of contamination/adulteration Wani M S et al. Various chemical, spectroscopic, and biological methods are also employed for the standardization. Some examples include infrared spectroscopy, liquid chromatography, high performance thin layer chromatography (HPTLC), nuclear magnetic resonance, mass spectroscopy, etc. (Chakravarthy Bk). While the herbal products are cheaper, the active ingredients of the medicinal plants are becoming increasingly expensive. As a result, herbal veterinary medicines are losing their edge over the allopathic drugs. Thus, there is also an urgent need to encourage research in this sector.

Nutritional therapy-

Nutrition is a key part of holistic care. Proper feeding:

- Strengthens immunity
- Prevents diseases
- Supports recovery
- Holistic approaches often include feeds nutritional supplements and functional to improve overall health and reduce disease risk.

- Interest in connecting the fields of nutrition and immunology have been fruitful into understanding how health and disease progress over time and how nutrition may be able to improve immune function Di Cerbo et al., 2017; Wu et al., 2018a.
- Nutrition plays a critical role in immune modulation and disease prevention.
- To understand species-specific responses and how they potentially can be modulated by diet, it is important to understand some basic immune response differences across companion and livestock species Day, 2007; Schultz and Magor, 2008; Gershwin, 2015; Guzman and Montoya, 2018.
- Most of the immunomodulation compounds perform a function related to dampening the immune system to offer a growth, immune, or performance benefit (vitamin D, omega-3 PUFA, phytogetic), while some alter interactions with other systems to provide a benefit (probiotics). Supplementation of probiotics or vitamin E at the right concentration and timing may enhance a desirable outcome such as antibody titer in response to a vaccine and can be taken into consideration with both livestock and companion animals to improve health outcomes.

Homeopathy-

Based on the principle: *"like cures like"*. The word "homeopathy" is derived from the Greek words "homios" meaning "similar," and "pathos" meaning "disease or suffering." In practicing homeopathy, the symptoms that an animal exhibits are all-important in choosing the appropriate remedy to stimulate a healing response. Whereas, in conventional medicine, the thinking may assume that symptoms or signs represent the disease itself and need to be controlled or eliminated, in homeopathy, a symptom or sign is seen, not as the disease itself, but as a signal of it.

In choosing a homeopathic remedy, all of an animal's clinical signs, even those that are seemingly unrelated to the primary problem, are taken into consideration, on the principle that all of the symptoms are "signs" of the body's reaction to external stimuli or internal imbalances. Homeopathy can be used to treat a surprising number of conditions in both large and small animals. It can be used as therapy in trauma and acute injuries; for example, in sprains, concussions, and insect stings. In such cases, the appropriate homeopathic remedy can minimize or eliminate swelling and pain, and shorten recovery time. It can be used in many types of inflammatory conditions, such as acute and chronic diarrhea, chronic gingivitis, acute and chronic respiratory conditions, and other conditions that may or may not be responsive to conventional therapies. Although homeopathy may be most effective in the treatment of conditions in which serious pathology has not yet occurred in the patient's system, it can also be very helpful in the treatment of many chronic conditions, such as arthritis and spondylitis.

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Homeopathy can also be helpful in palliating discomfort associated with cancer. Homeopathic remedies are very safe to use. Generally, no side effects are observed, if the remedy is used correctly. However, in the hands of persons with little or no knowledge of homeopathy, remedies may be overused or, much more commonly, the wrong remedy is used, and no effect at all will be seen. This obviously does not harm the patient, but it does it no good either and is one of the reasons why, in the recent past, homeopathy was seen as a treatment with little or no effectiveness Can Vel J Volume 40, August 1999.

Acupuncture and Physical Therapies- Acupuncture is a popular complementary treatment option in human medicine. Increasingly, owners also seek acupuncture for their animals.

Effectiveness of acupuncture in veterinary medicine –In addition to its analgesic effects, acupuncture also has anti-inflammatory effects. An example where this is clinically useful is in treatment of exuberant granulation tissue (“proud flesh”) in horses. Equine lower limb wounds often heal poorly and it can be difficult to reduce granulation tissue formation and achieve a cosmetic result. Implantation of gold beads at acupuncture points has been used to treat wounds on the cranial hock and cannon bone region. According to a study found that a single implantation effectively controlled excessive granulation tissue formation, reducing or eliminating the need for bandaging and eliminating surgical resection in thirty-five horses. The wounds healed with a cosmetically acceptable and functional result. Long-term follow-up for eighteen or more months demonstrated that the wounds had completely healed, with reduced fibrosis compared to horses not treated with acupoint gold bead implantation. Although this was a preliminary study, gold bead implantation produced significant results without adverse effects on the horses and this application of acupuncture is worthy of further clinical investigation. Frauenfelder H. (2008). It stimulates specific points to promote healing. Two main systems based on different veterinary acupuncture points, have persisted: the “traditional” or Traditional Chinese veterinary medicine (TCVM) technique and the “Trans positional” technique.

- Used in
 - Pain management
 - Neurological disorders
 - Musculoskeletal conditions.
 - Acupuncture stimulates nerves and increases blood circulation, promoting natural healing and reducing pain.

These therapies are increasingly included in integrative veterinary practices.

Environmental and Behavioral Management- Climate change, air and water quality, habitat alteration, biodiversity loss, and human-induced stressors affect many animal species. Using a

"One Health" strategy, veterinarians, ecologists, public health experts, and other professionals collaborate to combat emerging infectious diseases and protect the environment. . There is a significant impact from climate, as the metabolic rates, reproductive cycles, and overall physiological functioning of animals are all influenced by the high temperatures that they experience. There is a correlation between the loss of biodiversity and changes in food chains and disease dynamics, which in turn influences the overall health of animal populations.

Holistic care recognizes that environmental stressors contribute significantly to disease development.

Complementary and Alternative Veterinary Medicine (CAVM)-

CAVM includes therapies such as:

- Chiropractic care
- Aromatherapy
- Laser therapy
- Hydrotherapy

These therapies are increasingly used worldwide, though scientific validation varies across modalities.

Integration with Conventional Veterinary Medicine

Modern veterinary care is now using a combined approach where regular (conventional) treatments are used together with supportive (complementary) therapies. This helps in giving better care to animals.

Table: Traditional Therapies and Their Veterinary Applications

Traditional Therapy	Clinical Use	Animal Type	Evidence Support
Herbal Medicine	Digestive & skin disorders	Livestock & pets	Moderate
Acupuncture	Pain management	Companion animals	Strong
Ayurveda	Metabolic balance	Livestock	Emerging
Manual Therapy	Musculoskeletal issues	Horses & dogs	Moderate

Table: Integrative Approaches and Clinical Outcomes

Integrative Practice	Modern Therapy combined	Target condition	Clinical outcome
Acupuncture + NSAIDS	Pharmacotherapy	Chronic pain	Reduced pain & drug dose
Herbal therapy + Antibiotics	Infection control	Skin infections	Faster recovery
Physiotherapy + Surgery	Post-operative care	Orthopedic cases	Improved mobility
Nutritional therapy + Vaccination	Preventive care	Herd health	Enhanced immunity

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Source: <https://agriinnovationjournal.com/aij/index.php/JVRP/article/view/329/305>

1. What is Integration?

Integration means using:

- Modern veterinary methods like medicines, surgery, and lab tests
- Along with supportive therapies like herbal treatment, acupuncture, and proper nutrition

The main aim is to treat the disease effectively and improve overall health of the animal.

Advantages of Holistic Animal Healthcare

- Reduced dependency
- Lower treatment costs in rural settings
- Eco-friendly and sustainable
- Improved animal welfare
- Preventive health benefits

Holistic animal healthcare has a promising future, especially as people look for safer, more sustainable ways to care for animals.

It can play an important role in:

- Sustainable livestock production, by reducing dependence on chemicals
- Reducing antimicrobial resistance, through less use of antibiotics
- Improving animal welfare, by focusing on overall well-being

Supporting the One Health concept, which connects animal health with human and environmental health. In the coming years, more work is needed to make holistic practices stronger and more reliable. This includes:

- Conducting proper clinical trials to test how well complementary therapies work
- Developing standard treatment guidelines so that consistent practices are available.
- Building evidence-based integrative models that safely combine modern and traditional methods

Recent studies suggest that as more scientific evidence becomes available, integrative veterinary care will become more widely accepted and commonly used in everyday practice.

In simple terms, the future of animal healthcare is likely to be a balanced mix of modern science and natural care, working together for better animal health and sustainability.

Holistic approaches should complement—not replace—evidence-based veterinary medicine, especially in acute and life-threatening conditions.

Limitations and Challenges

- Despite its advantages, holistic animal healthcare faces several challenges:
- Limited Scientific Evidence
- Many complementary therapies lack strong clinical trials or standardized data.
- Lack of Standardization
- Dosage, treatment protocols, and quality of herbal products can vary widely.
- Risk of Delayed Treatment

Relying only on alternative therapies in serious conditions may delay effective medical care.

Need for Skilled Practitioners

Successful integration requires veterinarians trained in both conventional and complementary systems.

Conclusion

Holistic animal healthcare takes a wide view of veterinary medicine. It sees animal health as the result of many things working together—food, environment, how animals are managed, and their behavior. Instead of just fixing problems when they pop up, holistic care pushes for prevention and overall well-being. Still, the evidence shows holistic practices work best when you combine them with regular veterinary medicine. Don't toss out the standard treatments—just add scientifically proven complementary therapies on top. This blend gives animals more complete care and actually makes things more practical for vets and owners. Going this route, mixing both approaches, helps animals heal better, improves their quality of life, and makes animal healthcare more sustainable in the long run.

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DEVELOPMENT OF SUSTAINABLE AND CLIMATE-RESILIENT LIVESTOCK SYSTEMS

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Abstract

Livestock systems are a cornerstone of global agriculture, contributing significantly to food security, nutrition, and rural livelihoods. In developing countries, especially India, livestock supports smallholder farmers by providing income, employment, and nutritional resources such as milk, meat, and eggs. However, the sector is increasingly threatened by climate change, which manifests through rising temperatures, erratic rainfall, frequent droughts, and emerging disease patterns. These challenges adversely affect feed availability, water resources, animal health, and overall productivity. Sustainable and climate-resilient livestock systems aim to address these challenges by integrating environmental, economic, and social considerations into livestock production. Such systems focus on enhancing productivity while minimizing environmental impacts, improving resource-use efficiency, and strengthening the adaptive capacity of livestock and farmers. The concept aligns closely with climate-smart agriculture, emphasizing mitigation, adaptation, and food security simultaneously. This chapter provides a comprehensive overview of sustainable and climate-resilient livestock systems, including their concept, importance, components, challenges, and strategies for development. It highlights the role of technological innovations, policy support, and community participation in building resilient livestock systems capable of withstanding future climate uncertainties.

1. Introduction

Livestock farming is an integral component of agriculture, contributing significantly to food production, employment, and rural economies. In countries like India, livestock supports smallholder farmers by providing milk, meat, eggs, manure, and draught power. However, the sector is increasingly vulnerable to climate change, which affects feed availability, animal health, water resources, and overall productivity.

Climate change impacts, such as heat stress, droughts, and emerging diseases, have highlighted the need for resilient livestock systems. Sustainable livestock development focuses on maintaining productivity while minimizing environmental impact, whereas climate resilience refers to the ability of systems to adapt, recover, and continue functioning under climate stress (FAO, 2019). Therefore, integrating sustainability and resilience is essential for long-term livestock sector growth.

2. Concept of Sustainable and Climate-Resilient Livestock Systems

2.1 Sustainable Livestock Systems

Sustainable livestock systems aim to optimize production while conserving natural resources and maintaining ecological balance. These systems focus on efficient resource utilization, reduced greenhouse gas emissions, and improved animal welfare. Sustainability involves economic viability, environmental protection, and social equity, ensuring that livestock farming remains beneficial for present and future generations (Gerber et al., 2020).

2.2 Climate-Resilient Livestock Systems

Climate resilience in livestock systems refers to the capacity to withstand and recover from climate-related stresses such as extreme weather events, disease outbreaks, and feed shortages. Resilient systems incorporate adaptive strategies such as improved breeds, diversified production systems, and efficient resource management. These approaches help reduce vulnerability and enhance system stability under changing climatic conditions (Thornton et al., 2021).

3. Importance of Sustainable and Climate-Resilient Livestock Systems

3.1 Food and Nutritional Security

Livestock provides essential nutrients such as protein, vitamins, and minerals, contributing significantly to human nutrition. Sustainable livestock systems ensure a continuous supply of safe and nutritious food even under adverse climatic conditions. Climate-resilient practices help maintain productivity and prevent disruptions in food supply chains (FAO, 2021).

3.2 Livelihood Support and Economic Stability

Livestock farming is a major source of income for rural households. Climate-resilient systems protect farmers from economic losses caused by climate variability. By improving productivity and reducing risks, these systems enhance income stability and reduce poverty among smallholder farmers (Herrero et al., 2020).

3.3 Environmental Sustainability

Livestock systems contribute to greenhouse gas emissions, land degradation, and water use. Sustainable practices such as improved feeding, manure management, and rotational grazing

reduce environmental impacts. Climate-resilient systems also promote biodiversity conservation and efficient resource use (Gerber et al., 2020).

4. Key Components of Climate-Resilient Livestock Systems

4.1 Improved Breeds and Genetic Resources

Developing and promoting climate-resilient breeds is a key strategy for enhancing livestock productivity under changing conditions. Indigenous breeds often possess traits such as heat tolerance, disease resistance, and adaptability to low-input systems. Genetic improvement programs focus on enhancing these traits while maintaining productivity (FAO, 2019).

4.2 Feed and Fodder Management

Climate change affects the availability and quality of feed resources. Sustainable livestock systems emphasize efficient feed utilization, use of drought-resistant fodder crops, and incorporation of alternative feed sources. Improved feed management not only enhances productivity but also reduces methane emissions from livestock (Mottet et al., 2017).

4.3 Animal Health and Disease Management

Climate variability increases the risk of disease outbreaks, affecting livestock productivity and farmer livelihoods. Effective veterinary services, vaccination programs, and disease surveillance systems are essential components of resilient livestock systems. Preventive healthcare measures help reduce mortality and improve overall system stability (Thornton et al., 2021).

4.4 Water Resource Management

Water scarcity is a major challenge in livestock production under climate change. Efficient water management practices, such as rainwater harvesting and recycling, help ensure adequate water supply for animals. Sustainable systems also focus on reducing water wastage and improving water-use efficiency.

4.5 Integrated Farming Systems

Integration of livestock with crop production enhances resource efficiency and sustainability. Crop residues can be used as animal feed, while manure serves as fertilizer, creating a circular system. Integrated farming systems improve resilience by diversifying income sources and reducing dependence on external inputs (Herrero et al., 2020).

5. Role of Technology and Innovation

5.1 Climate-Smart Livestock Practices

Climate-smart practices aim to increase productivity, enhance resilience, and reduce emissions. These include improved feeding techniques, better housing systems, and efficient manure management. Adoption of such practices helps mitigate climate change while improving farm profitability (FAO, 2021).

5.2 Digital Technologies and Precision Livestock Farming

Digital tools such as sensors, mobile applications, and data analytics enable real-time monitoring of animal health, feed intake, and environmental conditions. Precision livestock farming improves efficiency, reduces resource wastage, and enhances decision-making. These technologies play a crucial role in developing resilient livestock systems (Wolfert et al., 2017).

5.3 Renewable Energy Integration

The use of renewable energy sources such as biogas and solar power reduces dependence on fossil fuels and lowers greenhouse gas emissions. Biogas production from animal waste not only provides energy but also improves waste management and environmental sustainability.

6. Challenges in Developing Sustainable Livestock Systems

6.1 Climate Variability and Increasing Environmental Stress

One of the most significant challenges in developing sustainable livestock systems is the increasing variability and unpredictability of climate conditions. Rising temperatures, irregular rainfall, prolonged droughts, and extreme weather events directly affect livestock productivity and health. Heat stress reduces feed intake, fertility, and milk production, while extreme weather events such as floods and cyclones can lead to large-scale livestock mortality. Furthermore, changing climatic conditions influence the distribution of pests and diseases, increasing the risk of outbreaks. These uncertainties make it difficult for farmers to plan and manage livestock operations effectively, thereby threatening long-term sustainability.

6.2 Resource Scarcity and Competition

Livestock production systems face growing pressure due to limited availability of natural resources such as land, water, and feed. Rapid population growth and urbanization have intensified competition for these resources, often prioritizing crop production and industrial use over livestock farming. In many regions, grazing lands are shrinking, and water resources are becoming scarce, particularly in arid and semi-arid areas. Additionally, climate change further exacerbates resource scarcity by reducing fodder availability and degrading pasturelands. These constraints hinder the adoption of sustainable practices and limit productivity improvements.

6.3 Limited Awareness, Skills, and Extension Support

A major barrier to the development of climate-resilient livestock systems is the lack of awareness and technical knowledge among farmers. Many smallholder farmers continue to rely on traditional practices that may not be suitable under changing climatic conditions. Inadequate extension services and limited access to training programs further restrict the dissemination of improved technologies and practices. Without proper guidance, farmers may be unable to adopt

innovations such as improved feeding strategies, climate-resilient breeds, and disease management practices, thereby reducing the effectiveness of sustainability initiatives.

6.4 Financial Constraints and Risk Factors

Financial limitations significantly affect the ability of farmers to invest in improved livestock systems. Adoption of climate-resilient technologies, infrastructure, and management practices often requires substantial initial investment, which may not be affordable for small and marginal farmers. Moreover, livestock farming is inherently risky due to uncertainties associated with climate change, disease outbreaks, and market fluctuations. Lack of access to credit, insurance, and financial support mechanisms further increase vulnerability, discouraging farmer from adopting innovative practices.

6.5 Policy Gaps and Institutional Weaknesses

The development of sustainable livestock systems is often hindered by inadequate policy frameworks and weak institutional support. In many cases, policies related to livestock, agriculture, and climate change are not well integrated, leading to fragmented approaches. Limited coordination among government agencies, research institutions, and extension services reduces the effectiveness of interventions. Additionally, insufficient investment in research, infrastructure, and capacity building further constrains the development of resilient livestock systems.

7. Strategies for Development of Climate-Resilient Livestock Systems

7.1 Strengthening Extension Services and Capacity Building

Enhancing farmer awareness and technical skills is fundamental for promoting sustainable livestock systems. Strengthening extension services can facilitate the dissemination of knowledge regarding improved practices, climate adaptation strategies, and efficient resource management. Training programs, workshops, and field demonstrations should be organized to educate farmers about modern technologies such as precision livestock farming, improved feeding techniques, and disease prevention measures. Capacity building initiatives should also focus on empowering women and youth, who play a crucial role in livestock management.

7.2 Policy Support and Institutional Strengthening

Effective policy frameworks are essential for promoting sustainable and climate-resilient livestock systems. Governments should design policies that provide incentives for adopting eco-friendly practices, such as subsidies for renewable energy use, improved breeds, and efficient water management systems. Strengthening institutional mechanisms can improve coordination among stakeholders, ensuring better implementation of programs. Additionally, integrating livestock development policies with climate change strategies can enhance overall effectiveness and sustainability.

7.3 Research, Innovation, and Technology Development

Continuous research and innovation are critical for addressing emerging challenges in livestock systems. Developing climate-resilient breeds, alternative feed resources, and improved disease management strategies can significantly enhance system resilience. Technological advancements such as digital monitoring systems, data analytics, and early warning systems can improve decision-making and reduce risks. Collaboration between research institutions, universities, and industry stakeholders is essential for accelerating innovation and ensuring practical application of research findings.

7.4 Sustainable Resource Management Practices

Efficient management of natural resources is key to sustainability. Practices such as rotational grazing, conservation agriculture, water harvesting, and integrated crop-livestock systems can improve resource-use efficiency and reduce environmental impact. Proper manure management not only reduces greenhouse gas emissions but also enhances soil fertility. Adoption of such practices can help maintain ecological balance while improving productivity.

7.5 Community Participation and Localized Approaches

Community-based approaches play a vital role in the successful implementation of sustainable livestock systems. Involving farmers in planning and decision-making ensures that interventions are tailored to local conditions and needs. Collective action, such as farmer groups and cooperatives, can enhance resource sharing, knowledge exchange, and market access. Localized strategies are more effective in addressing region-specific challenges and promoting long-term sustainability.

8. Conclusion (Expanded)

The development of sustainable and climate-resilient livestock systems is essential for ensuring food security, environmental sustainability, and socio-economic stability in the face of climate change. Livestock systems are highly vulnerable to climatic stresses, which affect productivity, animal health, and resource availability. Therefore, adopting integrated approaches that combine sustainability and resilience is crucial for the long-term viability of the sector.

This chapter highlights that sustainable livestock systems must focus on efficient resource utilization, reduced environmental impact, and improved animal welfare, while climate-resilient systems emphasize adaptability and risk management. The challenges identified, including climate variability, resource scarcity, lack of awareness, financial constraints, and policy gaps, indicate the need for comprehensive and coordinated efforts.

To address these challenges, strategies such as strengthening extension services, promoting research and innovation, improving policy support, and encouraging community participation are essential. The integration of modern technologies and traditional knowledge can further

enhance system resilience. Ultimately, a holistic and multidisciplinary approach involving farmers, researchers, policymakers, and institutions is required to build livestock systems that are not only productive but also sustainable and resilient to future climate uncertainties.

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STRATEGIES TO MITIGATE HEAT STRESS AND ENVIRONMENTAL CHALLENGES

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Abstract

Heat stress and environmental challenges have emerged as major constraints to sustainable livestock production, particularly in tropical and subtropical regions. Rising global temperatures, erratic climatic patterns, increased humidity, and frequent extreme weather events have significantly affected livestock productivity, reproduction, and health. Heat stress occurs when animals are unable to dissipate excess body heat, leading to physiological and metabolic disturbances that reduce feed intake, growth rate, milk yield, and fertility. In addition, environmental challenges such as water scarcity, poor housing, and disease outbreaks further exacerbate the vulnerability of livestock systems. Mitigating these challenges requires a comprehensive and integrated approach involving environmental management, nutritional strategies, genetic improvement, and technological innovations. Recent studies highlight that interventions such as improved housing, ventilation, cooling systems, and precision livestock farming can significantly reduce the adverse effects of heat stress (Azevedo et al., 2024; Thornton et al., 2021). Furthermore, climate-smart livestock practices emphasize adaptation, mitigation, and resilience-building strategies to sustain production under changing climatic conditions. This chapter provides a detailed overview of the causes and impacts of heat stress, followed by an in-depth discussion of various mitigation strategies and future perspectives for developing climate-resilient livestock systems.

1. Introduction

Livestock production plays a vital role in global food security, nutrition, and rural livelihoods. However, the sector is increasingly threatened by climate change, particularly heat stress, which is one of the most critical environmental stressors affecting animal productivity. Heat stress results from the imbalance between heat production and heat dissipation in animals, leading to physiological strain and reduced performance. In recent years, the frequency and intensity of heat waves have increased, especially in tropical regions, making livestock more vulnerable to thermal stress. Studies have shown that heat stress significantly reduces feed intake, growth rate, milk production, and reproductive efficiency, ultimately causing economic losses to farmers (De Silva et al., 2024).

Therefore, developing effective strategies to mitigate heat stress and environmental challenges is essential for ensuring sustainable livestock production.

2. Concept and Causes of Heat Stress in Livestock

2.1 Understanding Heat Stress

Heat stress occurs when animals are exposed to environmental conditions that exceed their thermoneutral zone, making it difficult to maintain normal body temperature. It is influenced by multiple factors such as temperature, humidity, solar radiation, and wind speed. The Temperature-Humidity Index (THI) is commonly used to assess the level of heat stress in animals.

Animals generate metabolic heat during digestion and production processes, which adds to environmental heat load. High-producing animals are particularly susceptible due to their higher metabolic rates (Kausar & Imran, 2024).

2.2 Causes of Heat Stress

The primary causes of heat stress include high ambient temperature, humidity, poor ventilation, inadequate housing, and lack of shade. Climate change has intensified these factors, leading to increased heat stress incidence. Additionally, management practices such as overcrowding and poor nutrition further exacerbate stress conditions.

3. Impact of Heat Stress on Livestock

3.1 Effects on Production and Reproduction

Heat stress adversely affects productivity by reducing feed intake, milk yield, and weight gain. It also impairs reproductive performance by affecting hormonal balance and fertility. Studies indicate that heat stress can significantly decrease average daily gain and feed efficiency in livestock (Azevedo et al., 2024).

3.2 Effects on Animal Health and Welfare

Heat stress compromises immune function, making animals more susceptible to diseases. Increased respiration rate, panting, and dehydration are common symptoms. Severe heat stress can lead to mortality if not managed properly.

3.3 Economic and Environmental Impacts

The economic losses due to heat stress include reduced productivity, increased veterinary costs, and mortality. Additionally, environmental stress can reduce feed efficiency, leading to higher greenhouse gas emissions per unit of production.

4. Environmental Management Strategies

4.1 Housing Design and Shelter Management

Proper housing is one of the most effective strategies to mitigate heat stress. Modifications such as increased roof height, proper orientation, and use of reflective roofing materials can



Strategies to Mitigate Heat Stress and Environmental Challenges

reduce heat load. Providing shade structures significantly improves animal comfort and productivity (Debbarma et al., 2023).

4.2 Ventilation and Airflow Management

Adequate ventilation helps remove excess heat and moisture from animal housing. Natural ventilation through open-sided sheds and mechanical ventilation using fans improves airflow and reduces heat stress.

4.3 Cooling Systems and Water Sprinkling

Cooling systems such as sprinklers, misters, and evaporative cooling are widely used to reduce body temperature. Studies show that access to shade and sprinkling improves feed intake and growth performance in cattle (Azevedo et al., 2024).

5. Nutritional Strategies for Heat Stress Mitigation

5.1 Feed Management and Diet Modification

Heat stress reduces feed intake, necessitating the use of high-quality, easily digestible feed. Adjusting feeding schedules to cooler periods of the day improves intake and nutrient utilization.

5.2 Use of Feed Additives and Supplements

Electrolytes, vitamins, antioxidants, and minerals play a crucial role in reducing heat stress effects. These supplements help maintain metabolic balance and improve immunity (Reddy et al., 2023).

5.3 Water Management

Adequate supply of clean and cool water is essential for maintaining hydration and regulating body temperature. Water intake increases significantly during heat stress conditions.

6. Genetic and Breeding Strategies

6.1 Selection of Heat-Tolerant Breeds

Indigenous breeds are generally more adapted to local climatic conditions and exhibit better heat tolerance compared to exotic breeds. Selecting and promoting such breeds enhances resilience.

6.2 Genetic Improvement Programs

Breeding programs focusing on heat tolerance traits can improve livestock resilience. Advances in genomics and biotechnology enable the identification of genes associated with heat tolerance.

7. Technological and Precision Livestock Approaches

7.1 Precision Livestock Farming

Technologies such as sensors, wearable devices, and automated monitoring systems enable real-time tracking of animal health and environmental conditions. These tools help in early detection of heat stress and timely intervention.

7.2 Climate-Smart Technologies

Climate-smart livestock practices include the use of renewable energy, efficient waste management, and sustainable resource use. These technologies contribute to both adaptation and mitigation of climate change (Frontiers, 2023).

8. Management and Behavioral Strategies

8.1 Feeding and Grazing Management

Adjusting feeding times to cooler hours reduces heat load. Grazing should be scheduled during early morning or late evening to avoid peak heat.

8.2 Stocking Density and Animal Handling

Reducing overcrowding improves airflow and reduces heat stress. Proper handling minimizes additional stress on animals.

9. Integrated and Future Approaches

Integrated approaches combining environmental, nutritional, genetic, and technological strategies are essential for effective heat stress mitigation. Future research should focus on developing cost-effective and scalable solutions for smallholder farmers. Climate-resilient livestock systems require strong policy support, research investment, and farmer awareness programs.

10. Conclusion

Heat stress and environmental challenges pose serious threats to livestock production, particularly under changing climatic conditions. Their impact on productivity, health, and economic viability necessitates urgent attention. This chapter highlights that no single strategy is sufficient; rather, a combination of environmental management, nutritional interventions, genetic improvement, and technological innovations is required.

Effective mitigation strategies such as improved housing, cooling systems, balanced nutrition, and precision farming technologies can significantly reduce the adverse effects of heat stress. Furthermore, promoting climate-resilient breeds and strengthening extension services can enhance adaptation capacity. A holistic and integrated approach involving farmers, researchers, and policymakers is essential to ensure sustainable livestock production in the face of climate change.

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LINKING PASTORAL LAND ACCESS WITH LIVESTOCK PRODUCTIVITY: A VETERINARY PERSPECTIVE ON RAIKA PASTORALISTS

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Abstract-

Pastoral land access plays a critical role in determining livestock health, productivity, and overall livelihood sustainability among traditional pastoral communities in India. This paper examines the interrelationship between pastoral land availability and livestock productivity from a veterinary and production-oriented perspective, with specific reference to the Raika pastoralists of Rajasthan and Gujarat. The Raika community, historically dependent on extensive grazing systems, has developed adaptive livestock management practices suited to arid and semi-arid ecosystems. However, shrinking grazing lands, fragmentation of common property resources, and increasing restrictions on mobility have significantly altered traditional production systems. Drawing upon secondary literature, field-based observations, and veterinary insights, this study highlights how reduced access to quality grazing directly impacts animal nutrition, leading to decreased milk yield, poor body condition, increased disease susceptibility, and reduced reproductive efficiency. The paper emphasizes the role of veterinary science in understanding these productivity constraints, particularly in relation to nutritional deficiencies, parasitic burdens, and stress-related disorders arising from inadequate pasture resources. Furthermore, the study explores how traditional Ethnoveterinary knowledge of the Raika pastoralists interacts with modern veterinary interventions in maintaining herd health under resource-constrained conditions. It also evaluates the implications of policy frameworks affecting grazing rights, including the decline of commons and the limited integration of pastoral systems into formal livestock development programs. The findings suggest that enhancing pastoral land access is not only a socio-economic necessity but also a veterinary imperative for improving livestock productivity. Strengthening community grazing systems, promoting sustainable rangeland management, and integrating mobile veterinary services can significantly improve animal health outcomes.



Linking Pastoral Land Access with Livestock Productivity

The paper concludes that a holistic approach combining land rights, veterinary support, and policy recognition of pastoral mobility is essential to sustain the productivity and resilience of Raika pastoral systems in a changing environmental and socio-political landscape.

Introduction

Pastoralism represents a vital livelihood system in arid and semi-arid regions, contributing significantly to livestock-based economies and ecological sustainability. Pastoralism represents a vital livelihood system in arid and semi-arid regions, contributing significantly to livestock-based economies and ecological sustainability. The Food and Agriculture organization (FAO, 2018) reports that pastoralists manage extensive rangelands globally and play a crucial role in ensuring food security through livestock production. In India, traditional pastoral communities such as the Raika pastoralists of Rajasthan have historically depended on common property resources and seasonal grazing lands to sustain their herds, particularly camels, sheep, and goats (Kavoori, 1999).

Over the past few decades, pastoral land access has been increasingly constrained due to land privatization, agricultural expansion, and restrictive policies, leading to significant challenges in maintaining traditional grazing systems (Government of India, 2007). According to the International Livestock Research Institute (ILRI, 2012), limited access to quality grazing resources results in nutritional deficiencies, increased disease susceptibility, and reduced reproductive performance in livestock.

From a veterinary perspective, grazing land availability is directly associated with animal health, productivity, and welfare. Poor pasture quality and inadequate feed intake can weaken immune responses, thereby increasing the incidence of infectious and parasitic diseases (Meena et al., 2012). Consequently, livestock productivity in terms of milk yield, growth rate, and reproductive efficiency declines significantly under conditions of restricted land access.

Therefore, analyzing the linkage between pastoral land access and livestock productivity is essential, particularly for the Raika community, whose socio-economic stability and cultural identity are deeply rooted in livestock rearing and traditional pastoral practices.

An estimated 200 million pastoralists raise livestock... in rangelands, which cover around half of the Earth's land.

Globally, pastoral systems contribute up to 20% of meat production and sustain around 200 million people (ILRI, 2012). In India, grazing lands have significantly declined from about 18% in the 1960s to less than 10% today, reducing fodder availability for pastoralists (Government of India, 2007). Traditional communities like the Raika pastoralists of Rajasthan, known for rearing camels, sheep, and goats, have been severely affected, with camel populations declining by more than 50% due to shrinking grazing resources (Kavoori, 1999;

Meena et al., 2012). From a veterinary perspective, reduced land access leads to poor nutrition, increased disease incidence, and decreased livestock productivity.

The pastoral system of the Raika pastoralists in Rajasthan has undergone significant transformation due to changing land use patterns and declining access to traditional grazing resources. Historically, the Raika community relied on extensive mobility and common property resources, but recent evidence highlights a sharp disruption in these systems. Contemporary reports indicate that “shrinking grazing lands, disappearing migration routes and declining access to commons are pushing the Raika pastoralists to the brink” (Scroll.in, 2026). Increasing agricultural expansion, infrastructure development, and land privatization have fragmented traditional migratory pathways, severely limiting access to quality grazing lands. Recent field-based studies further reveal that pastoral systems are now constrained by “degraded and shrunken pastures... and limited availability of feed and fodder resources throughout their migratory routes” (ResearchGate, 2022). In terms of land rights, despite policy frameworks such as the Forest Rights Act (2006), pastoral communities continue to face systemic exclusion, as “pastoral mobility and communal land and grazing rights remain largely unrecognized” (Häusling, 2026). This reflects a gap between policy intent and ground-level implementation, particularly for mobile pastoral groups like the Raikas.

From a veterinary perspective, these structural changes have direct implications for livestock health and productivity. Reduced grazing access leads to chronic fodder scarcity, increased disease incidence, and declining herd performance. Recent studies also report key challenges such as “fodder scarcity, disease outbreaks and restrictions on access to customary grazing lands” (Siripurapu et al., 2024). Therefore, the evolving land rights scenario not only threatens the livelihood security of Raika pastoralists but also undermines the health, productivity, and sustainability of their livestock systems.

GRAZING LANDS AND COMMONS ACCESS

Grazing lands and common property resources (CPRs) form the backbone of pastoral livestock production systems, particularly for communities such as the Raika pastoralists. In India, commons play a crucial role in sustaining livestock-based livelihoods, as “70 million hectares of land in India are under commons, and 48 to 75% of rural population depends on the commons” (Land Forum India). These commons include village grazing lands, forests, and fallow lands, which are essential sources of fodder, water, and mobility for pastoral herds.

The importance of commons for livestock production is further emphasized by studies stating that “the Commons are a critical resource for livestock production through grazing” (Rainfed Livestock Network, 2010). Traditionally, pastoralists like the Raikas depended on these shared resources along with seasonal migration routes to maintain herd productivity and ecological



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balance. However, over time, access to these grazing lands has declined due to land-use changes and encroachment.

Recent research highlights that “village commons are encroached upon by agriculture, reducing the overall availability of commons” (Paul F. Robbins, 2004). This has directly impacted pastoral mobility and access to fodder resources. Contemporary evidence further shows that “shrinking grazing lands, disappearing migration routes and declining access to commons are pushing the Raika pastoralists to the brink” (Scroll.in, 2026).

From a veterinary perspective, restricted access to grazing lands leads to fodder scarcity, poor nutrition, and increased disease incidence in livestock, ultimately reducing productivity. Thus, grazing lands and commons access are not only socio-economic resources but also critical determinants of animal health and sustainable livestock production systems among Raika pastoralists.

POLICY CHALLENGES AND RESTRICTIONS

Pastoralists face many policy-related challenges that affect their land rights and livelihoods. One major issue is that grazing lands are often classified as “wastelands” or “degraded lands.” This hides their true ecological and economic value. Because of this, these lands are often converted for other uses such as plantations, industries, and urban development.

Forest and conservation policies also restrict pastoral access. Protected areas and wildlife sanctuaries often ban grazing, even though research shows that pastoral practices can coexist with biodiversity conservation. Excluding pastoralists from forests not only affects their livelihoods but also disrupts traditional ecological management systems.

Another important challenge is the bias toward settled (sedentary) land use in policy frameworks. Mobility, which is essential for pastoralism, is often seen as incompatible with modern governance systems that focus on fixed boundaries and land ownership. This creates administrative barriers, especially when pastoralists move across different regions.

Climate change further exacerbates these challenges by increasing the variability of rainfall and the frequency of droughts. In arid regions like Rajasthan, this leads to heightened competition for scarce resources, intensifying conflicts between pastoralists, farmers, and other stakeholders (Rawat & Dookia, 2025).

Marginalization And Exclusion

Marginalization and exclusion of pastoralists, particularly the Raika community of Rajasthan, significantly affect livestock productivity and livelihood sustainability (Ilse Köhler-Rollefson, 2016; Food and Agriculture Organization, 2018). Traditionally, Raika pastoralists depend on common property resources and seasonal migration routes for grazing and herd maintenance (International Union for Conservation of Nature, 2011). However, land privatization,

agricultural expansion, and industrial development have reduced access to these grazing lands (Food and Agriculture Organization, 2018). Forest and conservation policies, including restrictions in protected areas, have further limited pastoral mobility and grazing rights (International Union for Conservation of Nature, 2011). This reduced access leads to inadequate nutrition in livestock, resulting in decreased milk production, poor reproductive efficiency, and increased disease susceptibility (Ilse Köhler-Rollefson, 2016). Social exclusion also occurs as pastoralists are often left out of policy-making and development programs related to livestock and land use (Food and Agriculture Organization, 2018). Economically, loss of grazing lands increases dependence on purchased feed, raising production costs and reducing profitability (Nitin Dookia & Rawat, 2025). Overall, marginalization weakens the resilience of pastoral systems and directly impacts livestock productivity among Raika pastoralists (Nitin Dookia & Rawat, 2025).

Land Rights Movements and Community Responses

Pastoral communities like the Raika have organized movements to protect grazing rights and access to forest resources. They protest against restrictions on grazing in forests and protected areas, emphasizing livelihood dependence on these lands. The Raika Biocultural Protocol (2009) recognizes community rights over grazing lands, livestock genetic resources, and traditional knowledge. It highlights the link between pastoralism and biodiversity conservation and warns that exclusion leads to ecological degradation. NGOs such as League for Pastoral Peoples support these movements through advocacy, documentation, and awareness. These efforts have increased policy visibility of pastoral issues, but challenges like weak implementation and legal barriers still remain.

Legal Frameworks and Protections in India

- India's legal framework governing pastoral land access is influenced by forest, land, and biodiversity laws that regulate grazing rights and resource use (Food and Agriculture Organization, 2018).
- The Forest Rights Act, 2006 recognizes the rights of forest-dwelling communities, including pastoralists, over grazing lands and traditional forest resources (Forest Rights Act 2006; Ministry of Tribal Affairs).
- The Indian Forest Act, 1927 historically imposed restrictions on grazing in reserved and protected forests, limiting pastoral mobility (Indian Forest Act 1927).
- The Wildlife (Protection) Act, 1972 restricts grazing within national parks and sanctuaries, affecting pastoral livelihoods and access to commons (Wildlife Protection Act 1972).

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- The Panchayats (Extension to Scheduled Areas) Act, 1996 (PESA) empowers local governance institutions to manage common resources and supports customary grazing rights (Panchayats Extension to Scheduled Areas Act 1996).
- The Biological Diversity Act, 2002 acknowledges the role of local communities in biodiversity conservation and protection of indigenous knowledge systems related to livestock (Biological Diversity Act 2002; National Biodiversity Authority).
- State-level laws such as the Rajasthan Tenancy Act, 1955 and pastureland regulations govern access to common grazing lands, though implementation remains inconsistent (Government of Rajasthan; Rawat & Nitin Dookia, 2025).
- Despite these legal provisions, overlapping jurisdictions, weak enforcement, and conservation-focused restrictions continue to limit pastoral land access, negatively impacting livestock productivity (Food and Agriculture Organization, 2018; Rawat & Nitin Dookia, 2025).

Conclusion

Pastoralism in India, particularly among the Raika community, represents a resilient and adaptive livelihood system. It has historically supported livestock productivity while maintaining ecological balance. However, this system is increasingly threatened by restrictive land-use policies and declining access to grazing resources. The loss of common lands and constraints on mobility have weakened traditional pastoral practices. These changes have negatively impacted livestock health, productivity, and overall livelihood security. Socio-economic transformations and policy biases toward sedentary systems further intensify these challenges. Climate variability also adds pressure by increasing resource scarcity and uncertainty. Despite these constraints, pastoralism continues to contribute significantly to rural economies. It plays a vital role in conserving indigenous livestock breeds and biodiversity. Pastoral systems also support sustainable use of fragile ecosystems. Strengthening land access rights is essential for improving livestock productivity. Inclusive policies that recognize pastoral mobility and traditional knowledge are needed. Participatory governance can enhance the effectiveness of resource management. A shift from exclusionary to community-based conservation approaches is crucial. Such strategies can improve resilience of pastoral communities. Ultimately, integrating pastoral needs with policy frameworks will ensure sustainable development and ecological stability.

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VALORIZATION OF SERICULTURE BYPRODUCTS FOR FUNCTIONAL LIVESTOCK FEED

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Introduction

The livestock sector encompasses the breeding, rearing, and management of domesticated animals, primarily cattle, buffaloes, sheep, goats, pigs, and poultry — for the production of milk, meat, eggs, fiber, hides, manure, and draft power. It spans a continuum from traditional smallholder mixed-farming systems to intensive commercial operations, serving as a critical component of agricultural economies worldwide.

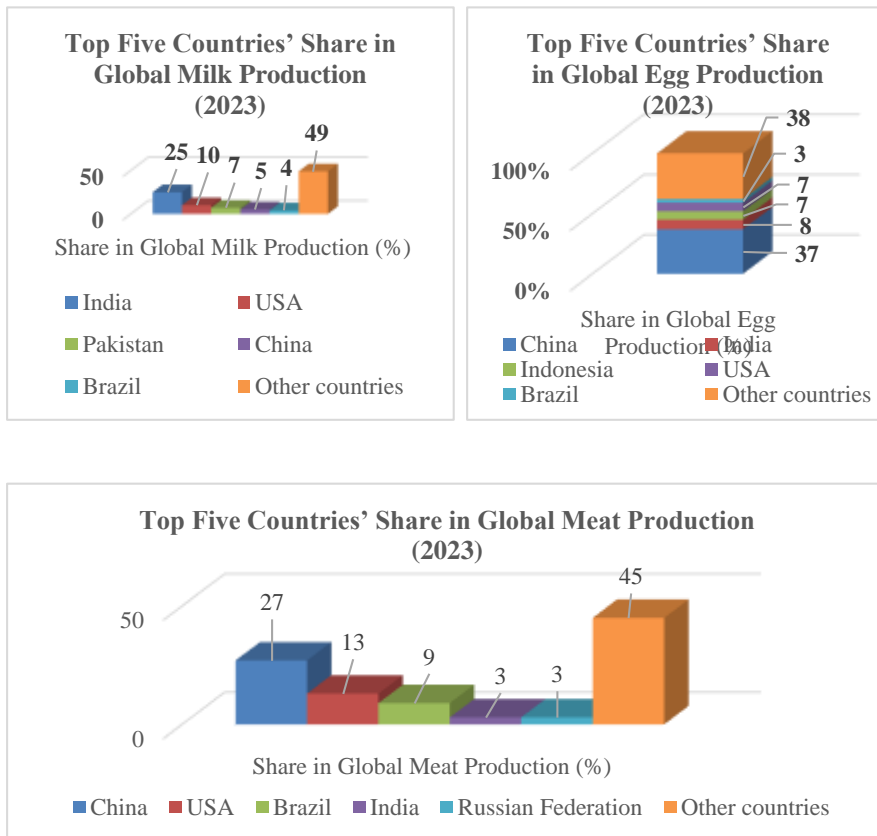


Fig 1: India in world’s major livestock production (2023) (Data collected from BAHS 2025)

Sustainable livestock production increasingly depends on identifying alternative feed resources that can reduce reliance on conventional inputs such as soybean meal and fish meal.

Rising costs, land-use pressures, and ecological concerns have made these traditional feed ingredients less viable in the long term. Consequently, attention has shifted toward underutilized agro-industrial residues and insect-derived biomass. Sericulture, a labor-intensive agro-based enterprise, generates substantial quantities of byproducts during silkworm rearing and silk processing. Among these, silkworm pupae and mulberry biomass residues are particularly significant due to their nutritional richness. Previously treated as waste or low-value products, these materials are now being reconsidered as functional feed ingredients capable of improving animal performance while contributing to waste minimization. Functional feeds for livestock are designed not only to meet nutritional requirements but also to enhance physiological functions such as immunity, metabolism, and product quality. Sericulture byproducts, owing to their protein content and bioactive compounds, fit well within this emerging paradigm.

2. Sericulture Byproducts: Types and Resource Flow

Beyond the primary production of silk, sericulture yields a diverse cascade of secondary products that possess significant economic value. These byproducts exhibit remarkable versatility and utility across multiple high-value domains, including the formulation of nutrient-rich compost, applications in human medicine and therapeutics, traditional and contemporary handicrafts, cosmetic formulations, the food industry, and various other emerging sectors.

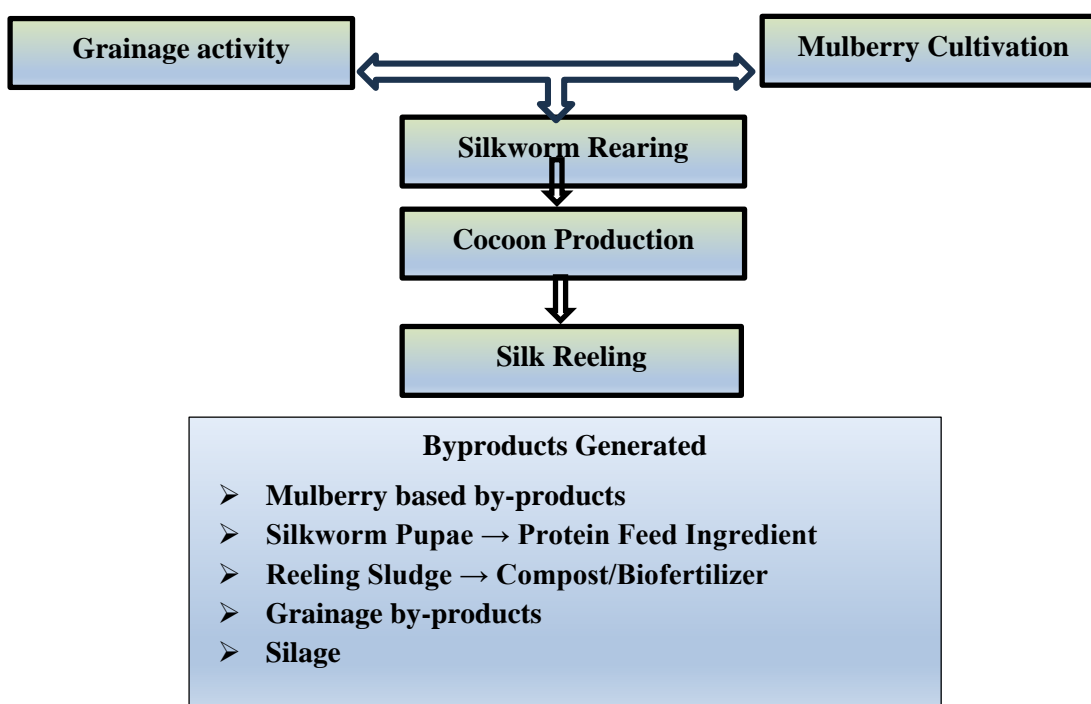


Figure 1: Sericulture activities, Byproducts and Utilization Pathways

2.1 Mulberry based by-products

Often discarded as waste or not used in sericulture, the leftover mulberry leaves, fruits, roots, bark, which are rich in nutrients and bioactive compounds, can be sustainably repurposed into animal feed, functional foods, nutraceuticals, and biofuels, supporting both economic value and environmental conservation.

2.2 Silkworm Pupae

While sericulture centers on silk production from *Bombyx mori*, the reeling process simultaneously yields silkworm pupae as a major byproduct, comprising roughly 60–70% of the total biomass. Once treated as waste, silkworm pupae are now increasingly recognized as a valuable resource due to their rich protein, lipid content, bioactive compounds, and growing nutritional, medicinal, and economic significance.

2.3 Reeling Waste

Reeling waste from sericulture includes different silk proteins i.e. Sericin, removed during degumming and fibroin, that contains biologically active proteins with antioxidant properties, offering potential as feed additives. Sericin, owing to its biocompatibility, biodegradability, wettability, and bioactive properties such as antiaging and wound healing, has gained significant traction across cosmetic, biomedical, pharmaceutical, and food sectors. Similarly, silk fibroin (SF), characterized by its safety, tunable physicochemical properties, and biodegradability, is emerging as an advanced biomaterial for applications including injectable systems, conductive scaffolds, and bio-inks in regenerative medicine.

2.4 Grainage by-products

The grainages yields substantial quantity of moths of both sexes and pierced cocoons as a by-product in the process of egg production which can be used in the preparation of animal feed mixtures. Also the defective cocoons and cocoons after moth emergence are used to prepare various creative cocoon crafts.

3. Use of sericulture by-products as livestock feed

Sericulture generates a diverse array of nutrient-rich byproducts from both mulberry cultivation and silkworm processing, offering significant potential for livestock feed applications while promoting sustainability and income diversification. Mulberry residues such as leaves, fruits, twigs, and roots are abundant in proteins, vitamins, minerals, and bioactive compounds, making them suitable as functional feed ingredients that can enhance animal growth, immunity, and productivity. In addition, various stages of sericulture including grainage, silkworm rearing, and post-cocoon processing produce substantial quantities of byproducts such as spent pupae and moths, which are particularly rich in high-quality protein and lipids. The integration of

these byproducts into livestock feed formulations not only reduces waste and environmental burden but also provides a cost-effective and nutritionally superior alternative to conventional feed resources.

3.1 Mulberry leaves as nutritious livestock feed

Beyond its conventional roles in sericulture, human nutrition, and traditional medicine, mulberry is increasingly recognized as a sustainable and climate-resilient alternative forage resource for livestock production. Unlike conventional grasses and shrubs that exhibit seasonal growth and are highly sensitive to environmental fluctuations, mulberry is a perennial species capable of providing a consistent and high-quality biomass supply across diverse agro-climatic conditions. Mulberry leaves are nutritionally rich, typically containing 10–30% crude protein along with adequate dietary fiber, which supports rumen function, digestion, and overall gut health. They also provide essential minerals such as calcium, potassium, magnesium, and phosphorus, contributing to skeletal integrity, enzymatic activity, and electrolyte balance. In addition, the presence of bioactive compounds, including flavonoids, anthocyanins, and essential fatty acids, imparts antioxidative and anti-inflammatory properties that enhance immune competence and disease resistance in livestock. The high moisture content (70–80%) further improves palatability and serves as a supplementary hydration source, particularly beneficial for young and small ruminants. Notably, the absence of significant anti-nutritional factors enhances its safety and feed efficiency. Owing to its superior digestibility, high biomass yield, and broad adaptability, mulberry has been widely utilized as a protein-rich fodder in several countries, contributing to improved growth performance, increased milk yield, and overall livestock productivity.

Table 1: Nutritional and biochemical composition of mulberry leaves (%/g/mg) (Rohela *et al.*, 2025)

#	Nutritional Components	Value
1	Crude Protein (%)	15.31–30.91
2	Crude Fat (%)	2.09–6.90
3	Crude Fiber (%)	9.9–13.85
4	Total Ash (%)	8.91–11.81
5	Carbohydrates (%)	10.70–13.70
6	Acid Detergent Fiber (ADF) (%)	17.33–28.00
7	Neutral Detergent Fiber (NDF) (%)	19.38–35.77
8	Acid Detergent Lignin (ADL) (%)	3.40–8.10

Valorization of Sericulture Byproducts for Functional Livestock Feed

#	Nutritional Components	Value
9	Hemicellulose (%)	2.50–12.80
10	Ascorbic acid (mg/100 g)	100–200
11	β-carotene (mg/100 g)	8.44–13.13
12	Iron (mg/100 g)	19.00–35.72
13	Zinc (mg/100 g)	0.72–3.65
14	Calcium (mg/100 g)	786.66–2226.66
15	Phosphorous (mg/100 g)	970
16	Magnesium (mg/100 g)	720
	Anti-nutritional Factors	
17	Oxalates (mg/100 g)	183
18	Phytates (mg/100 g)	156
19	Tannic acid (%)	0.13–0.36

3.2 Silkworm pupae as feed for livestock

Silkworm pupa meal is a protein-rich supplement for livestock, poultry, fish, and pets. Silkworm pupae have been widely reported to contain approximately 49–55% crude protein on a dry matter basis, making them comparable to conventional protein sources such as fish meal and soybean meal. Beyond their high protein content, they possess a well-balanced amino acid profile, including essential amino acids such as lysine, leucine, valine, methionine, and phenylalanine, which are critical for growth and metabolic functions. Additionally, silkworm pupae are rich in lipids, particularly polyunsaturated fatty acids, which serve as an important energy source and contribute to enhanced animal health and productivity. Notably, the presence of essential fatty acids such as alpha-linolenic acid further supports vital physiological processes and immune responses in livestock.

Table 1: Nutritional Composition of Silkworm Pupae (Dry Matter Basis) (Chethan *et al.*, 2026)

Component	Composition (%)	Importance in Animal Nutrition
Crude protein	49 to 55	Supports growth, muscle development, and metabolic activities
Lipids	25 to 30	Provides energy and essential fatty acids
Ash	4 to 6	Source of essential minerals
Moisture	5 to 10	Influences storage stability
Carbohydrates	5 to 8	Additional energy source

Table 2: Essential Amino Acid Profile of Silkworm Pupae (Chethan *et al.*, 2026)

Amino Acid	Content (g/100 g protein)	Nutritional Role
Lysine	6.0 to 7.5	Muscle growth and protein synthesis
Leucine	7.0 to 8.5	Tissue repair and growth
Valine	4.5 to 5.5	Energy metabolism
Methionine	2.0 to 2.5	Improves feed efficiency
Phenylalanine	4.0 to 5.0	Hormone and enzyme synthesis
Threonine	3.5 to 4.5	Immune function
Isoleucine	3.5 to 4.2	Muscle metabolism

Table 3: Mineral Composition of Silkworm Pupae (Chethan *et al.*, 2026)

Mineral	Content (mg/100 g)	Role in Animal Health
Calcium	120 to 150	Bone development
Phosphorus	500 to 700	Energy metabolism
Iron	5 to 8	Hemoglobin formation
Potassium	600 to 800	Muscle and nerve function
Magnesium	90 to 120	Enzyme activation
Zinc	2 to 4	Immune system support

Silkworm pupae represent a nutrient-dense byproduct of the sericulture industry with considerable potential as an alternative protein source in animal feed formulations. Their nutritional profile is characterized by a high crude protein content (49–55% on a dry matter basis) and substantial lipid levels (25–30%), along with a well-balanced composition of essential amino acids, minerals, and vitamins. Key amino acids such as lysine, methionine, and leucine play critical roles in muscle development, protein synthesis, and immune function, thereby supporting growth and metabolic efficiency in livestock and aquaculture species. In addition, the lipid fraction is rich in polyunsaturated fatty acids, which serve as an important energy source and contribute to improved physiological performance and productivity. However, the relatively high lipid content may necessitate partial defatting to enhance storage stability and feed quality.

Silkworm pupal meal, a nutrient-dense byproduct of the sericulture industry rich in high-quality protein, lipids, and essential amino acids, has demonstrated considerable potential as a sustainable alternative to conventional protein sources such as fish meal in compounded animal diets. In broiler chickens, dietary replacement of fish meal with SPM at levels of 5–15%

resulted in enhanced body weight gain and improved feed conversion efficiency. Similarly, in laying hens, the inclusion of SPM at 5–10% of the diet led to notable improvements in egg production rates and internal and external egg quality parameters. For finfish species, carp (*Cyprinus carpio*) exhibited superior growth performance when fish meal was replaced by SPM at 10–20%, while tilapia showed optimized feed conversion ratios with 10–15% dietary inclusion. In swine, incorporation of SPM at 5–10% of the total diet promoted improved average daily weight gain. These findings collectively underscore the efficacy of silkworm pupal meal as a viable, eco-friendly protein replacer across monogastric and aquatic livestock species, supporting both productive performance and resource circularity in animal nutrition systems. The incorporation of silkworm pupal meal into feed systems not only offers a nutritionally comparable alternative to conventional protein sources such as fish meal and soybean meal but also aligns with sustainable agricultural practices by valorizing sericulture byproducts. Consequently, its utilization can improve feed efficiency, reduce production costs, and support environmentally sustainable livestock and aquaculture systems, although further research on processing technologies and optimized feed formulations is essential to maximize its practical and economic feasibility.

4. Environmental and Economic Significance

The valorization of sericulture by-products, notably silkworm pupal meal and residual mulberry foliage (including leftover leaves, stalks, and twigs post-silkworm rearing), as proteinaceous and fibrous ingredients in livestock and aquafeeds represents a paradigmatic example of circular bioeconomy principles, yielding pronounced economic and environmental co-benefits. Economically, the conversion of these materials, historically regarded as waste or low-value residues, into high-value feed components substantially lowers formulation costs by partially substituting expensive, often imported protein sources such as fish meal and soybean meal, which are prone to price volatility; approximately 2 kg of dry pupae are generated per kg of raw silk, while mulberry plantations yield abundant post-rearing leaf biomass (with annual foliage productivity reaching 25–30 t/ha), enabling additional revenue streams for smallholder sericulturists through on-farm integration of livestock enterprises and reduced external feed expenditures. Environmentally, incorporation of silkworm pupa diminishes pressure on overexploited marine fisheries for fish meal production and curtails deforestation associated with soybean monocultures, whereas residual mulberry leaves and litter mitigate organic waste disposal challenges, prevent pollution from untreated residues, and enhance nutrient cycling through improved manure quality and potential biogas or vermicompost production. Furthermore, mulberry foliage supplementation has been linked to reduced enteric methane emissions in ruminants due to its bioactive flavonoids and optimized rumen fermentation

profiles, while overall system-level integration promotes soil conservation, carbon sequestration, biodiversity support in agroforestry systems, and lower greenhouse gas footprints across the livestock sector. This synergistic bio-circular approach not only augments the economic resilience of sericulture-dependent communities in Asia and other producing regions but also advances sustainable intensification of animal production by transforming locally abundant, nutrient-rich by-products into competitive feed resources with minimal ecological externalities.

5. Constraints and Challenges

Despite the promising nutritional profile and circular economy advantages of sericulture by-products such as silkworm pupal meal (SPM) and residual mulberry foliage, their widespread incorporation into compounded livestock and aquafeeds is constrained by several critical limitations. Foremost among these is the substantial variability in nutrient composition, which arises from differences in silkworm strains, mulberry cultivars, rearing conditions, seasonal fluctuations, and post-harvest processing methods (e.g., defatting efficiency), thereby complicating consistent diet formulation and necessitating rigorous batch-specific proximate and amino acid analyses to avoid sub-optimal performance or nutrient imbalances in target species. Additionally, the limited large-scale processing infrastructure—particularly for standardized drying, defatting, detoxification, and milling operations—restricts commercial scalability, elevates production costs, and results in inconsistent product quality, especially in major sericulture regions where smallholder-dominated systems predominate. Regulatory barriers further impede adoption, as insect-derived ingredients like SPM are subject to stringent approval processes concerning safety, allergenicity (e.g., chitin-related concerns), and maximum inclusion levels in many jurisdictions, even where partial approvals exist for poultry, swine, or aquaculture feeds. Finally, consumer perception issues represent a significant socio-economic hurdle; negative public attitudes toward insect- or by-product-derived feeds can translate into market resistance against animal products (meat, eggs, milk) from livestock fed such materials, driven by concerns over food safety, palatability, and “naturalness,” thereby slowing industry uptake despite scientific validation. Addressing these multifaceted constraints through targeted research, technological innovation, harmonized regulatory frameworks, and stakeholder education is essential for realizing the full potential of sericulture by-products in sustainable animal nutrition.

6. Conclusion

In synthesizing the multifaceted evidence on sericulture by-products—principally silkworm pupal meal and post-rearing mulberry foliage—their strategic integration into livestock and aquafeed formulations emerges as a compelling exemplar of circular bioeconomy principles in

animal nutrition. These locally abundant resources not only furnish high-quality protein, lipids, essential amino acids, and bioactive compounds capable of supporting growth performance, feed efficiency, and product quality across poultry, swine, and finfish species, but also deliver tangible reductions in production costs while alleviating environmental pressures associated with conventional feed ingredients. By transforming what were once disposal liabilities into nutritionally competitive inputs, sericulture-livestock integration fosters enhanced resource-use efficiency, nutrient cycling, diminished marine resource dependency, moderated enteric methane emissions, and strengthened economic viability for smallholder systems, particularly in Asia. Nevertheless, realizing this potential at scale necessitates concerted attention to persistent constraints, including intrasource nutrient heterogeneity, inadequate industrial processing capacities, evolving regulatory landscapes for insect-derived materials, and prevailing consumer apprehensions regarding feed provenance. Future research directions should therefore prioritize standardized processing protocols, comprehensive safety and allergenicity assessments, long-term multi-generational feeding trials, and system-level life-cycle analyses to quantify holistic sustainability gains.

Ultimately, the systematic valorization of sericulture by-products holds transformative promise for advancing sustainable intensification in global livestock production, bridging traditional agro-industries with contemporary demands for resilient, low-external-input feeding strategies in an era of mounting resource scarcity and climate imperatives.

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SEASONAL VARIATION IN SEMINAL PLASMA OF BULLS

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Buffaloes, often referred to as the “Black Gold” of India, represent a highly valuable livestock resource contributing significantly to milk and meat production while demonstrating strong adaptability to harsh and resource-limited environments. Reproductive efficiency is a key determinant of productivity in buffalo husbandry, as it directly governs the transmission of superior genetics through breeding programmes. Artificial insemination (AI), a widely adopted reproductive biotechnology, remains one of the most cost-effective and efficient tools for genetic improvement, particularly in buffaloes. However, the overall AI success is still limited by moderate conception rates and variable semen quality. Therefore, improving semen quality and identifying reliable fertility markers in breeding bulls is essential to enhance AI efficiency and reproductive performance. Seminal plasma (SP) is a complex fluid composed of secretions from the epididymis, prostate, seminal vesicles, and bulbourethral glands. It provides a protective and functional environment for spermatozoa during ejaculation and transit through the female reproductive tract. Beyond its nutritive role, seminal plasma actively regulates sperm function by influencing capacitation, acrosome reaction, membrane remodeling, and sperm–oocyte interaction. Its proteomic composition includes enzymes, signaling molecules, and regulatory proteins that collectively ensure sperm survival and fertilizing ability. Although traditionally underexplored, growing evidence highlights seminal plasma as a rich source of fertility-related biomarkers with diagnostic and functional significance. In bovines, a major fraction of seminal plasma proteins belongs to the Binder of Sperm Proteins (BSP) family, including BSP-A1, BSP-A2, BSP-A3, and BSP-30 kDa. These proteins are primarily secreted by the seminal vesicles and represent the dominant protein group in bovine seminal plasma. Structurally, BSP proteins are small acidic glycoproteins with molecular weights of approximately 15–16 kDa (BSP-A1, A2, A3) and 28–30 kDa (BSP-30 kDa). BSP-A1 and BSP-A2 originate from the same gene but differ in glycosylation patterns, forming distinct glycoforms. Functionally, BSP proteins bind to phospholipids on the sperm membrane immediately after ejaculation. This interaction stabilizes the membrane, regulates lipid exchange, and prevents premature capacitation and spontaneous acrosome reactions.

Through interaction with high-density lipoproteins (HDL), BSP proteins facilitate cholesterol efflux, thereby modifying membrane fluidity and preparing sperm for capacitation in a controlled manner. Thus, BSP proteins exhibit a dual role initially preserving sperm integrity in seminal plasma and later promoting capacitation under physiological conditions in the female reproductive tract.

Fertility-Associated Seminal Plasma and Sperm Proteins

Variations in seminal plasma protein composition are strongly associated with bull fertility status. High-fertility bulls often exhibit distinct protein profiles compared to low-fertility bulls, indicating the potential of proteomic markers in fertility prediction. Proteins such as FN1 (fibronectin-1) have been associated with improved sperm resistance to freezing and thawing, suggesting a role in cryoprotection. Similarly, spermadhesin family proteins contribute to membrane stabilization and regulation of capacitation-like changes, although their effectiveness may depend on physiological conditions. Additionally, seminal plasma proteins in the low molecular weight range (14–16 kDa) are consistently associated with improved sperm viability, further emphasizing their functional relevance in reproductive success. Cryopreservation significantly impacts sperm function due to oxidative stress, membrane damage, and metabolic disruption. Several sperm and seminal plasma proteins have been identified as key regulators of cryotolerance. Proteins such as AKAP4 and proAKAP4 are strongly associated with sperm structural integrity and post-thaw motility, making them reliable indicators of sperm quality. Aquaporins (AQP3 and AQP7) regulate water transport and are linked to enhanced freeze thaw survival. Mitochondrial membrane protein VDAC2 plays a role in ion exchange and energy regulation, with higher abundance linked to improved cryoresistance. Similarly, GSTM3 is involved in oxidative stress regulation, with differential expression associated with variations in sperm freezability. These proteins collectively highlight the molecular basis of sperm survival during cryopreservation and provide valuable biomarkers for semen evaluation. Several seminal plasma proteins contribute to sperm protection during cryopreservation by maintaining membrane stability, reducing oxidative stress, and regulating capacitation-like changes. Acidic seminal fluid proteins help reduce lipid peroxidation and neutralize oxidative damage during freezing. Supplementation with BSP-derived proteins has been shown to improve sperm motility, viability, acrosome integrity, and mitochondrial activity. Heat shock proteins (HSPs), including HSP10 and HSP90, play a critical role in maintaining protein stability and protecting sperm cells from thermal and oxidative stress. Increased expression of HSP90AA1 and HSPA8 is associated with enhanced



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post-thaw survival and motility, indicating their role in cryoprotection. Together, these molecular systems ensure sperm resilience under stress conditions.

Seasonal Variation in Seminal Plasma Proteins

Seasonal changes significantly influence reproductive physiology by altering endocrine function, thermoregulation, and accessory gland secretions. These changes directly affect seminal plasma composition and sperm quality. In buffalo bulls, seminal plasma protein profiles vary across seasons, with higher protein diversity often observed during cooler or rainy periods compared to summer. Elevated temperatures during summer impair spermatogenesis due to increased scrotal and testicular temperatures, reduced heat dissipation capacity, and physiological stress. Proteomic analyses reveal that different protein fractions are expressed seasonally, with certain proteins associated with improved sperm motility and oxidative protection being more abundant in favorable seasons. Conversely, stress-related or antifertility-associated proteins may appear under heat stress conditions. These findings confirm that environmental stress plays a major role in regulating seminal plasma composition and reproductive efficiency. Proteomic studies across species have demonstrated that seminal plasma and sperm proteins are valuable indicators of fertility, cryotolerance, and reproductive efficiency. The strong similarity between seminal vesicle secretions and seminal plasma confirms the major contribution of accessory glands to protein composition. Modern proteomic techniques, including mass spectrometry and chromatographic separation methods, have enabled the identification of fertility-associated proteins and seasonal biomarkers. These advancements provide a foundation for developing predictive tools for semen quality assessment beyond conventional sperm evaluation methods. Despite significant advances in semen evaluation, traditional parameters such as motility, morphology, and viability are insufficient to reliably predict fertility outcomes. There remains a lack of precise molecular markers that can consistently predict sperm fertilizing ability and cryotolerance in buffalo bulls. Although several seminal plasma and sperm-associated proteins have been identified, their functional roles are not fully understood, particularly under varying environmental and seasonal conditions. Furthermore, limited information is available on the integrative proteomic changes associated with fertility differences in buffalo bulls under field conditions. Therefore, there is a critical need to explore seminal plasma proteomics in relation to seasonal variation, sperm quality, and cryotolerance. Identifying reliable protein biomarkers will significantly improve bull selection strategies, enhance artificial insemination efficiency, and contribute to genetic improvement programmes in buffaloes.

Conclusion

Seminal plasma is a biologically active fluid with a complex proteomic composition that plays a central role in sperm function, fertilization, and cryosurvival. Proteins such as BSPs, heat shock proteins, and cryotolerance-associated markers collectively regulate membrane stability, capacitation, and stress response mechanisms. Seasonal and environmental factors further modulate these protein profiles, influencing overall reproductive efficiency. Advances in proteomic technologies offer powerful tools for identifying novel fertility biomarkers, paving the way for improved selection of superior breeding bulls and enhanced reproductive performance in buffalo populations.

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