

Bridging knowledge and practice: Management record-keeping and herbal formulations as tools to enhance small ruminant productivity in smallholder systems

Eny Martindah¹, Aswin R. Khairullah^{1*}, Andriani Andriani¹, Susan M. Noor¹, Tati Ariyanti¹, Priyono Priyono², Sri S. Prihandani¹, Raphaella Widiastuti¹, Widodo Suwito³, Eni Kusumaningtyas¹, Syahputra Wibowo⁴, Bima P. Pratama⁵

¹Research Center for Veterinary Science, National Research and Innovation Agency (BRIN), Jl. Raya Bogor Km. 46 Cibinong, Bogor, 16911, West Java, Indonesia.

²Research Center for Behavioral and Circular Economics, National Research and Innovation Agency (BRIN), Jl. Gatot Subroto No.10, RT.2/RW.2, Kuningan Barat, Mampang Prpt., South Jakarta, 12710, Daerah Khusus Ibukota Jakarta, Indonesia.

³Research Center for Food Technology and Processing, Jl. Jogja - Wonosari, km 31, 5. Playen, 174 WNO, Gading II, Gading, Playen, Gunungkidul Regency, 55861, Special Region of Yogyakarta, Indonesia.

⁴Eijkman Research Center for Molecular Biology, National Research and Innovation Agency (BRIN), Jl. Raya Bogor Km. 46 Cibinong, Bogor, 16911, West Java, Indonesia.

⁵Research Center for Process Technology, National Research and Innovation Agency (BRIN), KST BJ Habibie, Serpong, South Tangerang, 15314, Banten, Indonesia.

ARTICLE INFO

Received: 01 July 2026

Accepted: 16 September 2026

*Correspondence:

Corresponding author: Aswin R. Khairullah
E-mail address: aswinrafif@gmail.com

Keywords:

Herbal formulations, Productivity, Record-keeping, Small ruminants, Smallholder systems.

ABSTRACT

Smallholder livestock systems continue to have comparatively low small ruminant production, mostly as a result of poor livestock management, poor livestock health control, and non-data-based decision-making. Minimal livestock management records and a dependence on customs that are infrequently thoroughly assessed make the issue worse. However, two strategies that could practically and sustainably boost production efficiency are management records and the use of herbal formulations, especially in the setting of small-scale livestock farming with limited resources. This review article aimed to comprehensively examine the role of livestock management records and herbal formulations in increasing small ruminant productivity in smallholder livestock systems. The study's findings suggest that more quantifiable monitoring of livestock health, reproduction, and production performance can be supported by straightforward but consistent management records. According to reports, herbal formulations have the potential to promote animal health by acting as immunomodulatory, antibacterial, and antiparasitic agents. Combining these two methods promotes more logical decision-making at the farmer level and enables a more objective assessment of the efficacy of herbal-based interventions. The synergy of management records and herbal formulations can be an adaptive technique for raising the production of small ruminants, as this review highlights. When developing evidence-based and long-lasting smallholder livestock interventions, these findings have significant ramifications for livestock producers, extension agents, and policymakers.

Introduction

In many developing regions, smallholder livestock systems heavily rely on small ruminants, particularly sheep and goats (Bilotto *et al.*, 2024). These species are renowned for their ease of maintenance, comparatively quick reproductive cycles, and ability to adapt to habitats with minimal resources (Hussein *et al.*, 2024). Small ruminants are an essential part of integrated agricultural systems based on small plots of land, a flexible economic asset, a buffer for food security, and a source of animal protein for smallholder households (Anim-Jnr *et al.*, 2023).

Small ruminant production in smallholder livestock systems is typically low, despite their substantial potential (Jemberu *et al.*, 2022). Inadequate management techniques, inadequate livestock health care, and improper feeding methods for livestock physiological requirements are frequently blamed for low productivity and reproductive performance (Li *et al.*, 2025). It is challenging to precisely identify reasons limiting productivity and the effects of interventions because the majority of livestock producers still rely on empirical experience in livestock management without the help of data-based evaluation (Sargison, 2020).

Problems with livestock health have a significant impact on output (Moliso *et al.*, 2024). Growth, reproductive efficiency, and mortality rates are all directly impacted by the high prevalence of viral and parasitic illnesses in small ruminants (Fthenakis *et al.*, 2015). Disease management is frequently reactive and unplanned due to restricted availability to veterinary medications and animal health services (Nuvey *et al.*, 2023). However, the unchecked use of synthetic medications may raise production costs and raise the possibility of antimicrobial resistance, which is a worldwide problem from the standpoint of human and animal health (Jannah *et al.*, 2024).

Livestock management records are one essential component of smallholder livestock systems that has not gotten enough attention (Hernández-Jover *et al.*, 2019). Information on health, production, reproduction, and feed is inadequately documented due to the absence of organized recordkeeping (Mehmedi *et al.*, 2026). Because of this, decisions are made without reference to past data, which makes it challenging to assess management strategies' efficacy (Oral and Yildiz, 2025). Even in small-scale agricultural environments, straightforward, regular record-keeping has the potential to be a crucial instrument for tracking livestock performance and assisting with evidence-based decision-making (Morgan-Davies *et al.*, 2024).

However, in smallholder livestock systems, the use of herbal formulations has long been a part of animal management techniques (Nwafor and Nwafor, 2022). Based on traditional knowledge and experience, local medicinal herbs are utilized to prevent and treat health issues in livestock (Wendimu *et al.*, 2024). Herbal plants have bioactive chemicals with antibacterial, antiparasitic, and immunomodulatory properties that may improve livestock health and performance, according to a number of studies (Parham *et al.*, 2020; Jamil *et al.*, 2022; Alem, 2024). However, the application of herbal remedies in livestock husbandry is typically not backed by quantifiable assessment and sufficient standardization, making it challenging to reliably prove their advantages (Mpolokeng *et al.*, 2026).

This circumstance shows a disconnect between field practice and scientific understanding in the management of small ruminants (Herdiana *et al.*, 2021). One viable way to close this gap is to combine the use of herbal formulations with management record keeping (Ibeagha-Awemu *et al.*, 2026). The biological and economic effects of herbal use can be assessed by straightforward yet methodical record keeping, which also promotes

sustainable livestock management advancements (Wang *et al.*, 2023).

The purpose of this review article was to comprehensively examine the role of management record keeping and herbal formulations as an integrated approach to increasing small ruminant productivity in smallholder livestock systems, and to identify opportunities, challenges, and implications for its implementation based on available scientific evidence.

Management record-keeping in smallholder small ruminant systems

Management record-keeping is a fundamental component of small ruminant livestock systems because it serves as the basis for systematically monitoring livestock production, health, and reproductive performance, particularly in the context of smallholder livestock farms facing limited resources and access to information. Figure 1 illustrates the definition of livestock management record-keeping and highlights four essential areas that should be systematically monitored in smallholder small ruminant systems: production performance, health status, reproductive efficiency, and resource utilization.

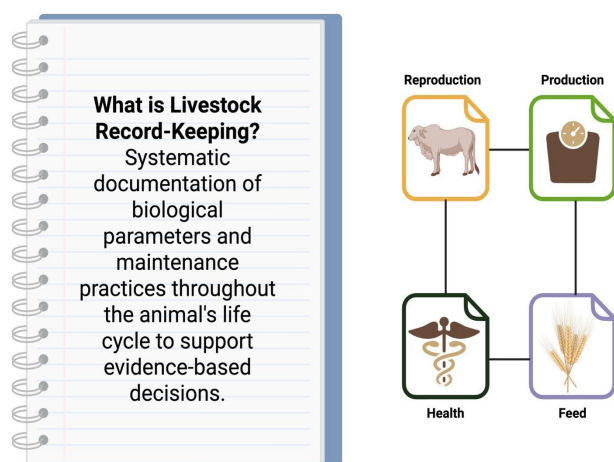


Figure 1. Livestock definition and 4 essential areas to track

Definition and types of livestock records

The methodical recording of biological characteristics and husbandry techniques that affect livestock performance over the course of the production cycle is known as livestock management recording (Romero-Zúñiga *et al.*, 2026). Recording provides a foundation for evidence-based decision-making in smallholder ruminant livestock systems, allowing for the objective assessment of management effectiveness and the early detection of issues that limit productivity (Dao *et al.*, 2026).

Mating time, pregnancy status, delivery time and outcome, and calving intervals are all included in reproductive records (Caraviello *et al.*, 2006). Because low reproductive performance directly affects output continuity and farmer revenue, this data is used to evaluate population stability and reproductive efficiency (Assefa *et al.*, 2026). Potential reproductive abnormalities can be detected early with organized reproductive recording, allowing for the implementation of the necessary corrective measures (Ali *et al.*, 2015).

Measuring livestock output, including body weight gain, milk production, and calf performance after weaning, is the main goal of production recording (Hossain *et al.*, 2025). The livestock's reaction to a mix of genetic, dietary, and environmental influences is reflected in these measures (King *et al.*, 2020). When evaluating the efficacy of management measures, such as the use of herbal formulations or the administration of supplemental feed, production data is also essential (Flores *et al.*, 2026).

Aspects of livestock health are recorded by keeping track of clinical symptoms, treatment options, illness incidence, and preventative initiatives including immunization and parasite management (Sheikh *et al.*, 2025).

In smallholder livestock systems, health information supports more effective and long-lasting preventive methods by facilitating the monitoring of disease trends and the assessment of control measures put in place (Munaf *et al.*, 2023).

The type, amount, and source of feed supplied, as well as the usage of natural additives or supplements, are all covered in feed records (Adesogan *et al.*, 2026). An overview of the effectiveness and sufficiency of feed supply, as well as its connection to livestock health and production performance, is given by feed data (Rauw *et al.*, 2025). Feed records are essential for evaluating quantifiable biological and economic effects in the context of herbal-based therapies (Wyngaarden *et al.*, 2020).

Benefits of record-keeping for productivity improvement

By offering precise and methodically documented data, livestock management records significantly increase the productivity of small ruminants (Swaminathan *et al.*, 2026). Farmers and extension agents can do evidence-based assessments of adopted husbandry practices because to the availability of historical data on livestock performance, ensuring that management choices are not exclusively based on experience or gut feeling (Obiorah *et al.*, 2025).

Records are used as a foundation for analysis in the context of decision-making to identify more successful husbandry techniques, such as modifying feed consumption, choosing replacement livestock, and putting health interventions into practice (Eriksen *et al.*, 2022). Decision-making is more focused and effective when performance is compared between individual livestock and throughout production periods thanks to documented data (Bearth *et al.*, 2026).

The early identification of health issues is another way that records are beneficial (Kappes *et al.*, 2023). Regularly documented trends in feed consumption, disease incidence, or output performance can serve as early warning signs of health issues before serious clinical symptoms manifest (Duthie *et al.*, 2021). This strategy decreases medical expenses, encourages quicker preventive action, and lessens the possibility of losses from decreased productivity or animal mortality (Puig *et al.*, 2022).

Additionally, by organized monitoring of reproductive parameters, records contribute to increased reproductive efficiency (Kaurivi *et al.*, 2020). It is possible to identify reproductive delays or failures that may lower production output by using information on mating time, pregnancy, and calving intervals (Koujalagi *et al.*, 2026). Reproductive tracking thus facilitates more precise breeding planning and directly enhances long-term productivity gains (Mikkola *et al.*, 2024).

Challenges in record-keeping adoption among smallholders

There are still a number of structural and behavioral obstacles to the adoption of livestock management recordkeeping in small-scale ruminant farming systems (Oral and Yildiz, 2025). Despite the fact that recording is acknowledged as a crucial tool for raising production, its adoption rate is rather low because of individual capacity limitations and the subsistence character of agricultural operations (Groher *et al.*, 2020).

A significant obstacle is low literacy, especially among farmers with little formal schooling (Ngoshe *et al.*, 2022). Record-keeping is sometimes seen as complicated and unfeasible due to challenges with reading, writing, and comprehending technical words (Delavenne *et al.*, 2025). Additionally, farmers who lack numerical literacy are unable to completely benefit from record-keeping because they are unable to evaluate basic statistics, such as changes in body weight or reproductive intervals (Tedeschi *et al.*, 2026).

Another factor contributing to the limited uptake of record-keeping is time constraints (Gichohi, 2020). Livestock maintenance tasks typically take place in conjunction with other major activities in smallholder livestock systems, such as the cultivation of food crops or non-agricultural labor (Assan, 2023). Because of this, record-keeping is frequently seen as an

extra burden unrelated to day-to-day operating requirements, particularly when the immediate advantages are not apparent (Resti *et al.*, 2024).

Adoption rates are influenced by perceptions of the advantages of record-keeping in addition to technical and operational variables (Oli *et al.*, 2025). Since many farmers still base their decisions on memory and empirical experience, they believe that preserving records adds little value (Sylvester *et al.*, 2015). The idea that record-keeping is not necessary for small-scale livestock management is strengthened by the lack of obvious feedback, such as quantifiable increases in productivity or cost savings (Mapiye and Dzama, 2024).

Simple and practical record-keeping models

For smallholder ruminant farms, management record-keeping models must be created with the farmer's workload, literacy levels, and resource limitations in mind (Resti *et al.*, 2024). Therefore, increasing acceptance and sustainability requires a straightforward, practical, and applicable solution to everyday operating needs (Raimi *et al.*, 2026).

For smallholder farmers, manual record books are the most popular and easily available method of keeping records (Tham-Agyekum *et al.*, 2010). Usually, these are straightforward tables that document significant occurrences like feedings, illnesses, treatments, and deliveries (Wulandari *et al.*, 2023). The flexibility, affordability, and lack of specific technological skills are the main benefits of manual record keeping (Mdoda and Nontu, 2026). When utilized regularly, manual record books can nevertheless yield helpful baseline data for assessing livestock performance despite their simplicity (Brocklehurst *et al.*, 2025).

Simple record-keeping apps are being offered as a more effective substitute as access to digital technology grows (Sennuga *et al.*, 2023). Quick data collection and long-term information storage are made possible by mobile applications with user-friendly interfaces (Shahab *et al.*, 2024). Digital applications not only make data management easier, but they also provide opportunity for basic analytics like livestock performance reviews or vaccine reminders (Daum *et al.*, 2022). However, the availability of devices, connectivity, and the farmer's proficiency with digital technology all play a significant role in how effective this strategy is (Stygar *et al.*, 2026).

The use of best practices in management record keeping places a strong emphasis on data relevancy, format simplicity, and a clear connection to farmers' perceived advantages (Bhaskaran *et al.*, 2024). Using straightforward symbols or codes, capturing crucial parameters that are absolutely necessary for decision-making, and combining record keeping with regular maintenance tasks are a few examples of best practices

(Montalván *et al.*, 2024). This method aids in raising farmers' awareness of the purpose of record keeping so that it is seen as a useful management tool rather than an administrative need (Gichohi, 2020).

Herbal formulations in small ruminant production

Herbal formulations have long been utilized in small ruminant production as a locally resource-based approach with the potential to support livestock health and increase productivity, particularly in smallholder farming systems with limited access to conventional veterinary inputs. Figure 2 presents an overview of traditional herbal remedies applied in small ruminant production, illustrating their roles in supporting animal health, improving productivity, and serving as accessible alternatives to conventional veterinary inputs in resource-limited smallholder farming systems.

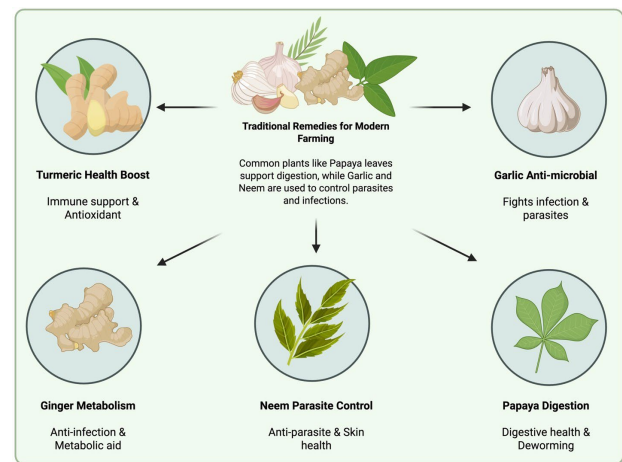


Figure 2. Traditional remedies for modern farming.

Traditional use of herbal remedies in smallholder systems

Herbal remedies have been used for generations in small ruminant livestock systems, and this practice is ingrained in rural communities' traditional knowledge (Rahman *et al.*, 2023). Farmers started using locally available biological resources as a result of their restricted access to synthetic medications and professional veterinary care (Masika *et al.*, 2000). The majority of the time, information on the choice, preparation, and application of herbal plants is transmitted orally and is grounded in practical experience (Hassen *et al.*, 2022). Despite its traditional origin, it exhibits adaptability to local circumstances (Mpolokeng *et al.*, 2026). Table 1 sum-

Table 1. Traditional utilization of herbal plants in smallholder small ruminant farming systems.

Herbal plant (scientific name)	Local name	Plant part used	Major reported bioactive compounds	Traditional purpose of use	Common application method	Quantitative dose/concentration	References
<i>Curcuma longa</i>	Turmeric	Rhizome	Curcuminoids, particularly curcumin, and essential oils	To enhance immunity and support general health	Decoction or mixed with feed	NR	Haris <i>et al.</i> (2022); Daham <i>et al.</i> (2026)
<i>Zingiber officinale</i>	Ginger	Rhizome	Gingerols, shogaols, and volatile oils	Anti-infective support and metabolic enhancement	Decoction or fermented feed	NR	Haris <i>et al.</i> (2022); Daham <i>et al.</i> (2026)
<i>Azadirachta indica</i>	Neem	Leaves	Limonoids, including azadirachtin and related compounds	Parasite control and management of skin disorders	Aqueous extract or mixed with feed	NR	Adhana <i>et al.</i> (2022); Daham <i>et al.</i> (2026)
<i>Allium sativum</i>	Garlic	Bulb	Organosulfur compounds, particularly allicin and related sulfur compounds	Antimicrobial and antiparasitic purposes	Crushed and mixed with feed	NR	Adhana <i>et al.</i> (2022); Daham <i>et al.</i> (2026)
<i>Carica papaya</i>	Papaya	Leaves	Papain, chymopapain, phenolic compounds, and flavonoids	To support digestive health and provide anti-parasitic effects	Decoction or fresh feed supplementation	NR	Lismawan <i>et al.</i> (2026); Daham <i>et al.</i> (2026)

NR = not reported in the cited traditional-use studies.

Note: The bioactive compounds listed in the table represent major phytochemical constituents reported for the respective plant species and should not be interpreted as standardized concentrations or active-principle percentages in the traditional preparations. The concentration and composition of these compounds may vary according to plant variety, plant part, growing conditions, harvest stage, storage, processing, and extraction method. Therefore, quantitative dosing or active-compound concentrations should not be extrapolated from the plant species alone and should preferably be established using standardized preparations and body-weight-based dose-response studies.

marizes examples of herbal plants traditionally used by small ruminant farmers and incorporates information on their major reported bioactive compounds and the availability of quantitative dosing data.

Small ruminant livestock farmers employ a variety of herbal plants to improve the health and productivity of their animals (Onuoha *et al.*, 2021). Plants containing bioactive compounds such as flavonoids, alkaloids, saponins, tannins, terpenoids, and essential oils are frequently used because of their reported antibacterial, antiparasitic, anti-inflammatory, antioxidant, and immunomodulatory properties (Odhaib *et al.*, 2021). Examples of often used plants are *Carica papaya* (papaya leaf) to improve digestive health, *Azadirachta indica* (neem) and *Allium sativum* (garlic) to fight parasites and infections, and *Curcuma longa* (turmeric) and *Zingiber officinale* (ginger) to boost immunity (Haris *et al.*, 2022; Adhana *et al.*, 2022; Lismawan *et al.*, 2026).

These plants are typically given fresh, in the form of a decoction, or just combined with feed in field practice (Daham *et al.*, 2026). However, the cited traditional-use studies generally do not provide standardized concentrations of active principles or precise quantitative dosing regimens (Wang *et al.*, 2023). Accordingly, the "NR" designation in Table 1 indicates that quantitative dose or concentration data were not reported in the cited traditional-use studies. This limitation is important because the biological activity and safety of herbal preparations depend on the concentration of bioactive constituents, plant part, preparation method, dose, route of administration, and duration of exposure (Buyel, 2023). Variations in dosage, processing techniques, and frequency of administration continue to be obstacles to maintaining consistent effectiveness, despite their comparatively simple and inexpensive use (Ahmed *et al.*, 2026).

To improve reproducibility, future applications should incorporate botanical authentication, standardized preparation procedures, quantitative characterization of relevant marker or active compounds, and body-weight-based dosing (Song *et al.*, 2026). Where quantitative information is unavailable, these practices should be regarded as traditional ethnoveterinary applications rather than standardized therapeutic regimens (Bhat *et al.*, 2023). Integrating traditional knowledge with phytochemical characterization and controlled dose-response studies would facilitate more reliable evaluation of efficacy, safety, and practical applicability in smallholder small ruminant production systems (Masika *et al.*, 2000).

Bioactive compounds and mechanisms of action

The availability of bioactive chemicals found in medicinal plants is the main factor that determines how well herbal formulations enhance

the health and productivity of small ruminants (Alem, 2024). It has been extensively documented that substances like flavonoids, alkaloids, terpenoids, saponins, tannins, and essential oils have biological actions related to disease prevention and enhancing animal immunity (Priyashantha *et al.*, 2026). These substances have complex modes of action that include both direct interaction with pathogens and modification of host physiological reactions (Wang *et al.*, 2023). Table 2 summarizes the main bioactive compound groups contained in herbal plants and their biological mechanisms of action in small ruminants.

The capacity of bioactive chemicals to prevent the growth of pathogenic germs or harm their cell structure is typically linked to the antimicrobial activity of herbal plants (Hemeg *et al.*, 2020). For instance, phenolics and essential oils can damage the integrity of bacterial and fungal cell membranes, resulting in intracellular component leakage and decreased cell viability (De Rossi *et al.*, 2025). Furthermore, certain flavonoids and alkaloids contribute to the suppression of infection development by preventing the creation of vital microbial proteins or enzymes (Roy *et al.*, 2022). These processes facilitate the use of herbal remedies as a supplement or substitute for traditional therapies in the management of infectious illnesses in small ruminants (Kuralkar and Kuralkar, 2021).

The nervous system, the parasite's surface structure, and energy metabolism are only a few of the ways that bioactive substances with antiparasitic activity function (Ranasinghe *et al.*, 2023). By attaching to structural proteins or blocking the parasites' capacity to feed, tannins and saponins are known to lower the vitality of gastrointestinal parasites (Adak and Kumar, 2022). These outcomes increase the nutritional status of livestock and lessen the burden of parasites (Jordon *et al.*, 2022). This herbal-based method has the potential to strategically lower the danger of drug resistance and dependence on synthetic anthelmintics (Liu *et al.*, 2020).

Apart from their direct impact on pathogens, a number of herbal substances also demonstrate immunomodulatory action, which contributes to bolstering the host's immunological response (Alhazmi *et al.*, 2021). Certain terpenoids, polysaccharides, and flavonoids can balance the inflammatory response, boost cytokine synthesis, and increase immune cell activity (Alem, 2024). In addition to promoting physiological recovery and productivity, this improved immune function aids animals in responding to disease challenges more successfully (Bostami *et al.*, 2021).

Evidence-based benefits of herbal formulations

Herbal compositions have a great deal of promise to improve the health of small ruminants, according to numerous experimental and field

Table 2. Major bioactive compounds and mechanisms of action of herbal formulations in small ruminants.

Bioactive compound group	Common examples	Primary mechanism of action	Biological target	Functional impact on livestock	References
Flavonoids	Quercetin, kaempferol	Antimicrobial, immunomodulatory, and antioxidant activities; inhibition of microbial enzymes and proteins	Bacteria, viruses, and host immune cells	Reduced infection incidence and enhanced immune resilience	Roy <i>et al.</i> (2022); Alhazmi <i>et al.</i> (2021); Alem (2024)
Alkaloids	Berberine, piperine	Inhibition of pathogen enzyme activity and protein synthesis	Pathogenic microorganisms	Improved infection control and maintenance of health status	Roy <i>et al.</i> (2022); Kuralkar and Kuralkar (2021)
Terpenoids	Limonene, thymol	Disruption of microbial cell membranes and modulation of inflammatory responses	Bacteria, fungi, and host tissues	Improved immune responses and metabolic health	De Rossi <i>et al.</i> (2025); Alem (2024)
Saponins	Steroidal and triterpenoid saponins	Disruption of parasite membrane integrity and interference with parasite metabolism	Gastrointestinal parasites	Reduced parasite burden and improved nutrient utilization	Adak and Kumar (2022); Jordon <i>et al.</i> (2022)
Tannins	Condensed tannins	Binding to structural proteins and inhibition of parasite nutrient uptake	Parasites and microorganisms	Parasite control and improved feed efficiency	Adak and Kumar (2022); Liu <i>et al.</i> (2020)
Essential oils	Eugenol, carvacrol	Membrane damage and induction of intracellular leakage	Pathogenic bacteria and fungi	Prevention and control of infectious diseases	Hemeg <i>et al.</i> (2020); De Rossi <i>et al.</i> (2025)
Polysaccharides	β -glucan	Stimulation of immune cell activity and cytokine production	Host immune system	Enhanced non-specific immune responses	Alhazmi <i>et al.</i> (2021); Bostami <i>et al.</i> (2021)

investigations (Odoemelam *et al.*, 2013). Certain herbs have been shown to improve non-specific immune responses and have antimicrobial and antiparasitic properties that lower the incidence of infectious and parasitic disorders (Jamil *et al.*, 2022). Livestock that are in better health have lower morbidity, greater endurance, and quicker physiological recovery (Tani *et al.*, 2025). These advantages are significant in smallholder livestock systems since they lower medical expenses and the usage of synthetic medications (Yanuartono *et al.*, 2026).

Herbal formulations have been demonstrated to affect livestock growth and productivity in addition to their effects on health (Rebez *et al.*, 2025). Numerous therapeutic herbs and phytobiotics have been shown to improve rumen microbiota balance and digestive tract function, which in turn increases feed intake, feed conversion efficiency, and body weight gain (Adetunji *et al.*, 2025). Herbs include bioactive substances that can improve nutrition consumption by reducing metabolic problems and stimulating the release of digestive enzymes (Contò *et al.*, 2026). Herbal formulations are a helpful strategy for sustainably enhancing production performance in small-scale livestock systems because of these benefits (Almuraee, 2026).

Although the scientific data is still evolving, reports of the advantages of herbal formulations in reproductive aspects have also been made (Shai *et al.*, 2022). According to a number of studies, giving sows specific herbs can enhance their physiological state, promote hormonal balance, and boost the likelihood of conception and successful birth (Parraguez *et al.*, 2021). These benefits are frequently linked to better general health and nutritional quality, both of which are important for successful reproduction (BenSouf *et al.*, 2025). Improving reproductive performance directly affects livestock population stability and production continuity in smallholder livestock farming (Cui *et al.*, 2024).

Safety, dosage, and standardization issues

Safety is still a big worry, even if herbal formulations may be a helpful intervention in small ruminant livestock systems (Joshua *et al.*, 2010). Certain bioactive substances in medical plants might have harmful consequences when taken excessively or over an extended period of time, therefore not all medicinal plants are safe at all dosages (van Wyk and Prinsloo, 2020). Risks of toxicity can show up as metabolic stress, digestive problems, or subclinical consequences that affect the welfare and performance of livestock (Byard and Musgrave, 2021). Consequently, the usage of herbs must be predicated on knowledge of the targeted livestock species' physiological traits and safety restrictions (Kuralkar and Kuralkar, 2021).

Quantitative safety parameters, including effective concentration (EC_{50}), lethal dose or concentration (LD_{50}/LC_{50}), no-observed-adverse-effect level (NOAEL), lowest-observed-adverse-effect level (LOAEL), and therapeutic index, remain insufficiently established for many herbal formulations used in small ruminants (Pandeya *et al.*, 2024). These parameters are formulation- and species-specific and should therefore be determined through appropriate dose-response and toxicological studies rather than extrapolated between different plants or preparations (Mulholland *et al.*, 2018). For example, excessive condensed tannin exposure has been associated with clinically and pathologically relevant toxicity in small ruminants (Al Rharad *et al.*, 2025). In sheep, administration of quebracho tannin extract containing approximately 760 g/kg condensed tannins at 3.0 g extract/kg live weight/day resulted in anorexia, weakness, depression, body-weight loss, and severe gastrointestinal lesions, including ruminal and reticular ulcers (Hervás *et al.*, 2003).

Toxicity has also been reported with hydrolysable tannins. Goats exposed to *Clidemia hirta*, containing approximately 19% hydrolysable tannins, developed biochemical and histopathological evidence of hepatic and renal injury, together with abomasitis and enteritis (Murdiati *et al.*, 1990). These findings indicate that excessive tannin exposure may compromise gastrointestinal and systemic health and emphasize the im-

portance of defining effective and safe dose ranges (Huang *et al.*, 2018). Similarly, potentially toxic plant alkaloids may cause hepatic, renal, gastrointestinal, neurological, or cardiovascular effects depending on their chemical structure and exposure level (Adibah and Azzreena, 2019).

The variety of herbal ingredients, which is impacted by plant genetic variables, agroecological circumstances, harvest timing, and processing techniques, is another important problem (Plyduang *et al.*, 2026). It is challenging to reliably estimate the efficacy and safety of herbal formulations because to this variance, which directly affects the concentration and content of bioactive components (Aware *et al.*, 2022). The use of fresh materials or basic preparations without standardization in smallholder livestock farming further raises the possibility of inconsistent biological responses in the animals (Farhanudin *et al.*, 2026). Therefore, standardization should include botanical authentication, specification of the plant part and preparation method, quantification of relevant bioactive compounds, and characterization of potentially toxic secondary metabolites such as tannins and alkaloids (Gupta *et al.*, 2021; Dawoud and Abdalbagi, 2025).

Determining the proper dosage, administration technique, and the stability of active ingredients during storage and application are additional difficulties in herbal preparations (Ansari *et al.*, 2024; Xue *et al.*, 2025). Uncertainty about dosage frequently results in speculation, which may lower efficacy or raise the possibility of adverse consequences (Banaee *et al.*, 2025; Dijkstra *et al.*, 2025). Where evidence is available, dose-response studies should be used to define effective exposure ranges and safety margins, while NOAEL, LOAEL, LD_{50}/LC_{50} , and therapeutic index can provide additional quantitative information on toxicity and the therapeutic window (Nair and Jacob, 2016; Pokhrel and Grady, 2021; Manglani *et al.*, 2021). However, interactions between chemicals in herbal combinations might result in antagonistic or synergistic effects that are still poorly understood scientifically (Orimaye *et al.*, 2024). This circumstance highlights the necessity of a more regulated, evidence-based formulation strategy (Grissinger, 2011; Alem, 2024).

Integrating record-keeping and herbal interventions

The integration of management record-keeping and herbal interventions enables data-driven evaluation of biological and managerial impacts, while strengthening knowledge transfer and farmer empowerment in small ruminant farming systems. Figure 3 illustrates the synergistic loop between systematic record-keeping and herbal interventions, emphasizing the continuous cycle of recording, treatment application, and outcome evaluation.

Using records to evaluate herbal intervention outcomes

When evaluating the effects of herbal formulations on small ruminant farming systems, livestock management records are an essential objective assessment tool (Iommelli *et al.*, 2025). Livestock reactions to herbal interventions can be quantitatively and longitudinally observed through methodically recorded data, guaranteeing that evaluations of efficacy are not exclusively dependent on the farmer's subjective opinions (Schmid *et al.*, 2012). This method makes it possible to combine conventional methods with data-driven scientific assessment (Masika *et al.*, 2000).

Records make it possible to identify changes in physiological and production indicators after herbal treatment in the context of health and performance monitoring (Dardouri *et al.*, 2025). It is possible to compare indicators between the pre- and post-intervention periods, including disease frequency, morbidity rates, feed intake, body weight gain, and milk production (Wójtowski *et al.*, 2025). In addition to identifying any adverse effects, consistent patterns of change in these measures can be utilized to evaluate the herbal formulation's contribution to enhancing animal health and performance (Giannenas *et al.*, 2018).

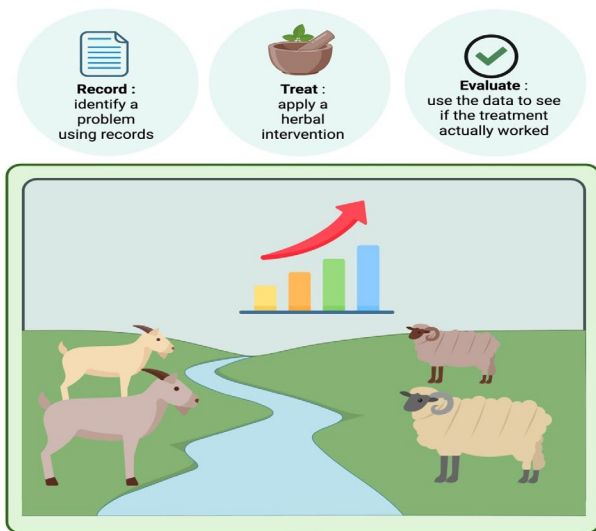


Figure 3. The Synergy Loop: Record, treat, evaluate

Records provide a more quantifiable assessment of the efficacy of herbal therapies in addition to monitoring (Chakraborty and Pal, 2012). Analysis of the causal link between herbal administration and livestock biological responses is made possible by integrated reproductive, health, and production data (Evrendilek, 2026). Comparing various herbal formulations, doses, or administration techniques makes this assessment even more pertinent (Jitäreanu *et al.*, 2023). Records are therefore used as a foundation for choosing the best and most effective solutions for local smallholder livestock farming circumstances (Abdu and Gudescho, 2026).

Knowledge transfer and farmer empowerment

Bridging the gap between scientific research findings and small-scale ruminant husbandry methods at the farmer level requires effective knowledge transmission (Makarabbi *et al.*, 2025). A data-driven extension method enables the delivery of information in a more contextual and pertinent manner to field situations when it comes to the implementation of management records and herbal formulations (Delavenne *et al.*, 2025). In order to provide farmers with both general recommendations and an understanding of the empirical foundation for each intervention adopted, data from recording productivity, health, and reproduction can be utilized as discussion material during extension activities (Tamsan and Yusriadi, 2022).

Understanding and confidence in management innovations tend to rise when extension makes use of real data from farmers' own animals (Daum *et al.*, 2025). This method assists farmers in seeing the clear connection between quantifiable livestock responses and adopted strategies, such as the use of herbal formulations or modifications to feeding schedules (Lundström and Lindblom, 2018). Instead of just being a one-way information transfer, this makes learning more experiential and participatory (Mehmedi *et al.*, 2026).

Beyond extension, a key component of empowerment is farmers' active involvement in the recording and assessment process (Forney, 2021). Increased analytical ability and a sense of control over the management techniques used are fostered by farmer participation in data gathering and interpretation (Prajapati *et al.*, 2025). By participating, farmers become more important decision-makers rather than just beneficiaries of advice or technology from outside sources (Lalani *et al.*, 2016).

Case studies and field-based evidence

The use of herbal formulations and management record keeping in small ruminant livestock systems is validated in large part by case studies and field-based research (Nuvey *et al.*, 2023). Field studies capture the complexity of real-world farm situations, including differences in envi-

ronment, resources, and husbandry procedures, in contrast to controlled experimental approaches (Lane *et al.*, 2025). A contextual evaluation of the efficacy of interventions is made possible by empirical data from the field, which also pinpoints the elements that contribute to or hinder their success (Ohashi *et al.*, 2024).

Simple record keeping in conjunction with herbal therapies has been shown in numerous field experiments to produce quantifiable changes in livestock performance and health (Kuralkar and Kuralkar, 2021). Farmers that regularly evaluate livestock responses to treatments frequently report indicators like decreased illness incidence, higher body weight gain, and enhanced reproductive efficiency (Evans *et al.*, 2022). Additionally, field data shows that maintaining records is essential for modifying the frequency and amount of herbal administration in accordance with local variables and livestock conditions (Mpolokeng *et al.*, 2026).

Community-based initiatives show great promise for boosting the uptake and sustainability of data-driven practices, going beyond individual studies (Hossein-Zadeh, 2026). Programs that bring together groups of farmers, extension agents, and supporting organizations allow for the sharing of experiences, standardization of basic procedures, and cooperative assessment of results (Ibnu *et al.*, 2018). Particularly in livestock communities with limited access to information and technology, this collaborative method enhances social learning and speeds up the spread of innovations (Vlaicu *et al.*, 2024).

Socio-economic and sustainability implications

The implementation of management records and herbal formulations in small ruminant farming has significant socio-economic and sustainability implications, especially in increasing business efficiency, farmer independence, and the resilience of the smallholder farming system.

Economic benefits for smallholders

For small ruminant farms, the use of herbal formulations and integrated management records may offer real financial advantages (Sejian *et al.*, 2025). Reduced production costs, especially those associated with spending on synthetic pharmaceuticals, are one of the primary effects that have been discovered (Rizvi *et al.*, 2022). The frequency of disease occurrences and the need for curative treatment can be decreased by using local herbs as a preventative strategy and to maintain livestock health, which will result in reduced and more manageable livestock health costs (Ibeagha-Awemu *et al.*, 2025).

Consistent record-keeping not only lowers expenses but also enables farmers to prevent inefficient input use and objectively assess the success of treatments (Hossein-Zadeh, 2026). Farmers may choose the right time and kind of interventions, including when synthetic medications are actually required, with the aid of documented health and productivity data (Datuti and Martiningsih, 2025). This strategy lowers the possibility of resource waste in small-scale livestock systems while simultaneously increasing economic efficiency (Kazemi, 2025).

Increased farmer revenues, which are mostly the result of better production performance and reproductive sustainability, are another indicator of economic benefits (Adetunji *et al.*, 2025). Higher market value and lower death rates are typically associated with livestock that are in better health and grow at their best (Li *et al.*, 2026). Additionally, more productive livestock results from increased reproductive efficiency, which immediately boosts output capacity and household financial stability (Rahman *et al.*, 2024).

Environmental and One Health perspectives

The environmental sustainability of small ruminant farming systems is significantly impacted by the integration of livestock management records and the use of herbal formulations (Oral and Yıldız, 2025). Maintaining accurate records makes it possible to use feed, medications, and other inputs as efficiently as possible, which lowers resource waste and

environmental stress (Kuralkar and Kuralkar, 2021). Additionally, by lowering dependency on synthetic inputs, which typically have a larger environmental impact during production and distribution, the use of regional herbal ingredients promotes the idea of sustainable use of biological resources (Folina *et al.*, 2025).

This strategy helps manage antimicrobial resistance (AMR), a world-wide problem, from the standpoint of One Health (Dardouri *et al.*, 2025). The selection and spread of resistant microbes are facilitated by the unchecked use of antibiotics in livestock farming, which may have an effect on the health of humans, animals, and the environment (Khairullah *et al.*, 2025). Antimicrobial and immunomodulatory herbal formulations can be used as supportive interventions to lessen the need for antibiotics, especially for treating mild diseases and preventing them (Zheng *et al.*, 2025).

By facilitating more logical drug use monitoring, livestock health records strategically contribute to the elimination of antimicrobial resistance (Werner *et al.*, 2018). Farmers and extension agents can assess when the use of antibiotics is actually necessary by using historical data on illness incidence and response to herbal therapies (Manyi-Loh *et al.*, 2018). In keeping with the guidelines for the wise use of antibiotics, this strategy promotes more cautious and responsible treatment methods (Abate and Birhanu, 2025).

Policy and extension implications

Conducive policy support plays a major role in the successful deployment of herbal formulations and livestock management records in small ruminant farming systems (Sejian *et al.*, 2025). Wider adoption at the farmer level might be encouraged by public policies that acknowledge basic record keeping as a component of fundamental management practices (Sarma *et al.*, 2025). The creation of technical standards, the provision of standardized but adaptable record keeping forms, and the acknowledgment of record keeping as a performance indicator in smallholder livestock development initiatives are all ways to achieve this support (Resti *et al.*, 2024).

It is strategically possible to increase the impact of government initiatives both nationally and regionally by incorporating this technique (Enshaie *et al.*, 2025). As part of the intervention package, management record keeping and the usage of local herbs can be incorporated into extension programs, livestock support, and livestock area development (Dilbato *et al.*, 2023). This method enables continuous monitoring of the efficacy of interventions and modification to local conditions by evaluating programs based on field data (Solazzo *et al.*, 2024).

In order to bridge policy and implementation in the field, extension workers and their helpers play a critical role (Ike, 2024). Increased comprehension and confidence in suggested practices can result from targeted extension services based on data from farmer record keeping (Ahmadzai *et al.*, 2025). Additionally, training extension workers on evidence-based herbal use and basic record keeping will increase their capability, which will enhance the quality of support and the sustainability of adoption (Wang *et al.*, 2023).

Research gaps and future research directions

There are still a number of research gaps that need to be filled, despite the fact that the integration of herbal formulations and management record keeping in small ruminant livestock systems has been well documented (Perkins *et al.*, 2026). The lack of standardization in herbal formulations' ingredient composition, processing techniques, and dose is a major problem (Sachan *et al.*, 2016). Direct comparisons are frequently challenging because to the variability in bioactive chemical concentration caused by variations in plant sources and preparation methods (Vaou *et al.*, 2022). In order to guarantee the constant efficacy and safety of herbal formulations, more research concentrated on developing standard parameters is required (Kunle *et al.*, 2012).

The digitalization of livestock management record systems that are flexible enough to accommodate smallholder livestock farmers is the next area of study (Himu and Raihan, 2024). While the potential of basic digital technologies—like mobile phone-based applications—has not been thoroughly investigated, the majority of research still place a strong emphasis on manual record keeping (Thar *et al.*, 2021). It is essential to do research on the viability, acceptance rates, and effects of digital record keeping on livestock production and decision-making, especially when it comes to enhancing management effectiveness and long-term data gathering (Groher *et al.*, 2020).

Large-scale field trials and longitudinal studies are desperately needed because the majority of the scientific evidence that is currently available is either short-term or based on sparse observations (Sejian *et al.*, 2025). A more complete picture of the long-term effects of management records and the application of herbal formulations on livestock productivity, health, and reproduction will be provided by long-term study (Kashuri *et al.*, 2026). To evaluate the generalizability of research findings and their practical relevance to smallholder livestock production, field experiments spanning a range of agroecological settings and husbandry systems are also crucial (Hosseini *et al.*, 2026).

Conclusion

In order to boost small ruminant productivity in smallholder livestock systems, this paper highlights the complimentary strategic methods of using herbal formulations and keeping livestock management records. Data-driven decision-making is supported by the systematic monitoring of production, health, and reproductive performance made possible by management records. Herbal remedies, on the other hand, provide a different approach to health care that may lower manufacturing costs and the danger of becoming dependent on synthetic medications, particularly in environments where veterinary care is scarce.

Practically speaking, small-scale livestock producers can benefit from the integration of these two systems since it can be adapted to local resources, farmers' skill levels, and socioeconomic circumstances. Easy record-keeping makes it possible to assess the efficacy of herbal use more impartially, upgrading conventional methods into more quantifiable and long-lasting management techniques.

Acknowledgement

This review was supported by the Research Organization for Health, National Research and Innovation Agency (BRIN), Indonesia.

Conflict of interest

The authors declare that there is no conflict of interest.

References

- Abate, T.A., Birhanu, A.G., 2025. Antibiotic Use in Livestock and Environmental Antibiotic Resistance: A Narrative Review. *Environ. Health Insights* 19, 11786302251357775. doi: 10.1177/11786302251357775.
- Abdu, A., Gudescho, G., 2026. Medicinal plants used to treat livestock diseases in Bure district, Illubabor zone, Oromia Regional State, Ethiopia. *BMC Vet. Res.* 22, 6. doi: 10.1186/s12917-025-05157-1.
- Adak, M., Kumar, P., 2022. Herbal anthelmintic agents: a narrative review. *J. Tradit. Chin. Med.* 42, 641–651. doi: 10.19852/j.cnki.jtcm.2022.04.007.
- Adesogan, A.T., Mckune, S.L., Serra, R., Miller, L.C., Bamikole, M.A., Laborde, J.E.A., Dubeux, J.C.B. Jr., Adeoti, T.M., 2026. Animal board invited review: Benefits of livestock and animal-source foods in developing countries. *Animal* 20, 101722. doi: 10.1016/j.animal.2025.101722.
- Adetunji, A.O., Price, J., Owusu, H., Adewale, E.F., Adesina, P.A., Saliu, T.P., Zhu, Z., Xedzro, C., Asiamah, E., Islam, S., 2025. Mechanisms by which phytogetic extracts enhance livestock reproductive health: current insights and future directions. *Front. Vet. Sci.* 12, 1568577. doi: 10.3389/fvets.2025.1568577.
- Adhana, M., Lathwal, S.S., Singh, P., Devi, I., Kumar, A., 2022. Anthelmintic Potency of Garlic (*Allium sativum*) and Neem (*Azadirachta indica*) combination As Herbal Anthelmintic in Lactating Karan Fries Cows. *Indian J. Anim. Sci.* 92, 706–710. doi: 10.56093/ijans.v92i6.115035.
- Adibah, K.Z.M., Azzeena, M.A., 2019. Plant toxins: alkaloids and their toxicities. *GSC Biol. Pharm. Sci.* 6, 21–29. doi: 10.30574/gscbps.2019.6.2.0003.
- Ahmadzai, M.R., Ismail, M.H., Zaki, P.H., Magiman, M.M., Bawon, P., Rahmawaty, Ullah, H., 2025. Transforming livestock production: unraveling the impact of socioeconomic dynamics and land use changes in Khost Province. *J. Land Use Sci.* 20, 82–97. doi: 10.1080/15487717.2025.2048577.

- 10.1080/1747423X.2025.2483491.
- Ahmed, S., Alsharif, K.F., Aschner, M., Alzahrani, K.J., Akkol, E.K., Türkcanoglu, E.G., Khan, H., 2026. A deep dive into herbal extraction: Techniques, trends, and technological advancements. *S. Afr. J. Bot.* 188, 9–37. doi: 10.1016/j.sajb.2025.11005.
- Al Rhadar, A., El Aayadi, S., Avril, C., Souradjou, A., Sow, F., Camara, Y., Hornick, J.L., Boukrouh, S., 2025. Meta-Analysis of Dietary Tannins in Small Ruminant Diets: Effects on Growth Performance, Serum Metabolites, Antioxidant Status, Ruminal Fermentation, Meat Quality, and Fatty Acid Profile. *Animals (Basel)* 15, 596. doi: 10.3390/ani15040596.
- Alem, W.T., 2024. Effect of herbal extracts in animal nutrition as feed additives. *Heliyon* 10, e24973. doi: 10.1016/j.heliyon.2024.e24973.
- Alhazmi, H.A., Najmi, A., Javed, S.A., Sultana, S., Al Bratty, M., Makeen, H.A., Meraya, A.M., Ahsan, W., Mohan, S., Taha, M.M.E., Khalid, A., 2021. Medicinal Plants and Isolated Molecules Demonstrating Immunomodulation Activity as Potential Alternative Therapies for Viral Diseases Including COVID-19. *Front. Immunol.* 12, 637553. doi: 10.3389/fimmu.2021.637553.
- Ali, T., Lemma, A., Yilma, T., 2015. Effect of Management Practices on Reproductive Performance of Smallholder Dairy Cattle. *Austin J. Vet. Sci. Anim. Husb.* 2, 1015.
- Almurae, A.A., 2026. Nano-formulated herbal bioactives in animal-based functional foods: A nutritional approach to enhancing bioavailability and health benefits. *Appl. Food Res.* 6, 101587. doi: 10.1016/j.afres.2025.101587.
- Anim-Jnr, A.S., Sasu, P., Bosch, C., Mabiki, F.P., Frimpong, Y.O., Emmambux, M.N., Greathead, H.M.R., 2023. Sustainable Small Ruminant Production in Low- and Middle-Income African Countries: Harnessing the Potential of Agroecology. *Sustainability* 15, 15326. doi: 10.3390/su152115326.
- Ansari, F.A., Perazzolli, M., Husain, F.M., Khan, A.S., Ahmed, N.Z., Meena, R.P., 2024. Novel decontamination approaches for stability and shelf-life improvement of herbal drugs: A concise review. *Microbe* 3, 100070. doi: 10.1016/j.microb.2024.100070.
- Assan, N., 2023. Sustainable small-scale animal agriculture and food security in Africa. *Sustain. Soc. Dev.* 1, 2342. doi: 10.54517/ssd.v1i2.2342.
- Assefa, S., Duguma, B., Worku, Z., 2026. Assessment of Breeding Practices and Productive and Reproductive Performance of Multiple Livestock Species in Mixed Farming System in Majang Zone, Southwest Ethiopia. *Vet. Med. Sci.* 12, e70712. doi: 10.1002/vms3.70712.
- Aware, C.B., Patil, D.N., Suryawanshi, S.S., Mali, P.R., Rane, M.R., Gurav, R.G., Jadhav, J.P., 2022. Natural bioactive products as promising therapeutics: A review of natural product-based drug development. *S. Afr. J. Bot.* 151, 512–528. doi: 10.1016/j.sajb.2022.05.028.
- Banaee, M., Sharma, D., Sinha, R., Mikušková, N., Velišek, J., Faggio, C., 2025. Herbal remedies in aquaculture: efficacy, risks, and the need for quality assurance. *Aquacult. Int.* 33, 492. doi: 10.1007/s10499-025-02120-7.
- Bearth, A., Carmo, L.P., de Oliveira, V.H.S., Correia-Gomes, C., Boerlage, A., 2026. Designing a data-based dashboard for decision making in animal farming: Traffic lights vs. Sequential colours. *Comput. Electron. Agric.* 240, 111217. doi: 10.1016/j.compag.2025.111217.
- BenSouf, I., Saidani, M., Maazoun, A., Bejaoui, B., Larbi, M.B., M'Hamdi, N., Aggad, H., Joly, N., Rojas, J., Morillo, M., Martin, P., 2025. Use of Natural Biomolecules in Animal Feed to Enhance Livestock Reproduction. *Int. J. Mol. Sci.* 26, 2328. doi: 10.3390/ijms26052328.
- Bhaskaran, H.S., Gordon, M., Neethirajan, S., 2024. Development of a cloud-based IoT system for livestock health monitoring using AWS and python. *Smart Agric. Technol.* 9, 100524. doi: 10.1016/j.atech.2024.100524.
- Bhat, N.A., Jeri, L., Karmakar, D., Mipun, P., Bharali, P., Sheikh, N., Nongkynrih, C.J., Kumar, Y., 2023. Ethnoveterinary practices of medicinal plants used for the treatment of different cattle diseases: A case study in East Khasi Hill district of Meghalaya, North East India. *Heliyon* 9, e18214. doi: 10.1016/j.heliyon.2023.e18214.
- Bilotto, F., Harrison, M.T., Vibart, R., Mackay, A., Christie-Whitehead, K.M., Ferreira, C.S.S., Cottrell, R.S., Forster, D., Chang, J., 2024. Towards resilient, inclusive, sustainable livestock farming systems. *Trends Food Sci. Technol.* 152, 104668. doi: 10.1016/j.tifs.2024.104668.
- Bostami, A.B.M.R., Khan, M.R.I., Rabbi, A.K.M.Z., Siddiqui, M.N., Islam, M.T., 2021. Boosting animal performance, immune index and antioxidant status in post-weaned bull calves through dietary augmentation of selective traditional medicinal plants. *Vet. Anim. Sci.* 14, 100197. doi: 10.1016/j.vas.2021.100197.
- Brocklehurst, S., Fang, Z., Butler, A., 2025. Real-Time Auto-Monitoring of Livestock: Quantitative Framework and Challenges. *Sensors* 25, 5871. doi: 10.3390/s25185871.
- Buyel, J.F., 2023. Product safety aspects of plant molecular farming. *Front. Bioeng. Biotechnol.* 11, 1238917. doi: 10.3389/fbioe.2023.1238917.
- Byard, R.W., Musgrave, I., 2021. The potential side effects of herbal preparations in domestic animals. *Forensic Sci. Med. Pathol.* 17, 723–725. doi: 10.1007/s12024-021-00418-5.
- Caraviello, D.Z., Weigel, K.A., Craven, M., Gianola, D., Cook, N.B., Nordlund, K.V., Fricke, P.M., Wiltbank, M.C., 2006. Analysis of reproductive performance of lactating cows on large dairy farms using machine learning algorithms. *J. Dairy Sci.* 89, 4703–4722. doi: 10.3168/jds.S0022-0302(06)72521-8.
- Chakraborty, S., Pal, S.K., 2021. Plants for cattle health: A review of ethno- veterinary herbs in veterinary health care. *Ann. Ayurvedic Med.* 1, 144–152.
- Conto, M., Castrica, M., Rinaldi, S., Failla, S., 2026. Natural Bioactive Compounds as Feed Additives: Strategies for Sustainable and Functional Livestock Production. *Appl. Sci.* 16, 2344. doi: 10.3390/ap16052344.
- Cui, D., Wang, L., Wang, L., He, J., Li, Y., Zhang, Z., Wang, S., 2024. Efficacy of an herbal formula Guixiong Yimu San in preventing retained placenta and improving reproductive performance in cows. *Sci. Rep.* 14, 12673. doi: 10.1038/s41598-024-63521-x.
- Daham, S.S., Mahmoud, O.R., Yonis, L.A., 2026. The Role of Medicinal Plants in Treating Intestinal Parasites. *Am. J. Biol. Nat. Sci.* 3, 1–16. doi: 10.51699/ajbns.v3i5.2293.
- Dao, S.D., Gostar, A.K., Tennakoon, R., Chuah, W.Q., Bab-Hadiashar, A., 2026. Modernizing Livestock Operations: Smart Feedlot Technologies and Their Impact. *Animals (Basel)* 16, 1244. doi: 10.3390/ani16081244.
- Dardouri, M., Mtibaa, M.M., Azaiez, S., Khachroub, A.M., Mansour, W., 2025. Herbs impact on poultry health and antimicrobial resistance: a scoping review with one health perspective. *BMC Vet. Res.* 21, 499. doi: 10.1186/s12917-025-04760-6.
- Datuti, S., Martiningsih, N.G.A.G.E., 2025. Innovative Strategies to Increase Livestock Productivity Through the Integration of Traditional Herbal Medicine with a Sustainable Entrepreneurship Approach. *Int. J. Multidiscip. Res. Creat. Innov. Ideas* 1, 395–408.
- Daum, T., Ravichandran, T., Kariuki, J., Chagunda, M., Birner, R., 2022. Connected cows and cyber chickens? Stocktaking and case studies of digital livestock tools in Kenya and India. *Agric. Syst.* 196, 103353. doi: 10.1016/j.agsys.2021.103353.
- Daum, T., Scheiterle, L., Yameogo, V., Adegbola, Y.P., Mulinge, W., Kergna, A.O., Daudu, C., Angara, U.A., Zossou, R.C., Nientao, A., Fatunbi, O., Isuyi, L., Birner, R., 2025. Moving beyond the productivity paradigm: Agricultural innovation systems and sustainable transformation in Africa. *Agric. Syst.* 229, 104445. doi: 10.1016/j.agsys.2025.104445.
- Dawoud, A.D.H., Abdalbagi, M., 2025. Standardization of Medicinal Plants: Ensuring Quality, Safety, and Global Regulatory Compliance in Herbal Drug Development. *Plant Biotechnol. Persp.* 7, 89–102. doi: 10.61882/pbp.7.4.12.
- De Rossi, L., Rocchetti, G., Lucini, L., Rebocchi, A., 2025. Antimicrobial Potential of Polyphenols: Mechanisms of Action and Microbial Responses-A Narrative Review. *Antioxidants (Basel)* 14, 200. doi: 10.3390/antiox14020200.
- Delavenne, C., van Schaik, G., Frössling, J., Cameron, A., Faverjon, C., 2025. Reusability challenges of livestock production data to improve animal health. *Sci. Data* 12, 458. doi: 10.1038/s41597-025-04785-4.
- Dijkstra, J., Bannink, A., Congio, G.F.S., Ellis, J.L., Eugène, M., Garcia, F., Niu, M., Vibart, R.E., Yáñez-Ruiz, D.R., Kebreab, E., 2025. Feed additives for methane mitigation: Modeling the impact of feed additives on enteric methane emission of ruminants—Approaches and recommendations. *J. Dairy Sci.* 108, 356–374. doi: 10.3168/jds.2024-25049.
- Dilbato, T., Begna, F., Tolosa, T., 2023. Medicinal plants and non-plant remedies used in the treatment of livestock ailments in Dawuro Zone, Southwestern Ethiopia. *Ethiop. Vet. J.* 27, 72–92. doi: 10.4314/evj.v27i1.4.
- Duthie, C.A., Bowen, J.M., Bell, D.J., Miller, G.A., Mason, C., Haskell, M.J., 2021. Feeding behaviour and activity as early indicators of disease in pre-weaned dairy calves. *Animal* 15, 100150. doi: 10.1016/j.animal.2020.100150.
- Enshaie, E., Nigam, S., Patel, S., Rai, V., 2025. Livestock Antibiotics Use and Antimicrobial Resistance. *Antibiotics* 14, 621. doi: 10.3390/antibiotics14060621.
- Eriksen, E.O., Pedersen, K.S., Larsen, I., Nielsen, J.P., 2022. Evidence-Based Recommendations for Herd Health Management of Porcine Post-Weaning Diarrhea. *Animals* 12, 1737. doi: 10.3390/ani12141737.
- Evans, H.C., Briggs, E.F., Burnett, R.H., Contreras-Correa, Z.E., Duvic, M.A., Dysart, L.M., Gilmore, A.A., Messman, R.D., Reid, D., Ugur, M.R., Kaya, A., Memili, E., 2022. Harnessing the value of reproductive hormones in cattle production with considerations to animal welfare and human health. *J. Anim. Sci.* 100, skac177. doi: 10.1093/jas/skac177.
- Evrendilek, G.A., 2026. Postbiotics and Phytochemicals as Functional Feed Additives: Impact on Gut Health and Growth Performance. *Appl. Sci.* 16, 1518. doi: 10.3390/app16031518.
- Farhanudin, P.A., Rimayanti, R., Legowo, D., Hamid, I.S., Plumeriastuti, H., Rahmahani, J., Setiawan, B., Rahardjo, H.M., Puspitasari, Y., Sunarso, A., 2026. Field evaluation of ethnoveterinary herbal medicine for sustainable duck health management in smallholder systems in Palembang Village, Indonesia. *World J. Adv. Res. Rev.* 29, 936–942. doi: 10.30574/wjarr.2026.29.2.0406.
- Flores, R.A., Fletcher, P.L.C., Son, K.Y., Min, W., 2026. Insights into Non-Antibiotic Alternative and Emerging Control Strategies for Chicken Coccidiosis. *Animals* 16, 348. doi: 10.3390/ani16020348.
- Folina, A., Kakabouki, I., Baginetas, K., Bilalis, D., 2025. Integration of Bioresources for Sustainable Development in Organic Farming: A Comprehensive Review. *Resources* 14, 102. doi: 10.3390/resources14070102.
- Forney, J., 2021. Farmers' empowerment and learning processes in accountability practices: An assemblage perspective. *J. Rural Stud.* 86, 673–683. doi: 10.1016/j.jrurstud.2021.05.021.
- Fthenakis, G.C., Mavrogianni, V.S., Gallidis, E., Papadopoulos, E., 2015. Interactions between parasitic infections and reproductive efficiency in sheep. *Vet. Parasitol.* 208, 56–66. doi: 10.1016/j.vetpar.2014.12.017.
- Giannenas, I., Bonos, E., Skoufos, I., Tzora, A., Stylianaki, I., Lazari, D., Tsinas, A., Christaki, E., Florou-Paneri, P., 2018. Effect of herbal feed additives on performance parameters, intestinal microbiota, intestinal morphology and meat lipid oxidation of broiler chickens. *Br. Poult. Sci.* 59, 545–553. doi: 10.1080/00071668.2018.1483577.
- Gichohi, P.M., 2020. The role of record keeping and maintenance in enhancing decision making among smallholder dairy farmers in Gitugi Ward in Murang'a County, Kenya. *Inf. Dev.* 36, 535–545. doi: 10.1177/0266666919879728.
- Grissinger, M., 2011. Lack of standard dosing units and measurements creates mishaps in intravenous drug administration. *P T* 36, 10–21.
- Groher, T., Heitkamp, K., Umstätter, C., 2020. Digital technology adoption in livestock production with a special focus on ruminant farming. *Animal* 14, 2404–2413. doi: 10.1017/S175713120001391.
- Gupta, M., Chaudhary, P.H., Tawar, M.G., Shrivastava, B., 2021. Need and scope of standardization of herbal medicines - A review. *Int. J. Green Pharm.* 15, 346–352. doi: 10.22377/ijgp.v15i4.3179.
- Haris, M.I., Mayulu, H., Suyadi, S., 2022. Nutrient, phytochemical, and digestibility evaluation of papaya leaves (*Carica papaya* L.) as an alternative feedstuff for ruminants. *J. Ilmu-Ilmu Peternakan* 32, 87–98. doi: 10.21776/ubjiip.2022.032.01.09.
- Hassen, A., Muche, M., Muasya, A.M., Tsegay, B.A., 2022. Exploration of traditional plant-based medicines used for livestock ailments in northeastern Ethiopia. *S. Afr. J. Bot.* 146, 230–242. doi: 10.1016/j.sajb.2021.10.018.
- Hemeg, H.A., Moussa, I.M., Ibrahim, S., Dawoud, T.M., Alhaji, J.H., Mubarak, A.S., Kabli, S.A., Alsubki, R.A., Tawfik, A.M., Marouf, S.A., 2020. Antimicrobial effect of different herbal plant extracts against different microbial population. *Saudi J. Biol. Sci.* 27, 3221–3227. doi: 10.1016/j.sjbs.2020.08.015.
- Herdiana, Y., Wathoni, N., Sriwidodo, S., Adnyane, I.K.M., 2021. Veterinary Drug Development from Indonesian Herbal Origin: Challenges and Opportunities. *Indones. J. Pharm.* 3, 26–37. doi: 10.24198/rdjp.v3i1.33632.
- Hernández-Jover, M., Hayes, L., Woodgate, R., Rast, L., Toribio, J.A.L.M.L., 2019. Animal Health Management Practices Among Smallholder Livestock Producers in Australia and Their Contribution to the Surveillance System. *Front. Vet. Sci.* 6, 191. doi: 10.3389/fvets.2019.00191.
- Hervás, G., Pérez, V., Giraldez, F.J., Mantecón, A.R., Almar, M.M., Frutos, P., 2003. Intoxication of sheep with quebracho tannin extract. *J. Comp. Pathol.* 129, 44–54. doi: 10.1016/s0021-9975(02)00168-8.
- Himu, H.A., Raihan, A., 2024. Digital Transformation of Livestock Farming for Sustainable Development. *J. Vet. Med. Sci.* 1, 1–8. doi: 10.61148/JVMS/007.
- Hossain, M.R.H., Islam, R., McGrath, S.R., Islam, M.Z., Lamb, D., 2025. Learning-based estimation of cattle weight gain and its influencing factors. *Comput. Electron. Agric.* 231, 110033. doi: 10.1016/j.compag.2025.110033.
- Hosseini-Zadeh, N.G., 2026. Advancing climate-resilient livestock systems: Next-generation emission mitigation strategies and integrated technological innovations. *Vet. Anim. Sci.* 31, 100588. doi: 10.1016/j.vas.2026.100588.
- Hosseini, E., Tsegay, Z.T., Smaoui, S., Elfallah, W., Antoniadou, M., Varzakas, T., Caraher, M., 2026. One Health Approaches to Ethical, Secure, and Sustainable Food Systems and Ecosystems: Plant-Based Diets and Livestock in the African Context. *Foods* 15, 85. doi: 10.3390/foods15010085.
- Huang, Q., Liu, X., Zhao, G., Hu, T., Wang, Y., 2018. Potential and challenges of tannins as an alternative to in-feed antibiotics for farm animal production. *Anim. Nutr.* 4, 137–150. doi: 10.1016/j.aninu.2017.09.004.
- Hussein, J., Bilotto, F., Mbui, D., Omondi, P., Harrison, M.T., Crane, T.A., Sircely, J., 2024. Exploring smallholder farm resilience to climate change: intended and actual adaptation. *Pastor. Res. Policy Pract.* 14, 13424. doi: 10.3389/past.2024.13424.
- Ibeagha-Awemu, E.M., Omonijo, F.A., Bemji, M.N., Duranna, O., Kwoji, I.D., Ozoje, M.O., Osei-Amponsah, R., 2026. The Role of Modern Technologies for Improving the Production Environment of Livestock in Africa. In: Ibeagha-Awemu, E.M., Peters, S.O., Djikeng, A., Rege, J.E.O. (eds) *African Livestock Genetic Resources and Sustainable Breeding Strategies*. Sustainable Development Goals Series. Springer, Cham. doi: 10.1007/978-3-031-92076-9_21.
- Ibeagha-Awemu, E.M., Omonijo, F.A., Piché, L.C., Vincent, A.T., 2025. Alternatives to antibiotics for sustainable livestock production in the context of the One Health approach: tackling a common foe. *Front. Vet. Sci.* 12, 1605215. doi: 10.3389/fvets.2025.1605215.
- Ibnu, M., Offermans, A., Glasbergen, P., 2018. Certification and Farmer Organisation: Indonesian Smallholder Perceptions of Benefits. *Bull. Indones. Econ. Stud.* 54, 387–415. doi: 10.1080/00074918.2018.1506093.
- Ike, C., 2024. The Role of Extension Services in Implementing Livestock Policies. *Int. J. Livest. Policy* 3, 55–68. doi: 10.47941/ijlp.1964.
- Iommelli, P., Spina, A.A., Vastolo, A., Infascelli, L., Lotito, D., Musco, N., Tudisco, R., 2025. Functional and Economic Role of Some Mediterranean Medicinal Plants in Dairy Ruminants' Feeding: A Review of the Effects of Garlic, Oregano, and Rosemary. *Animals* 15, 657. doi: 10.3390/ani15050657.
- Jamil, M., Aleem, M.T., Shaikat, A., Khan, A., Mohsin, M., Rehman, T.U., Abbas, R.Z., Saleemi, M.K., Khatoun, A., Babar, W., Yan, R., Li, K., 2022. Medicinal Plants as an Alternative to Control Poultry Parasitic Diseases. *Life (Basel)* 12, 449. doi: 10.3390/life12030449.
- Jannah, N., Fahrurrisa, Paramitadewi, Y.V., Wibowo, H., Kurniawan, F.A., Komarudin, N.A., Hidayat, A., 2024. Antibiotic Utilization and Its Implications Among Ruminant Farmers and Stakeholders in Sumbawa Regency, Indonesia. *Vet. Med. Int.* 2024, 6519659. doi: 10.1155/vmi/6519659.
- Jemberu, W.T., Li, Y., Asfaw, W., Mayberry, D., Schrobback, P., Rushton, J., Knight-Jones, T.J.D., 2022.

- Population, biomass, and economic value of small ruminants in Ethiopia. *Front. Vet. Sci.* 9, 972887. doi: 10.3389/fvets.2022.972887.
- Jitäreanu, A., Trifan, A., Vieriu, M., Caba, I.C., Mărtu, I., Agoraei, L., 2023. Current Trends in Toxicity Assessment of Herbal Medicines: A Narrative Review. *Processes* 11, 83. doi: 10.3390/pr11010083.
- Jordan, M.W., Willis, K.J., Bürkner, P.C., Petrokofsky, G., 2022. Rotational grazing and multispecies herbal leys increase productivity in temperate pastoral systems – A meta-analysis. *Agric. Ecosyst. Environ.* 337, 108075. doi: 10.1016/j.agee.2022.108075.
- Joshua, A.J., Goudar, K.S., Sameera, N., Kumar, G.P., Murali, B., Dinakar, N., Amit, A., 2010. Safety Assessment of Herbal Formulations, Rumbion™ and Tyrel™ in Albino Wistar Rats. *Am. J. Pharmacol. Toxicol.* 5, 42–47. doi: 10.3844/ajtp.2010.42.47
- Kappes, A., Tozoneyi, T., Shakil, G., Railey, A.F., McIntyre, K.M., Mayberry, D.E., Rushton, J., Pendell, D.L., Marsh, T.L., 2023. Livestock health and disease economics: a scoping review of selected literature. *Front. Vet. Sci.* 10, 1168649. doi: 10.3389/fvets.2023.1168649.
- Kaurivi, Y.B., Laven, R., Parkinson, T., Hickson, R., Stafford, K., 2020. Effect of Animal Welfare on the Reproductive Performance of Extensive Pasture-Based Beef Cows in New Zealand. *Vet. Sci.* 7, 200. doi: 10.3390/vetsci7040200.
- Kazemi, M., 2025. Recycling Agricultural Waste: Sustainable Solutions for Enhancing Livestock Nutrition. *Vet. Med. Sci.* 11, e70321. doi: 10.1002/vms3.70321.
- Khairullah, A.R., Moses, I.B., Yanestria, S.M., Dameanti, F.N.A.E.P., Effendi, M.H., Tang, J.Y.H., Tyansingsih, W., Budiastuti, B., Kusala, M.K.J., Kurniasih, D.A.A., Wardhani, B.W.K., Wibowo, S., Ma'ruf, I.F., Fauziah, I., Ahmad, R.Z., Latifah, L., 2025. Potential of the livestock industry environment as a reservoir for spreading antimicrobial resistance. *Open Vet. J.* 15, 504–518. doi: 10.5455/OVJ.2025.v15i2.2.
- Kashuri, M., Ikrar, T., Sutriyo, Mun'im, A., Yanuar, A., 2026. Evidence-based production framework for herbal medicine regulation in Indonesia. *Front. Pharmacol.* 16, 1730273. doi: 10.3389/fphar.2025.1730273.
- King, T.M., Musgrave, J.A., Funston, R.N., Mulliniks, J.T., 2020. Impact of cow milk production on cow-calf performance in the Nebraska Sandhills. *Transl. Anim. Sci.* 4, S145–S148. doi: 10.1093/tas/txaa123.
- Koujalagi, S., Choudhary, J., Nikam, V.D., Azad, M.S., Singh, D., Mahanthesh, M.T., Chennakadan, N.J., Yadav, R.S., 2026. Boosting Reproductive Efficiency in Livestock: Management Strategies and Approaches. *J. Sci. Res. Rep.* 32, 92–111. doi: 10.9734/jsrr/2026/v32i54158.
- Kunle, O.F., Egharevba, H.O., Ahmadu, P.O., 2012. Standardization of herbal medicines – A review. *Int. J. Biodivers. Conserv.* 4, 101–112. doi: 10.5897/IJBC11.163.
- Kuralkar, P., Kuralkar, S.V., 2021. Role of herbal products in animal production – An updated review. *J. Ethnopharmacol.* 278, 114246. doi: 10.1016/j.jep.2021.114246.
- Lalani, B., Dorward, P., Holloway, G., Wauters, E., 2016. Smallholder farmers' motivations for using Conservation Agriculture and the roles of yield, labour and soil fertility in decision making. *Agric. Syst.* 146, 80–90. doi: 10.1016/j.agry.2016.04.002.
- Lane, J.K., Kelly, T., Bird, B., Chenais, E., Roug, A., Vidal, G., Gallardo, R., Zhou, H., VanHoy, G., Smith, W., 2025. A One Health Approach to Reducing Livestock Disease Prevalence in Developing Countries: Advances, Challenges, and Prospects. *Annu. Rev. Anim. Biosci.* 13, 277–302. doi: 10.1146/annurev-animal-111523-102133.
- Li, T., Raja, B.R., Liao, J., Zheng, L., Yin, F., Gan, S., Sun, X., Lyu, G., Ma, J., 2025. The characteristics, influence factors, and regulatory strategies of growth retardation in ruminants: a review. *Front. Vet. Sci.* 12, 1566427. doi: 10.3389/fvets.2025.1566427.
- Li, Y., Noro, S.M., Putri, R., Nugroho, W.S., Chaters, G., Larkins, A., Smith, D., Kusumaningtyas, E., Endrawati, D., Hewajuli, D.A., Nuradji, H., Dharmayanti, N.L.P.I., Mayberry, D., 2026. Understanding the value and causes of mortality and production losses for beef cattle in East Java, Indonesia. *Prev. Vet. Med.* 254, 106906. doi: 10.1016/j.prevetmed.2026.106906.
- Lismawan, G.N., Septiani, D., Ramadhani, B.C., Ramadhani, A.S., 2026. Comparison of the Immunomodulatory Activity of Red Ginger (*Zingiber officinale* var. *rubrum*) Extract and Turmeric (*Curcuma longa* L.) on Immune Responses in Experimental Animals: A Literature Review. *J. Pharm. Sci.* 9, 575–587. doi: 10.36490/journal-jps.com.v9i1.1194.
- Liu, M., Panda, S.K., Luyten, W., 2020. Plant-Based Natural Products for the Discovery and Development of Novel Anthelmintics against Nematodes. *Biomolecules* 10, 426. doi: 10.3390/biom10030426.
- Lundström, C., Lindblom, J., 2018. Considering farmers' situated knowledge of using agricultural decision support systems (AgriDSS) to Foster farming practices: The case of CropSAT. *Agric. Syst.* 159, 9–20. doi: 10.1016/j.agry.2017.10.004.
- Makarabbi, G., Sabu, A., Saxena, N., Sharma, M.L., 2025. An analysis of knowledge, attitude and practice gaps in scientific buffalo husbandry. *PLoS One* 20, e0327208. doi: 10.1371/journal.pone.0327208.
- Manglani, N., Bhatt, D., Singh, S., John, P.J., Soni, I., 2021. Estimation of Median Lethal Dose of Fenpropatrin in Wistar Rat. *J. Ecophysiol. Occup. Health* 21, 16–22. doi: 10.18311/jeo/2021/26345.
- Manyi-Loh, C., Mamphweli, S., Meyer, E., Okoh, A., 2018. Antibiotic Use in Agriculture and Its Consequential Resistance in Environmental Sources: Potential Public Health Implications. *Molecules* 23, 795. doi: 10.3390/molecules23040795.
- Mapiye, O., Dzama, K., 2024. Strengthening research-extension-farmer-input linkage system for sustainable smallholder livestock farming in Africa: progress and prospects. *Trop. Anim. Health Prod.* 56, 363. doi: 10.1007/s11250-024-04210-9.
- Masika, P.J., van Averbek, W., Sonandi, A., 2000. Use of herbal remedies by small-scale farmers to treat livestock diseases in Central Eastern Cape Province, South Africa. *J. S. Afr. Vet. Assoc.* 71, 87–91. doi: 10.4102/jsava.v71i2.685.
- Moda, L., Nontu, Y., 2026. Assessing the determinants and impact of financial record-keeping among smallholder vegetable farmers in the Eastern Cape Province: an empirical study. *Front. Sustain. Food Syst.* 10, 1644827. doi: 10.3389/fsufs.2026.1644827.
- Mehmedi, B., Muharremi, S., Youngs, C.R., Haziri, I., Sinani, A., Aliu, H., Hodolli, G., Heta, S., Cana, A., Saegerman, C., 2026. Assessment of Biosecurity Practices on Small Ruminant Farms in Kosovo After an Outbreak of Peste des Petits Ruminants: A Pilot Study. *Animals* 16, 1905. doi: 10.3390/ani16121905.
- Mikkola, M., Desmet, K.L.J., Kommisrud, E., Riegler, M.A., 2024. Recent advancements to increase success in assisted reproductive technologies in cattle. *Anim. Reprod.* 21, e20240031. doi: 10.1590/1984-3143-AR2024-0031.
- Moliso, M.M., Molla, W., Arke, A., Nana, T., Zewudie, F.A., Tibebe, A., Haile, A., Rekek, M., Magnusson, U., Wieland, B., Knight-Jones, T., 2024. The impact of the herd health interventions in small ruminants in low input production systems in Ethiopia. *Front. Vet. Sci.* 11, 1371571. doi: 10.3389/fvets.2024.1371571.
- Montalván, S., Arcos, P., Sarzosa, P., Rocha, R.A., Yoo, S.G., Kim, Y., 2024. Technologies and Solutions for Cattle Tracking: A Review of the State of the Art. *Sensors (Basel)* 24, 6486. doi: 10.3390/s24196486.
- Morgan-Davies, C., Tesnière, G., Gautier, J.M., Jørgensen, G.H.M., González-García, E., Patsios, S.I., Sossidou, E.N., Keady, T.W.J., McClean, B., Kenyon, F., Caja, G., Grøva, L., Decandia, M., Ciszter, L., Halachmi, I., Dwyer, C.M., 2024. Review: Exploring the use of precision livestock farming for small ruminant welfare management. *Animal* 18, 101233. doi: 10.1016/j.animal.2024.101233.
- Mpolokeng, T.G., Shikwambana, N., Chakale, M.V., Asong, J.A., McGaw, L.J., Amoo, S.O., Masondo, N.A., Aremu, A.O., 2026. Alternative Approaches and Plant-Based Remedies for Livestock Health Management Among the Batswana of Southern Africa: A Review. *Chem. Biodivers.* 23, e03248. doi: 10.1002/cbdv.202503248.
- Mulholland, T., McAllister, M., Patek, S., Flint, D., Underwood, M., Sim, A., Edwards, J., Zagnoni, M., 2018. Drug screening of biopsy-derived spheroids using a self-generated microfluidic concentration gradient. *Sci. Rep.* 8, 14672. doi: 10.1038/s41598-018-33055-0.
- Munaf, S., Swingler, K., Brulisaue, F., O'Hare, A., Gunn, G., Reeves, A., 2023. Social media network analysis of Smallholder livestock farming communities in the United Kingdom. *Heliyon* 10, e23265. doi: 10.1016/j.heliyon.2023.e23265.
- Murdiati, T.B., McSweeney, C.S., Campbell, R.S., Stoltz, D.S., 1990. Prevention of hydrolysable tannin toxicity in goats fed *Clidemia hirta* by calcium hydroxide supplementation. *J. Appl. Toxicol.* 10, 325–331. doi: 10.1002/jat.2550100504.
- Nair, A.B., Jacob, S., 2016. A simple practice guide for dose conversion between animals and human. *J. Basic Clin. Pharm.* 7, 27–31. doi: 10.4103/0976-0105.177703.
- Ngoshe, Y.B., Etter, E., Gomez-Vazquez, J.P., Thompson, P.N., 2022. Knowledge, Attitudes, and Practices of Communal Livestock Farmers regarding Animal Health and Zoonoses in Far Northern KwaZulu-Natal, South Africa. *Int. J. Environ. Res. Public Health* 20, 511. doi: 10.3390/ijerph20010511.
- Nuvey, F.S., Mensah, G.I., Zinsstag, J., Hattendorf, J., Fink, G., Bonhof, B., Addo, K.K., 2023. Management of diseases in a ruminant livestock production system: a participatory appraisal of the performance of veterinary services delivery, and utilization in Ghana. *BMC Vet. Res.* 19, 237. doi: 10.1186/s12917-023-03793-z.
- Nwafor, I.C., Nwafor, C.U., 2022. African smallholder farmers and the treatment of livestock diseases using ethnoveterinary medicine: A commentary. *Pastoralism* 12, 29. doi: 10.1186/s13570-022-00244-6.
- Obiorah, C.A., Nduubuisi, O.G., Ali, S.E., Aku, U.T., Nesiama, O., Agbakhamen, C.O., 2025. Advanced Livestock Management: Integrating Technology and Best Practices for Enhanced Performance. *Int. J. Innovative Food Nut. Sust. Agric.* 13, 61–68.
- Odhaib, K.J., Al-Hajjar, Q.N., Alallawee, M.H.A., 2021. Incorporation of Herbal Plants in the Diet of Ruminants: Effect on Meat Quality. *Iraqi J. Vet. Med.* 45, 22–30. doi: 10.30539/ijvm.v45i1.1036.
- Odoemelam, V.U., Etuk, I.F., Ndelekute, E.K., 2013. Herbs and Spices: Options for Sustainable Animal Production. *J. Biol. Agric. Healthcare* 3, 116–123.
- Ohashi, T., Saijo, M., Suzuki, K., Arafuka, S., 2024. From conservatism to innovation: The sequential and iterative process of smart livestock technology adoption in Japanese small-farm systems. *Technol. Forecast. Soc. Change* 208, 123692. doi: 10.1016/j.techfore.2024.123692.
- Oli, D., Gyawali, B., Acharya, S., Oshikoya, S., 2025. Factors influencing learning attitude of farmers regarding adoption of farming technologies in farms of Kentucky, USA. *Smart Agric. Technol.* 10, 100801. doi: 10.1016/j.satech.2025.100801.
- Onuoha, E.U., Ani, A.O., Anaeto, F.C., Umunakwe, P.C., Okereke-Ejiogu, E.N., 2021. Determinants of Use of Medicinal Plants for the Treatment of Small Ruminants' Diseases in Imo State, Nigeria. *Int. J. Appl. Sci. Res.* 4, 47–55.
- Oral, H.H., Yıldız, F., 2025. Structural Characteristics of Small Ruminant Production in Mus, Türkiye: A Model for Organic Livestock on the Basis of Sustainability. *Sustainability* 17, 3019. doi: 10.3390/su1703019.
- Orimaye, O.E., Ekunseitan, D.A., Omaliko, P.C., Fasina, Y.O., 2024. Mitigation Potential of Herbal Extracts and Constituent Bioactive Compounds on Salmonella in Meat-Type Poultry. *Animals (Basel)* 14, 1087. doi: 10.3390/ani14071087.
- Pandey, P.R., Lamichhane, R., Lamichhane, G., Lee, K.H., Jung, H.J., 2024. Toxicological Evaluation of a Polyherbal Formulation (18KHT01) and Validation of UPLC-DAD Method for Quality Control. *Biomed. Res. Int.* 2024, 1767618. doi: 10.1155/2024/1767618.
- Parham, S., Kharazi, A.Z., Bakhsheshi-Rad, H.R., Nur, H., Ismail, A.F., Sharif, S., RamaKrishna, S., Berto, F., 2020. Antioxidant, Antimicrobial and Antiviral Properties of Herbal Materials. *Antioxidants (Basel)* 9, 1309. doi: 10.3390/antiox9121309.
- Parraguez, V.H., Sales, F., Peralta, O.A., De los Reyes, M., Campos, A., González, J., Peralta, W., Cabezón, C., González-Bulnes, A., 2021. Maternal Supplementation with Herbal Antioxidants during Pregnancy in Swine. *Antioxidants* 10, 658. doi: 10.3390/antiox10050658.
- Perkins, L.S., Barnes, K.D., Cristobal, O., Dimonaco, N.J., Godoy-Santos, F., Kyriazakis, I., Lawther, K., Lively, F.O., Morrison, S.J., Nugent, A.P., Scollan, N.D., Theodoridou, K., Woodside, J.V., Yan, T., Huws, S.A., 2026. Challenges and innovations for sustainable ruminant production based upon One Health principles. *Proc. Nutr. Soc.* 85, 185–197. doi: 10.1017/S0029665125100633.
- Plyduang, T., Monton, C., Suksaeree, J., 2026. Sustainable green extraction approaches for herbal phytochemicals supporting environmentally friendly and climate responsive product development. *Sustain. Chem. Clim. Action* 8, 100184. doi: 10.1016/j.scca.2026.100184.
- Pokhrel, L.R., Grady, K.D., 2021. Risk assessment of occupational exposure to anesthesia Isoflurane in the hospital and veterinary settings. *Sci. Total Environ.* 783, 146894. doi: 10.1016/j.scitotenv.2021.146894.
- Prajapati, C.S., Priya, N.K., Bishnoi, S., Vishwakarma, S.K., Buaneswari, K., Shastri, S., Tripathi, S., Jadhav, A., 2025. The Role of Participatory Approaches in Modern Agricultural Extension: Bridging Knowledge Gaps for Sustainable Farming Practices. *J. Exp. Agric. Int.* 47, 204–222. doi: 10.9734/jeai/2025/v47i23281.
- Priyashantha, H., Jayathissa, I.S., Vidanaratchchi, J.K., Jayarathna, S., Mapiye, C., Maggolino, A., Ponnampalam, E.N., 2026. Phytochemicals in Ruminant Diets: Mechanistic Insights, Product Quality Enhancement, and Pathways to Sustainable Milk and Meat Production-Invited Review. *Animals (Basel)* 16, 425. doi: 10.3390/ani16030425.
- Puig, A., Ruiz, M., Bassols, M., Fraile, L., Amengol, R., 2022. Technological Tools for the Early Detection of Bovine Respiratory Disease in Farms. *Animals (Basel)* 12, 2623. doi: 10.3390/ani12192623.
- Rahman, I.U., Ijaz, F., Bussmann, R.W., 2023. Editorial: Ethnoveterinary practices in livestock: Animal production, healthcare, and livelihood development. *Front. Vet. Sci.* 9, 1086311. doi: 10.3389/fvets.2022.1086311.
- Rahman, M.A., Reddy, M.R.A., Shuvo, A.A.S., Chowdhury, R., Hossain, E., Sayem, S.M., Rashid, M.H., Al-Mamun, M., 2024. Influence of herbal supplementation on nutrient digestibility, blood biomarkers, milk yield, and quality in tropical crossbred cows. *PLoS One* 19, e0313419. doi: 10.1371/journal.pone.0313419.
- Raimi, C.O., Bamigboye, F.O., Mukaila, A.O., 2026. Evaluation of Farm Record Keeping, Benefits and Challenges of Small Ruminant Production in Gbonyin Ekiti Local Government Area. *J. Agric. Technol.* 2, 1–20.
- Ranasinghe, S., Armson, A., Lymbery, A.J., Zahedi, A., Ash, A., 2023. Medicinal plants as a source of antiparasitics: an overview of experimental studies. *Pathog. Glob. Health* 117, 535–553. doi: 10.1080/20477724.2023.2179454.
- Rauw, W.M., Baumgard, L.H., Dekkers, J.C.M., 2025. Review: Feed efficiency and metabolic flexibility in livestock. *Animal* 19, 101376. doi: 10.1016/j.animal.2024.101376.
- Rebez, E.B., Devaraj, C., Ninan, J., Silpa, M.V., Perumal, S.V., Sahoo, A., Dunshea, F.R., Sejian, V., 2025. Effects of Herbal Supplementation on Growth Performance of Kenguri Sheep Exposed to Heat Stress. *Animals (Basel)* 15, 1285. doi: 10.3390/ani15091285.
- Resti, Y., Reynoso, G.G., Probst, L., Indriarsi, S., Mindara, G.P., Hakim, A., Wurzing, M., 2024. A review of on-farm recording tools for smallholder dairy farming in developing countries. *Trop. Anim. Health Prod.* 56, 168. doi: 10.1007/s11250-024-04024-9.
- Rizvi, S.A.A., Einstein, G.P., Tulp, O.L., Sainvil, F., Branly, R., 2022. Introduction to Traditional Medicine and Their Role in Prevention and Treatment of Emerging and Re-Emerging Diseases. *Biomolecules* 12, 1442. doi: 10.3390/biom12101442.
- Romero-Zúñiga, J.J., Galina, C.S., Geffroy, M., Corro, M.D., Maquiver, M., 2026. Productive and Reproductive Record Keeping in Low-to-Middle-Income Tropical Livestock Systems: Challenges and Perspectives. *Animals* 16, 1691. doi: 10.3390/ani16111691.
- Roy, A., Khan, A., Ahmad, I., Alghamdi, S., Rajab, B.S., Babalghith, A.O., Alshahrani, M.Y., Islam, S., Islam, M.R., 2022. Flavonoids a Bioactive Compound from Medicinal Plants and Its Therapeutic Applications. *Biomed. Res. Int.* 2022, 5445291. doi: 10.1155/2022/5445291.
- Sachan, A.K., Vishnoi, G., Kumar, R., 2016. Need of standardization of herbal medicines in Modern era. *Int. J. Phytomed.* 8, 300–307. doi: 10.5138/09750185.1847.
- Sargison, N., 2020. The critical importance of planned small ruminant livestock health and production in addressing global challenges surrounding food production and poverty alleviation. *N. Z. Vet. J.* 68, 136–144. doi: 10.1080/00480169.2020.1719373.
- Sarma, P.K., Sarowar, S., Rabbani, G., Golap, A.K.M.M.R., 2025. Understanding farmer's knowledge, attitudes, and practices towards adopting livestock interventions for food and nutrition security in Bangladesh using latent class analysis. *Sci. Rep.* 15, 32308. doi: 10.1038/s41598-023265.

- 025-96283-1.
- Schmid, K., Ivemeyer, S., Vogl, C., Klarer, F., Meier, B., Hamburger, M., Walkenhorst, M., 2012. Traditional use of herbal remedies in livestock by farmers in 3 Swiss cantons (Aargau, Zurich, Schaffhausen). *Forsch. Komplementmed.* 19, 125–136. doi: 10.1159/000339336.
- Sejian, V., Devaraj, C., Shashank, C.G., Silpa, M.V., Sahoo, A., Bhatta, R., 2025. The Role of Prebiotic and Herbal Supplementation in Enhancing Welfare and Resilience of Kenguri Sheep Subjected to Transportation Stress. *Vet. Sci.* 12, 442. doi: 10.3390/vetsci12050442.
- Sennuga, S.O., Ujoyi, S.A., Bamidele, J., Onjewu, S.S., Lai-Solarin, W.I., Omole, A.A., 2023. Exploring the Role of Smartphone Apps for Livestock Farmers Data Management Extension and Informed Decision Making in Nigeria. *Int. J. Probiotics Diet.* 3, 46–53.
- Shahab, H., Iqbal, M., Sohaib, A., ur Rehman, A., Bermak, A., Munir, K., 2024. Design and implementation of an IoT-based monitoring system for early detection of lumpy skin disease in cattle. *Smart Agric. Technol.* 9, 100609. doi: 10.1016/j.atech.2024.100609.
- Shai, K., Lebelo, S.L., Ng'ambi, J.W., Mabelebele, M., Sebola, N.A., 2022. A review of the possibilities of utilising medicinal plants in improving the reproductive performance of male ruminants. *All Life* 15, 1208–1221. doi: 10.1080/26895293.2022.2147225.
- Sheikh, S.A., Rai, S., Kirmani, S., Chhabra, K., 2025. Disease management in livestock. *Indian Farmer* 12, 596–603.
- Solazzo, D., Moretti, M.V., Tchamba, J.J., Rafael, M.F.F., Tonini, M., Fico, G., Basterrechea, T., Levi, S., Marini, L., Bruschi, P., 2024. Preserving Ethnoveterinary Medicine (EVM) along the Transhumance Routes in Southwestern Angola: Synergies between International Cooperation and Academic Research. *Plants (Basel)* 13, 670. doi: 10.3390/plants13050670.
- Song, J., Sun, H., Li, Z., Yan, G., Kong, L., Liu, L., Wang, X., 2026. Angelica sinensis as a Multi-Targeted Natural Product Candidate: Constituent-Specific Mechanisms, Exposure Constraints, and Translational Development Challenges. *Pharmaceuticals* 19, 1073. doi: 10.3390/ph19071073.
- Stygar, A., Niemi, J.K., Norton, T., Kayhan, H., Marcus, A.M.C., Allain, C., Lebreton, A., Anestis, V., Bartzanas, T., Vouraki, S., Arsenos, G., Pastell, M., 2026. "Please, mind the gap": A narrative review on digitalization gaps and barriers in the livestock sector. *Comput. Electron. Agric.* 251, 112013. doi: 10.1016/j.compag.2026.112013.
- Swaminathan, M., Aldayood, K., Tibbo, M., Ghosh, K., Shaikhi, A., Haddad, N., 2026. Transforming Small Ruminant Productivity Through a Farm Service Delivery Model: Evidence from a Pilot Study in Saudi Arabia. *Animals* 16, 1094. doi: 10.3390/ani16071094.
- Sylvester, K.M., Brown, D.G., Leonard, S.H., Merchant, E., Hutchins, M., 2015. Exploring agent-level calculations of risk and returns in relation to observed land-use changes in the US Great Plains, 1870–1940. *Reg. Environ. Change* 15, 301–315. doi: 10.1007/s10113-014-0628-6.
- Tamsan, H., Yusriadi, Y., 2022. Quality of agricultural extension on productivity of farmers: Human capital perspective. *Uncertain Supply Chain Manag.* 10, 625–663. doi: 10.5267/j.uscm.2021.11.003.
- Tani, S.A.A., Candra, A., Makmur, M., 2025. Evaluating the Impact of Indonesian Herbal Mixture on Recovery and Performance of Bali Cattle After Long-Distance Transportation. *Am. J. Anim. Vet. Sci.* 20, 145–152. doi: 10.3844/ajavsp.2025.145.152.
- Tedeschi, L.O., Guarnido-Lopez, P., Menendez, H.M., Seo, S., 2026. Invited Review - Advancing precision livestock farming: integrating artificial intelligence and emerging technologies for sustainable livestock management. *Anim. Biosci.* 39, 250289. doi: 10.5713/ab.25.0289.
- Tham-Agyekum, E.K., Appiah, P., Nimoh, F., 2010. Assessing Farm Record Keeping Behaviour among Small-Scale Poultry Farmers in the Ga East Municipality. *J. Agric. Sci.* 2, 52–62. doi: 10.5539/jas.v2n4p52.
- Thar, S.P., Ramilan, T., Farquharson, R.J., Pang, A., Chen, D., 2021. An empirical analysis of the use of agricultural mobile applications among smallholder farmers in Myanmar. *Electron. J. Inf. Syst. Dev. Ctries.* 87, e12159. doi: 10.1002/isd2.12159.
- van Wyk, A.S., Prinsloo, G., 2020. Health, safety and quality concerns of plant-based traditional medicines and herbal remedies. *S. Afr. J. Bot.* 133, 54–62. doi: 10.1016/j.sajb.2020.06.031.
- Vaou, N., Stavropoulou, E., Voidarou, C.C., Tsakris, Z., Rozos, G., Tsigalou, C., Bezirtzoglou, E., 2022. Interactions between Medical Plant-Derived Bioactive Compounds: Focus on Antimicrobial Combination Effects. *Antibiotics (Basel)* 11, 1014. doi: 10.3390/antibiotics11081014.
- Vlaicu, P.A., Gras, M.A., Untea, A.E., Lefter, N.A., Rotar, M.C., 2024. Advancing Livestock Technology: Intelligent Systemization for Enhanced Productivity, Welfare, and Sustainability. *AgriEngineering* 6, 1479–1496. doi: 10.3390/agriengineering6020084.
- Wang, H., Chen, Y., Wang, L., Liu, Q., Yang, S., Wang, C., 2023. Advancing herbal medicine: enhancing product quality and safety through robust quality control practices. *Front. Pharmacol.* 14, 1265178. doi: 10.3389/fphar.2023.1265178.
- Wendimu, A., Bojago, E., Abraham, Y., 2024. Medicinal ethnoveterinary plants used for treating livestock ailments in the omo-gibe and rift valley basins of Ethiopia. *BMC Vet. Res.* 20, 166. doi: 10.1186/s12917-024-04019-6.
- Werner, N., McEwen, S., Kreienbrock, L., 2018. Monitoring Antimicrobial Drug Usage in Animals: Methods and Applications. *Microbiol. Spectr.* 6, 10.1128/microbiolspec.arba-0015-2017. doi: 10.1128/microbiolspec.arba-0015-2017.
- Wójtowski, J.A., Pikul, J., Mikołajczak, P., Czopowicz, M., Kaba, J., Foksowicz-Flaczyk, J., Antkowiak, I., Pytlewski, J., Markiewicz-Kęszycka, M., Stanisławski, D., 2025. Effect of herbal feed additives on milk performance and health status of dairy goats. *J. Vet. Res.* 69, 263–272. doi: 10.2478/jvetres-2025-0021.
- Wulandari, E., Karyani, T., Ernah, Alamsyah, R.T.P., 2023. What Makes Farmers Record Farm Financial Transactions? Empirical Evidence from Potato Farmers in Indonesia. *Int. J. Financ. Stud.* 11, 19. doi: 10.3390/ijfs11010019.
- Wyngaarden, S.L., Lightburn, K.K., Martin, R.C., 2020. Optimizing livestock feed provision to improve the efficiency of the agri-food system. *Agroecol. Sustain. Food Syst.* 44, 188–214. doi: 10.1080/21683565.2019.1633455.
- Xue, B., Thompson, J.P., Yan, T., Stergiadis, S., Smith, L., Theodoridou, K., 2025. Dose-response effects of dietary inclusion of agro-industrial by-products on in vitro ruminal fermentation and methane production. *J. Sci. Food Agric.* 105, 5447–5457. doi: 10.1002/jsfa.14263.
- Yanuartono, Y., Nururrozi, A., Indarjulianto, S., Paryuni, A.D., Datrianto, D.S., Rosyadi, I., Purnamaningsih, H., 2026. Growth performance and physiometabolic safety of probiotic–Curcuma herbal supplementation in local female lambs of Indonesia. *Vet. World* 19, 964–977. doi: 10.14202/vetworld.2026.964-977.
- Zheng, S., Li, Y., Chen, C., Wang, N., Yang, F., 2025. Solutions to the Dilemma of Antibiotics Use in Livestock and Poultry Farming: Regulation Policy and Alternatives. *Toxics* 13, 348. doi: 10.3390/toxics13050348.