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Use of soybean meal-based moxifloxacin pellets in equine nutrition and health

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Pellets formulated from organic biomass, such as soybean meal, are increasingly used in animal nutrition and controlled drug delivery systems. This review aims to explore the advancements and challenges in developing and evaluating soybean meal-based moxifloxacin pellets specifically for equine applications. The focus includes production techniques, the role of soybean meal in equine diets, and the therapeutic potential of moxifloxacin. Soybean meal, known for its high protein and lysine content, is a valuable feed component for equines and offers advantages in pellet formulation. Moxifloxacin, a broad-spectrum antibiotic, has shown effectiveness in treating a range of bacterial infections in horses, with the added benefit of controlled release when delivered in pellet form. This combination presents a novel strategy for improving both nutrition and targeted medication in equines. However, further research is required to assess its safety and therapeutic efficacy.

KEYWORDS

moxifloxacin pellets, soybean meal, equine, bacterial infection, antibiotics

1 Introduction

In the field of nutrition and veterinary medicine, the combination of technology and biotechnology has led to promising innovations. Among them, compacted biomass pellets emerge as an efficient and sustainable solution, with applications ranging from animal feed to drug delivery. Pellets, which are small cylinders of organic biomass, not only provide an economical and environmentally friendly way to feed animals of various species, but also facilitate the development of controlled-release formulations for drugs (Ghebre, 2022).

Dehydration of forage for pelleting offers additional benefits by allowing higher dry matter concentration and minimizing loss through microbial decomposition. Agricultural residues, such as soybean meal, have established themselves as a valuable protein source, especially in pig and poultry feed, due to their high protein content and their ability to be processed to eliminate potential toxic factors (Barrientos, 2010; Inyang et al., 2019). Soybean meal stands out not only for its nutritional value, but also for its absorptive properties, which make it suitable for applications in the removal of heavy metals and chemicals (Daneshvar et al., 2002). In the equine context, soybean meal is particularly useful due to its lysine content, an essential amino acid for tissue growth and repair (Daneshvar et al., 2002; Bockisch et al., 2023).

In parallel, moxifloxacin, a potent antibiotic of the fluoroquinolone class, has been shown to be effective against a wide range of bacterial infections, including those affecting equines. Its advanced chemical structure gives it a broad spectrum of action and high efficacy in inhibiting bacterial replication (Gardner et al., 2004). However, the administration of moxifloxacin in equines presents challenges related to drug stability, controlled release and precise dosing (OMS, 2020).

The integration of moxifloxacin into soybean meal-based pellets represents an innovative strategy to improve drug delivery in equines, ensuring controlled and effective release of the antibiotic. However, this approach requires careful evaluation of its stability, acceptability by animals and compliance with safety regulations to avoid adverse effects and the development of bacterial resistance (Humma and Patel, 2024).

The combination of soybean meal pellets with moxifloxacin offers an opportunity to optimize treatment administration in equines, improving efficiency and sustainability in veterinary practice. Continued research in this field is essential to overcome the challenges and maximize the benefits of this innovative solution. Therefore, this review discusses the development and evaluation of soybean meal-based moxifloxacin pellets for equine applications, focusing on production techniques, the role of soybean meal in equine diets, the therapeutic potential of moxifloxacin, and the advantages of its controlled release in pellet form. By integrating nutrition and drug delivery, this approach presents a novel strategy for improving both equine health and treatment efficiency. However, further research is needed to ensure its safety, efficacy, and regulatory compliance.

2 Pellets

Pellets are tiny cylinders of compacted biomass, usually made from organic materials, and are used as animal feed. This product is both ecological, sustainable and economical, and offers a wide range of applications (Ghebre, 2022). Pellets are produced by extrusion-spheronization, with subsequent coating. This method offers significant advantages for the development of enteric formulations and the controlled release of active ingredients, making it suitable for both monogastric and ruminant animals (Medrano, 2005).

Forage dehydration for pelletization optimizes preservation by increasing dry matter content and reducing the proliferation of degradative microorganisms by limiting water availability. This process enhances stability, preserves nutritional value, and facilitates storage and processing in pellet form (Barrientos, 2010). Agricultural waste or excluded biomass is used as various bioabsorbents in the elimination of heavy metals and chemicals present in wastewater, such as soybean meal (Magesh et al., 2020).

2.1 Use of pellets in equines

Through pelleting, it has been possible to mold a mixture of ingredients, which once compacted in a cylindrical or spherical form are called pellets (Loor, 2016). The use of pellets has become a key element in the commercial manufacture of equine feed since their granular form simplifies their handling (Muhammad, 2024). In addition, they can be produced using agricultural by-products, which represents an option for their use (López, 2017). Among the advantages of using pellets in equines are that they help improve the digestibility of nutrients, reduce energy during feed consumption, prevent nutrient selection, reduce waste in feeders and improve economic reward and productive parameters (Loor, 2016). Soto and Rojas (2016) evaluated the potential replacement of balanced feed with *Stylosanthes multilinea* pellets in equines, using incremental inclusion levels of 0, 15, 30, and 45%. The results indicated that replacing up to 45% of the balanced feed with pellets did not produce significant effects on apparent digestibility, dry matter content, or crude protein concentration of the total ration. In a study conducted by Christ et al. (2020), the use of wood pellets as bedding material in individual horse stalls was evaluated and compared to wheat straw. The results indicated that, from an economic perspective, the use of wood pellets reduces costs. Additionally, it was observed that horses housed on this type of bedding spent less time searching for food. Pellets used in equine nutrition are highly palatable, which is one of their key advantages. Ryon et al. (2023) evaluated the palatability of pellets formulated with *Cannabis sativa*, soybean meal, beet pulp, and rice bran. Their findings indicated that all formulations were well accepted by horses, with those containing *Cannabis sativa* exhibiting the highest palatability compared to the other formulations. Symoens et al. (2024) recently compared the effectiveness of steamed hay and alfalfa pellets in enhancing pulmonary function and reducing inflammation in horses with severe asthma. Their findings showed that alfalfa pellets reduced the weighted clinical scores from 13 to 2, whereas steamed hay just lowered the scores from 10 to 6.

3 Soybean meal

Soybean meal is currently considered the protein source of choice for feeding growing and finishing pigs and poultry due to its high protein content (37.5%), high digestibility (82%), good balance of amino acids, consistent quality, and low costs compared to other protein sources. Soybean meal is a by-product of soybean oil extraction, produced through a combination of pressure and solvent extraction, followed by thermal treatment of the seeds (Ovuchimeru, 2020) Raw soybean seeds contain various antinutritional factors, including trypsin inhibitors, hemagglutinins, saponins, and a vitamin A inhibitory factor. However, these compounds are temperature-sensitive and can be effectively eliminated through proper processing (Inyang et al., 2019).

3.1 Absorptive properties

Soybean flour exhibits absorbent properties due to its chemical composition, which includes a variety of functional groups and components that facilitate the adsorption of various substances. Among its main absorbent properties, it stands out for its ability to adsorb liquids, particularly water, due to the presence of polysaccharides such as cellulose and hemicellulose, which form bonds with water molecules, thus enabling moisture absorption. Within this liquid adsorption property, its ability to absorb oils and fats is also notable, owing to its high concentration of proteins and fiber (Huang et al., 2024).

Additionally, soybean flour exhibits absorption properties mediated by functional groups such as amino (-NH2) and carboxyl (-COOH), which can interact with various substances through electrostatic interactions. These characteristics give soybean flour the ability to: (i) absorb and retain essential nutrients, such as amino acids, proteins, and minerals, along the digestive tract, and (ii) absorb toxic compounds or contaminants, such as certain heavy metals, through an ion-exchange mechanism (Daneshvar et al., 2002). These properties make soybean flour a promising material for antibiotic adsorption, particularly due to its low cost and widespread use in animal feed.

3.2 Soybean meal in equine feed

The equine is a monogastric herbivore with a relatively small stomach, however, it has a well-developed and functional cecum and colon. Its digestive process is fundamentally enzymatic from the mouth to the terminal part of the ileum and to a lesser degree in the cecum and colon where the fermentation of crude fiber and other nutrients takes place with 70% of the efficiency of ruminants (Arrieta et al., 2007). They have developed their cecum where a large number of microorganisms are housed, which break down the cellulose that cannot be digested in the upper digestive tract. Volatile fatty acids are produced in the cecum and absorbed as a source of energy (Martínez Marín, 2008).

Soybean meal is one of the primary protein sources due to its high lysine content. This essential amino acid plays a crucial role in foal growth, as horses cannot synthesize it on their own. Lysine is vital for tissue generation and repair, making it particularly important for growing foals, which require more protein than mature horses (Bockisch et al., 2023). When horses lack access to pasture and their diet primarily consists of cereals, lysine deficiency becomes more pronounced, reducing the overall quality of the ingested protein (Hoyos et al., 2022).

4 Moxifloxacin

Moxifloxacin, a potent fluoroquinolone antibiotic developed by Bayer AG and approved by the FDA in 1999, is effective against a variety of bacterial infections, especially respiratory infections, and is a valuable addition to the antibiotic armamentarium because of its broad spectrum of action (Meena et al., 2019). Moxifloxacin is highly effective against a variety of bacterial infections. It is approved by the FDA to treat community-acquired pneumonia caused by susceptible strains of *Streptococcus pneumoniae* and *Mycoplasma pneumoniae*, acute bacterial sinusitis, bacterial exacerbations of chronic bronchitis, and complicated skin and cutaneous tissue infections (Humma and Patel, 2024) (Figure 1).

4.1 Pharmacology and mechanisms of action of moxifloxacin

Clinically used quinolones have a two-ring structure, with nitrogen at the 1-position, a carbonyl group at the 4-position and a carboxyl group at the 3-position (Millanao et al., 2021). The potency and spectrum are significantly increased when a fluorine atom is attached at the 6-position, possibly because of improved tissue penetration and binding to bacterial topoisomerases (Alós, 2009), see Figure 2. Antibiotics of the fluoroquinolone class show excellent activity against Gram-negative aerobes including Enterobacteria, *Pseudomonas aeruginosa*, *Mycoplasma* spp., *Rikettsia* spp. and *Escherichia* spp. (de Jesús, 2007). It should be noted that Gram-negative bacteria possess an outer membrane that is often a permeability barrier to an antibiotic molecule as it surrounds the peptidoglycan layer of the cell wall and as a consequence, Gram-negative bacteria generally have reduced susceptibility to antibiotics compared to Gram-positive bacteria (Kuriyama et al., 2014). Compounds that carry a double ring derived from the pyrrolidone ring in position 7 increase their activity against Gram-positive bacteria; if they carry a methoxy group in position 8, their activity against anaerobes improves, which is the case of moxifloxacin and gatifloxacin, fourth-generation fluoroquinolones (Alós, 2009).

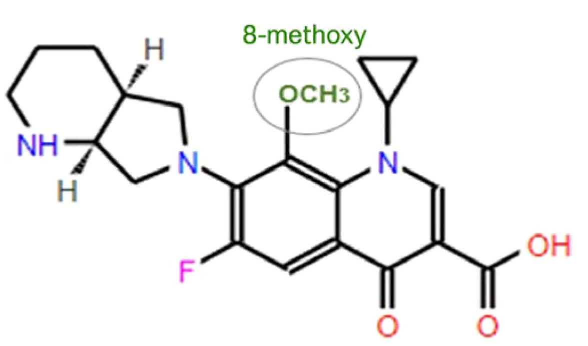

FIGURE 1
Chemical structure of moxifloxacin, synthetic antimicrobial agent, fourth generation fluoroquinolone due to its methoxy group at position 8 (Made with https://biomodel.uah.es/en/DIY/JSME/draw.es.htm).

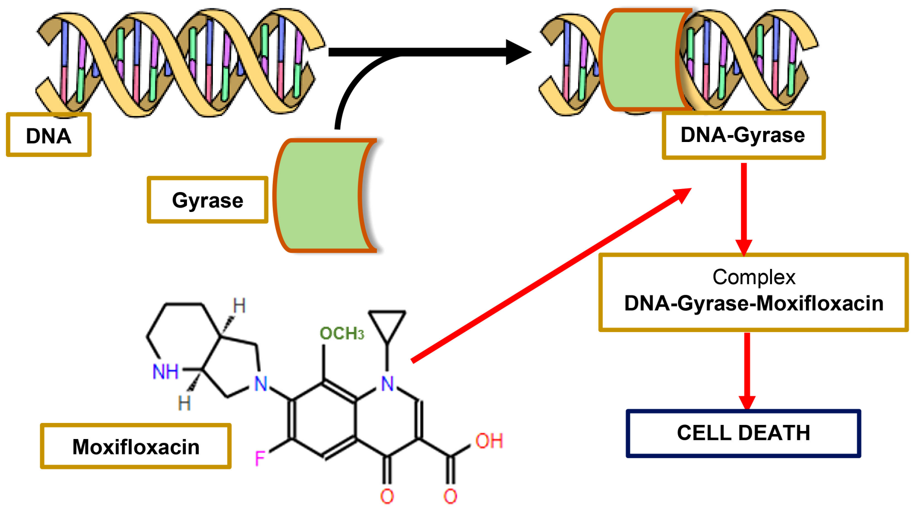

FIGURE 2
When DNA gyrase is exposed to moxifloxacin, the drug interacts on the surface of the alpha-helical domain of the enzyme forming an irreversible complex of quinolone, gyrase, and DNA, preventing the progression of the replication fork and transcription complexes, leading to cell death (Own elaboration using Microsoft Office Power Point https://biomodel.uah.es/en/DIY/JSME/draw.es.htm for the elaboration of the chemical structure of moxifloxacin and https://smart.servier.com/ for the images).

Moxifloxacin, like other quinolones, inhibits the bacterial enzymes topoisomerase II (DNA gyrase) and topoisomerase IV, which are required for the replication, transcription, repair, and recombination of DNA and RNA in bacterial cells (Carrillo et al., 2018). When DNA gyrase is exposed to a quinolone, the drug interacts with the surface of the alpha-helical domain of the enzyme, compromising DNA anchoring and repair. Toxic effects occur through the formation of an irreversible complex formed by quinolone, gyrase, and DNA. This complex prevents replication fork progression and transcription complexes, leading to chromosome fragmentation and cell death (Stroman et al., 2005; Marín, 2008) (see Figure 3).

Moxifloxacin has a slightly different chemical structure from older veterinary fluoroquinolones by the 8-methoxy substitution. As a result of this modification, this new generation of drugs has broad-spectrum antimicrobial activity against Gram-positive bacteria and anaerobes (Papich, 2020). The fourth-generation quinolones (moxifloxacin, trovafloxacin), retain activity against microorganisms especially *A. aureus* and Enterococcus, *S. pneumoniae*, *Klebsiella pneumoniae*, *Haemophilus influenzae*, *Legionella pneumophila*, *Moraxella catarrhalis* and to a lesser extent *Chlamydia pneumoniae* and *Mycoplasma* pneumoniae (Balfour and Wiseman, 1999; Constantinou et al., 2007) being at least 2 to 8 times more potent than the first-generation quinolones (ofloxacin and ciprofloxacin) in their *in vitro* activity (Rolston et al., 2006). As stated by de Jesús (2007) and Valdéz-Cruz et al. (2013), Table 1 lists the majority of bacteria responsible for common diseases in equines, highlighting the *in vitro* activity of Moxifloxacin against them.

Survival curves show that when the concentration of fluoroquinolones is close to the minimum inhibitory concentration (MIC) of the bacteria, the drug stops bacterial growth, however, when the concentration is increased in relation to the bacterial MICs, cell death increases up to a certain concentration of the drug (optimal bactericidal concentration), but an increase above this optimum can lead to a decrease in the bactericidal effect (Marín, 2008).

In respect to Table 1, it is shown that moxifloxacin presented improved activity against penicillin-sensitive and -resistant pneumococci, a comparatively high activity against Gram-positive cocci and bacilli; likewise, better activity compared to ciprofloxacin and levofloxacin, reaching inhibition of more than 70% at concentrations of 1.0 µg/mL; it had similar activity against gram-negative organisms compared to the second and third generation of fluoroquinolones; it had a rapid elimination rate of fluoroquinolone-resistant organisms. On the other hand, although MICs give information about a specific antibiotic concentration that inhibits the growth of a bacterial strain, it does not distinguish between bactericidal or bacteriostatic effects, nor does *in vitro* activity imply *in vivo* efficacy, so the mutant prevention concentration (MPC) will be 8 to 10 times higher than the MIC, where the range of concentrations between MIC and MPC is defined as the mutant selection window. The MPC is an important concept to prevent the growth of organisms that have some level of drug resistance prior to therapy (Pong et al., 1999; Schedletzky et al., 1999; Blondeau et al., 2000; Hoogkamp and Roelofs, 2000; Blondeau and Hansen, 2001; Rolston et al., 2003; Stroman et al., 2005; Kim et al., 2006; Odenholt and Cars, 2006; Rolston et al., 2006; Constantinou et al., 2007; Singh et al., 2009; Gao et al., 2019).

4.2 Adverse effects of moxifloxacin in horses

There are few studies addressing the adverse effects of moxifloxacin use in horses. In a study by Gardner et al. (2004), the efficacy of this antibiotic was evaluated against bacterial infections in horses, with an emphasis on its application in the treatment of pneumonia. The results showed that moxifloxacin has potent activity against key respiratory

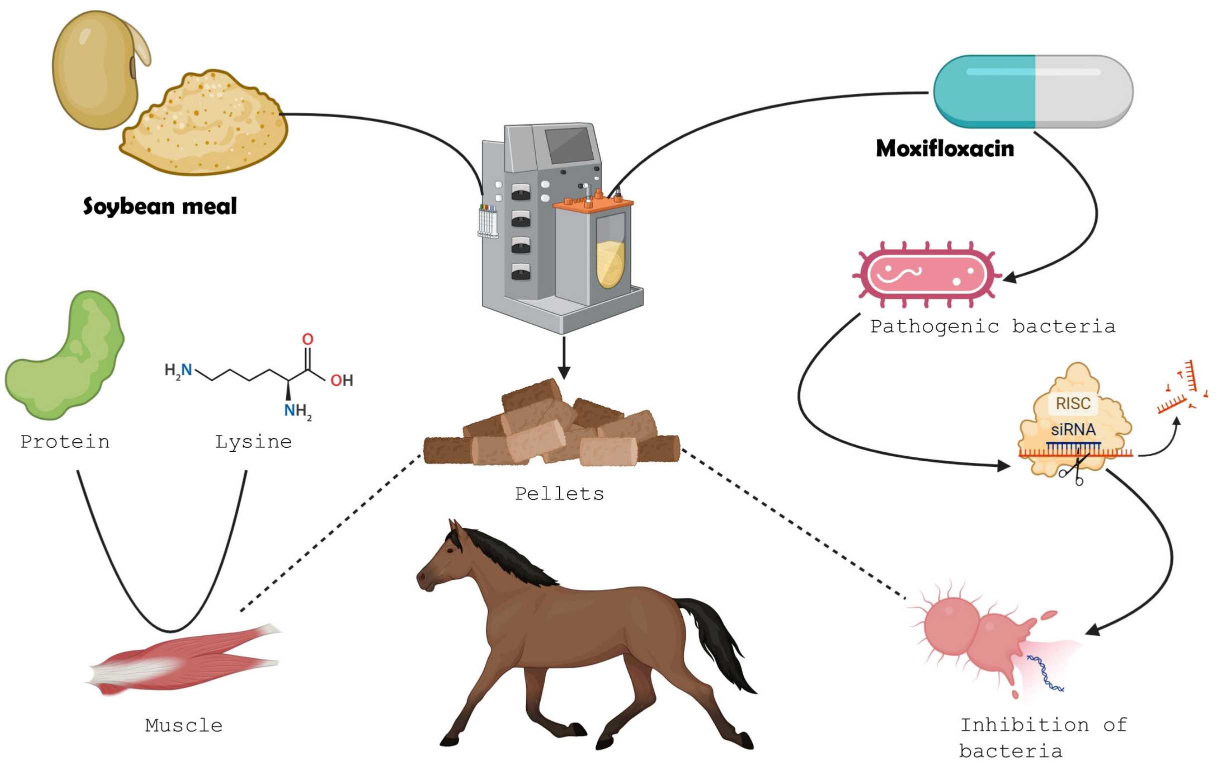

FIGURE 3
Effect of soybean meal pellet with moxifloxacin on digestive and metabolic levels in horses (Made with images from https://www.biorender.com/).

pathogens in horses. Despite its favorable characteristics, such as high systemic availability and a prolonged half-life, its use is not recommended for the treatment of equine bacterial pneumonia due to associated gastrointestinal side effects. In this study, four mares developed mild intermittent diarrhea, which began approximately 8 hours after the administration of the first dose of moxifloxacin. Additionally, one of the mares experienced a brief episode of colic 12 hours after the third dose. Toxins A and/or B from Clostridium difficile were isolated from the feces of the mare that exhibited the most severe diarrhea. These gastrointestinal side effects highlight the concerns associated with the use of moxifloxacin in the treatment of bacterial infections in horse.

In a study conducted by Sumano López et al. (2020) on adverse drug reactions in horses, it is noted that fluoroquinolones can induce joint damage in developing or immature animals. This finding suggests that these drugs should not be administered to young animals still in critical stages of bone development, such as growing horses and pregnant mares. These results highlight the importance of considering the age and developmental stage of the animal when evaluating the use of these medications to prevent significant adverse effects.

5 The importance of formulating antibiotic pellets with soybean meal

Pelletizing costs vary depending on the physical characteristics of the ingredients. If the raw material includes fibrous elements such as bagasse, bran, or ground alfalfa, the pelleting machine requires more energy to compress these materials (Muhammad, 2024). On the other hand, if denser ingredients are used, such as grains and soybean meal, the compression process consumes less energy (Loor, 2016; Muhammad, 2024). Therefore, soybean meal pellets have already been developed for use in horse diets. Table 2 details the chemical composition of these soybean meal pellets (Nahashon and Kilonzo, 2011; Pacheco et al., 2013; Pettersson and Pontoppi, 2013; López, 2017; Frempong et al., 2019; Lyu et al., 2021; Ryon et al., 2023).

In addition, pellets have been shown to improve animal nutrition by increasing nutrient and fat digestibility, reducing energy consumption during feeding, preventing ingredient selection by horses, having good acceptance, improving economic performance and optimizing production parameters (Loor, 2016; Ryon et al., 2023). *In vitro* studies of the antibacterial activity of moxifloxane have been performed on Gram-positive bacterial strains such as *Streptococcus pneumoniae*, *Staphilococcus aureus*, *Pseudomonas. aeruginosa*, *S. equi* sub spp. Zooepidemicus, Coagulase-negative *Staphylococcus* spp., *Rhodococcus equi*, *Enterococcus faecalis*, *Enterococcus faecium*; and Gram-negative strains *Serratia marcescens*, *Escherichia coli*, *Klebsiella pneumoniae*, *Pasteurella* spp., *Salmonella* spp. and *Brucella* spp. where the minimum inhibitory concentration to disable bacterial strains has been demonstrated. In addition, the FDA has approved this antibiotic for the treatment of pneumonia caused by *Streptococcus pneumoniae* and *Mycoplasma pneumoniae* (Humma and Patel, 2024). The use of moxifloxacin has been reported to inhibit the bacteria *Streptococcus equinus* (Zheng

TABLE 1 *In vitro* activity of Moxifloxacin in different strains bacterial.

Moxifloxacin Concentration (MIC)	Bacterium	Gram positive/negative	Reference
0.25–2 μg/mL	*Streptococcus pneumoniae*	Positive	(Blondeau and Hansen, 2001)
.03–8 μg/mL	*Staphilococcus aureus*	Positive	(Pong et al., 1999; Hoogkamp and Roelofs, 2000; Blondeau and Hansen, 2001; Kim et al., 2006)
0.047–32 μg/mL	*Pseudomonas aeruginosa*	Positive	(Blondeau and Hansen, 2001; Kim et al., 2006)
0.125 μg/mL	Coagulase negative Staphylococcus spp.	Positive	(Kim et al., 2006)
0.03–0.12 μg/mL	*Rhodococcus equi*	Positive	(Rolston et al., 2003)
0.03–4.0 μg/mL	*Enterococcus faecalis*	Positive	(Rolston et al., 2003)
1.0–32.0 μg/mL	*Enterococcus faecium*	Positive	(Hoogkamp and Roelofs, 2000; Rolston et al., 2003)
0.25 μg/mL	*Serratia marcescens*	Negative	(Kim et al., 2006)
0.0625 mg/L, 0.03–128 mg/L	*Escherichia coli*	Negative	(Singh et al., 2009; Christ et al., 2020)
0.03–1.0 μg/mL	*Klebsiella pneumoniae*	Negative	(Rolston et al., 2003; Gao et al., 2019)
<0.25 mg/L	*Pasteurellaspp.*	Negative	(Odenholt and Cars, 2006)
0.03–0.5 μg/mL	*Salmonellaspp.*	Negative	(Blondeau et al., 2000; Rolston et al., 2003)

et al., 2024), which causes equine adenitis, this disease is an infection whose most common symptoms include fever (between 40 and 41°C) and signs associated with fever such as loss of appetite, weakness, and muscle pain. Initially, inflammation of the regional lymph nodes, purulent nasal discharge, and severe pharyngitis are observed which can make swallowing difficult. Possible complications of this disease include sinusitis, mucopurulent infection in the guttural pouches (empyema), immune-mediated inflammation of blood vessels due to the high antigen load (hemorrhagic purpura), and abscesses in the thoracic and abdominal cavities, which are transmitted directly and indirectly through contact with mucopurulent secretions from infected horses, which represents a problem in the equine population (Blondeau and Hansen, 2001; López, 2017).

Therefore, soybean meal is a profitable and efficient option for the production of moxifloxacin pellets, which would have a dual purpose, which would be to improve animal nutrition and the administration of medication.

6 Indications and clinical uses of moxifloxacin in equines

Moxifloxacin is an advanced fluoroquinolone antibiotic (Marín, 2008) and potent activity against key respiratory pathogens of the horse (Gardner et al., 2004). Although it is a human drug, it has been used in animals for the treatment of infections refractory to other drugs, including ocular, cutaneous,

TABLE 2 Chemical composition of soybean meals.

Reported unit/ Nutrient	DM	ME	CF	CF	CP	NFE	ADF	Ash	NDF	Reference
%	–	2.23 kcal/kg	7.0	0.8	44.0	–	–	–	–	(Nahashon and Kilonzo, 2011)
%	–	3.05 kcal/kg	–	5.79	21.0	–	–	–	–	(Pacheco et al., 2013)
g/kg dry matter	–	–	–	17–21	490–540	–	–	–	–	(Pettersson and Pontoppi, 2013)
%	–	–	–	–	48.8	–	–	–	–	(López, 2017)
%	–	12.61 (MJ/kg)	–	8.34	21.24	–	–	–	–	(Frempong et al., 2019)
g/kg dry matter	884.3	–	49.9	11.9	549.7	203.4	–	6.94	–	(Lyu et al., 2021)
%	89.8	2.85 (kcal/kg)	–	2.0	52.1	–	7.7	7.4	12.0	(Ryon et al., 2023)

DM, dry matter; CF, crude fibre; CF, crude fat; CP, crude protein; NFE, nitrogen-free extract; ADF, acid detergent fiber; NDF, neutral detergent fiber; -, not determined.

and tissue infections (De Linde et al., 2014; Meena et al., 2019). The spectrum of activity includes Gram-positive cocci and anaerobic bacteria that may be resistant to other quinolones (Papich, 2020).

According to Table 3, the proposed approach proved to be effective for the treatment of indolent ulcers in horses treated with moxifloxacin, in addition to the fact that corneal ulceration or ulcerative keratitis is a frequent reason for veterinary consultation in the equine clinic, since it involves ocular pain and vision defects (Blanco et al., 2016). There are few documented and published cases of the administration of moxifloxacin in horses, but as for other common diseases in equines, they are:

Brucellosis is a highly contagious zoonotic disease that affects a wide variety of domestic and wild animal species, including mainly cattle, pigs, horses, sheep, goats, and dogs, and is present worldwide. In the equine species, the occurrence of this disease is important, because these animals are potential hosts and contribute to the introduction of the disease in unaffected areas, as well as the maintenance where it is endemic (Rosero and Jiménez, 2016; Tique et al., 2016). Fluoroquinolones, whether first-generation or newer 8-methoxy derivatives, could be useful in the treatment of brucellosis (Barkai et al., 2004). Something that is also supported by the data in Table 1.

Mumps are a highly contagious and serious infection of horses and other equines caused by the bacteria *Streptococcus equi*, however, there is debate among veterinarians as to whether to treat an animal with mumps with antibiotics. Gardner et al (Gardner et al., 2004),mentioned that according to the calculations in their study of pharmacokinetics/pharmacodynamic relationships, AUC/MIC and Cmax/MIC, predict clinical success for the treatment of most pathogenic respiratory diseases of the horse. On the other hand, Gao et al (Gao et al., 2019), propose moxifloxacin hybrids that decrease toxicity in cells and have greater bactericidal activity against antibiotic-resistant strains, as an alternative to solve the toxicity caused.

Although new fluoroquinolones are available, these should be reserved for resistant infections in order to avoid the development of multi-resistant microorganisms and, as with most antibiotic treatments, these should follow a precise analysis and diagnosis in order to avoid unnecessary treatment, considering the increase in antibiotic resistance rates (Carrillo et al., 2018) so complete care must be taken when medicating any animal, not just equines.

6.1 Effect of the drug on digestive and metabolic levels in equines

Some factors that can influence digestion in equines are animal individuality, chemical composition of the feed, feeding capacity, type of work, physical form of the feed, physiological stage, water content of the feed, speed of transit of the feed in the digestive tract (48–72 hours) and amount of fiber in the ration (Van Weyenberg et al., 2006). Equines present digestive physiology with determining characteristics such as efficient mastication, rapid gastric passage rate, intense enzymatic digestion in the small intestine, and prolonged microbial action in the large intestine (Arrieta et al., 2007). The digestive system of horses has adapted to be able to ingest large quantities of grass very evenly distributed throughout the day and to obtain energy efficiently from it. The enzymatic digestion of the feed releases glucose, amino acids and fatty acids for absorption. Additionally, the well-developed large intestine enables the acquisition of supplementary energy in the form of volatile fatty acids through the microbial fermentation of fiber and the fraction of the feed that is not enzymatically digested (Martínez Marín, 2008).

Fluoroquinolones are well absorbed after oral administration in animals with a single-chamber stomach and the newer ones tend to have a longer half-life. Most fluoroquinolones are metabolized in the liver; they are eliminated mainly through the kidneys, although some are excreted in bile (Marín, 2008; Carrillo et al., 2018) and the elimination pathways of moxifloxacin are balanced, not depending exclusively on renal or hepatic function. Moxifloxacin has a low plasma protein binding, approximately 40–42%, which is important since only the free drug is active against the bacteria and can penetrate the target tissues. The plasma protein to which it mainly binds is albumin (Carretero Colomer, 2001). Its bioavailability is excellent and allows oral administration in most situations; this bioavailability is approximately 100%, it does not decrease with concomitant food intake, but gastrointestinal undesirable effects are the most frequent. They occur in 2–20% of cases, depending on the molecules and situations, and constitute 50% of the side effects of fluoroquinolones (Revest and Tattevin, 2014) (Figure 3).

TABLE 3 Equine diseases treated with moxifloxacin.

Clinical diagnosis	Age	Moxifloxacin dosage	Reference
Corneal ulcer	2 geldings 1 stallion 3 mares, average age 9.3	Moxifloxacin 0.5% every 4 hours for 7 doses	(Clode et al., 2010)
Kerachitis	9 adult mixed breed horses	Moxifloxacin 0.5%	(Westermeyer et al., 2011)
Indolent ulcer. Severe blepharospasm and severe pain in the left eye	2 year old Quarter Horse	VIGAMOX 5 mg/ml eye drops based on moxifloxacin in solution and hyaluronic acid (Hyabak), both every 4/4 hours for 14 days	(de Melo et al., 2018)
Stromal corneal abscess	16 year old male equine	Moxifloxacin (Vigamox) 3 drops every 2 hours	(Castellanos, 2019)

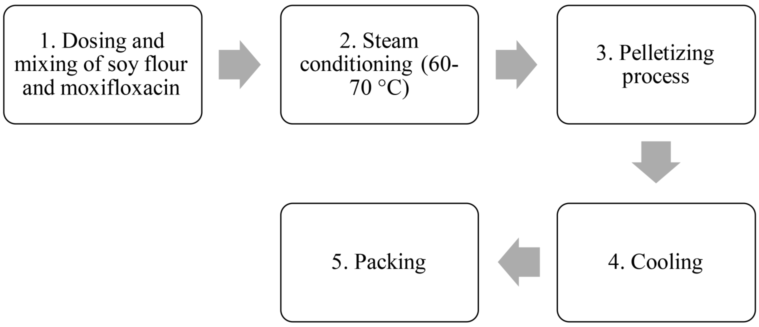

FIGURE 4
Proposal for forming moxifloxacin pellets with soy flour for administration in equines, starting with obtaining soy flour and the antibiotic. (Own elaboration using Microsoft Office PowerPoint).

7 Formation of pellets based on soy flour and moxifloxacin

Figure 4 presents a proposal for the formation of moxifloxacin pellets with soy flour for administration in horses, from the obtaining of soy flour and the antibiotic. For this, the methodology of Muhammad (2024) and Loor (2016) was taken as a reference. The process begins with the precise weighing and homogenization of the ingredients in the recommended proportions of 95% soybean flour and 5% moxifloxacin. During the steam conditioning phase, the combined application of heat, moisture, and pressure facilitates the gelatinization and homogenization of the mixture, optimizing its physicochemical properties for further processing. The ideal temperature for this stage ranges between 60 and 70°C to ensure proper conditioning. The pelletization stage, a critical step in the process, involves mechanical manipulation to compact and bind the ingredients, ensuring the structural integrity of the final product. This stage represents the highest energy consumption within the entire production process. During the cooling process, both the temperature and humidity of the pellets are reduced, with subtle changes occurring that can affect their quality. Finally, the pellets are sifted before packaging and storage. It is anticipated that this product could have a minimum 2-month shelf life after production, although further tests are needed to accurately determine the extent of shelf stability.

7.1 Challenges for the inclusion of soybean meal-based moxifloxacin pellets

It is suggested to perform *in vitro* and *in vivo* tests to test the efficacy of this product to know its antibiotic stability, controlled release, precise dosage, and animal acceptance.

Antibiotic stability: Ensuring that the antibiotic maintains its potency over the shelf life of the pellet is a crucial challenge (Barrueco et al., 2013).

Controlled release: Designing pellets that release the antibiotic in a controlled and effective manner in the body can be complex. It is important that the drug is released at the right time and place to maximize its effectiveness and minimize side effects (Thapa et al., 2018).

Precise dosage: Ensuring that each pellet contains a precise and consistent dose of the antibiotic is essential to ensure the effectiveness of the treatment and avoid problems of bacterial resistance (Sumano López et al., 2020).

Acceptance by the animal: Pellets must be palatable to the animals that will consume them. If the antibiotic or ingredients in the pellet alter the taste or texture, the animals may reject it, which could compromise the treatment (Ryon et al., 2023).

Regulation and security: Complying with safety standards and regulations for the use of antibiotics in animals is essential. This includes ensuring that the antibiotic levels in the pellet are safe and do not cause adverse effects (Loor, 2016; Sumano López et al., 2020).

8 Conclusions

The development of soybean meal-based moxifloxacin pellets for equine use holds great promise, offering sustainability and the potential for more efficient drug delivery. These pellets are designed to facilitate controlled antibiotic release, which is crucial for effectively treating bacterial infections in horses. However, ensuring consistent controlled release, maintaining antibiotic stability, achieving accurate dosing, and securing animal acceptance remain significant challenges. Additionally, adhering to safety regulations is critical to prevent adverse effects and reduce the risk of bacterial resistance. Further *in vitro* and *in vivo* research is essential to overcome the obstacles and validate the viability of these granules as a safe and effective therapeutic option in veterinary medicine.

Author contributions

DRV: Conceptualization, Writing – original draft. JVG: Investigation, Writing – original draft. TDA: Visualization, Writing – original draft. DGO: Investigation, Writing – original draft.

AZMS: Validation, Writing – original draft. SKR: Conceptualization, Funding acquisition, Writing – original draft. MMMYE: Methodology, Resources, Writing – original draft.

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References

Alós, J. I. (2009). Quinolonas. *Enferm. Infecc. Microbiol. Clin.* 27, 290–297. doi: 10.1016/J.EIMC.2009.03.001

Arrieta, G., Peña, C., Hurtado Nery, V. L., and Iregui, A. (2007). Utilización de materias primas regionales en la alimentación de equinos criollos adultos en el municipio de Villavicencio. *Orinoquia* 11, 92–98. doi: 10.22579/20112629.174

Balfour, J. A. B., and Wiseman, L. R. (1999). Moxifloxacin. *Drugs* 57, 363–373. doi: 10.2165/00003495-199957030-00007

Barkai, G., Leibovitz, E., Smolnikov, A., Tal, A., and Cohen, E. (2004). Susceptibility of Mexican brucella isolates to moxifloxacin, ciprofloxacin and other antimicrobials used in the treatment of human brucellosis. *Scand. J. Infect. Dis.* 36, 232–234. doi: 10.1080/00365540410020767

Barrientos, J. A. (2010). Producíón de peletizado a partir de forraje de soya (Glycine max. L. Merr. var CIGRAS 06) para la alimentacíónd en bovinos de carne y leche. Available online at: https://repositorioslatinoamericanos.uChile.cl/handle/2250/1593517 (Accessed Sep. 09, 2024).

Barrueco, N., Escobar Rodríguez, I., García Díaz, B., Gil Alegre, M. E., López Lunar, E., and Ventura Valares, M. G. (2013). Estabilidad de medicamentos en la práctica clínica: de la seguridad a la eficiencia. *Farmacia. Hospital.* 37, 175–177. doi: 10.7399/FH.2013.37.3.587

Blanco, A. M., José, F., Bringas, V., Luis, Á., and Gonzalo, O. (2016). *Trabajo Fin de* (Zaragoza, España: Universidad de Zaragoza).

Blondeau, J. M., and Hansen, G. T. (2001). Moxifloxacin: a review of the microbiological, pharmacological, clinical and safety features. *Expert Opin. Pharmacother.* 2, 317–335. doi: 10.1517/14656566.2.2.317

Blondeau, J. M., Laskowski, R., Bjarnason, J., and Stewart, C. (2000). Comparative *in vitro* activity of gatifloxacin, grepafloxacin, levofloxacin, moxifloxacin and trovafloxacin against 4151 Gram-negative and Gram-positive organisms. *Int. J. Antimicrob. Agents* 14, 45–50. doi: 10.1016/S0924-8579(99)00143-0

Bockisch, F., Taubert, J., Coenen, M., and Vervuert, I. (2023). Protein evaluation of feedstuffs for horses. *Animals* 13, 2624. doi: 10.3390/ANI13162624

Carretero Colomer, M. (2001).Moxifloxacino. In: *Offarm: farmacia y sociedad* 20. Available online at: https://dialnet.unirioja.es/servlet/articulo?codigo=5325884 (Accessed Sep. 09, 2024). ISSN 0212-047X, ISSN-e 1578-1569.

Carrillo, J. L., Flores, F. J., and Rodríguez, A. N. (2018). Actualización en la prescripción de fluoroquinolonas. *Med. Interna. México.* 34, 89–105. Available at: http://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S0186-48662018000100011&lng=es&tlng=es (Accessed November 21, 2024).

Castellanos, A. L. (2019). Reporte de caso: Absceso corneal estromal de un equino adulto raza silla Argentina [Archivo PDF]. Repositorio Universidad de Ciencias Aplicadas y Ambientales. Available online at: https://repository.udca.edu.co/server/api/core/bitstreams/fae764e0-7bbb-4108-b0a9-6789db6f766d/content.

Christ, F., Schneider, D., Schneider, S., and Benz, B. (2020). Ökonomische Bewertung von Holzpellets in der Pferdehaltung unter Berücksichtigung ethologischer und stallklimatischer Parameter. *Agric. Engineering.eu.* 75, 61–79. doi: 10.15150/LT.2020.3233

Clode, A. B., Davis, J. L., Salmon, J., LaFevers, H., and Gilger, B. C. (2010). Aqueous humor and plasma concentrations of ciprofloxacin and moxifloxacin following topical ocular administration in ophthalmologically normal horses. *Am. J. Vet. Res.* 71, 564–569. doi: 10.2460/AJVR.71.5.564

Constantinou, M., Daniell, M., Snibson, G. R., Vu, H. T., and Taylor, H. R. (2007). Clinical efficacy of moxifloxacin in the treatment of bacterial keratitis: a randomized clinical trial. *Ophthalmology* 114, 1622–1629. doi: 10.1016/J.OPHTHA.2006.12.011

Daneshvar, N., Salari, D., and Aber, S. (2002). Chromium adsorption and Cr(VI) reduction to trivalent chromium in aqueous solutions by soya cake. *J. Hazard. Mater.* 94, 49–61. doi: 10.1016/S0304-3894(02)00054-7

de Jesús, C. D. F. (2007). "Terapia con antimicrobianos en equinos," Revista de Sanidad Militar. Available online at: https://www.imbiomed.com.mx/articulo.php?id=43223 (Accessed Sep. 03, 2024).

De Linde, M., Andersen, P. H., Thomsen, P. D., Plummer, C. E., Mangan, B., Heegaard, S., et al. (2014). Equine deep stromal abscesses (51 cases – 2004–2009) – P art 1: the clinical aspects with attention to the duration of the corneal disease, treatment history, clinical appearance, and microbiology results. *Vet. Ophthalmol.* 17, 6–13. doi: 10.1111/vop.12103

de Melo, J. C., Fagundes, B., and de Melo, V. C. (2018). Tratamento de úlcera indolente em equino. *Rev. Acad. Ciec. Anim.* 16, 1. doi: 10.7213/1981-4178.2018.162501

Frempong, N. S., Nortey, T. N. N., Paulk, C., and Stark, C. R. (2019). Evaluating the Effect of replacing fish meal in broiler diets with either Soybean meal or poultry by-product Meal on Broiler Performance and total feed cost per kilogram of gain. *J. Appl. Poult. Res.* 28, 912–918. doi: 10.3382/JAPR/PFZ049

Gao, F., Ye, L., Kong, F., Huang, G., and Xiao, J. (2019). Design, synthesis and antibacterial activity evaluation of moxifloxacin-amide-1,2,3-triazole-isatin hybrids. *Bioorg. Chem.* 91, 103162. doi: 10.1016/J.BIOORG.2019.103162

Gardner, S. Y., Davis, J. L., Jones, S. L., Lafevers, D. H., Hoskins, M. S., Mcarver, E. M., et al. (2004). Moxifloxacin pharmacokinetics in horses and disposition into phagocytes after oral dosing. *J. Vet. Pharmacol. Ther.* 27, 57–60. doi: 10.1046/J.0140-7783.2003.00529.X

Ghebre, I. (2022). Pharmaceutical pelletization technology. *Pharm. Pelletization. Technol.* 13, 1–14. doi: 10.1201/9781003066231/PHARMACEUTICAL-PELLETIZATION-TECHNOLOGY-ISAAC-GHEBRE-SELASSIE

Hoogkamp, J. A. A., and Roelofs, J. (2000). Comparative *in vitro* activity of moxifloxacin against Gram-positive clinical isolates. *J. Antimicrob. Chemother.* 45, 31–39. doi: 10.1093/JAC/45.1.31

Hoyos, J. F., Hernández, D. A., and Velasquez, B. L. (2022). Condiciones de bienestar en sistemas de producción animal. *SSRN. Electron. J.* 1, 1–12. doi: 10.2139/SSRN.4182002

Huang, Y., Liu, L., Sun, B., Zhu, Y., Lv, M., Li, Y., et al. (2024). A comprehensive review on harnessing soy proteins in the manufacture of healthy foods through extrusion. *Foods* 13, 2215. doi: 10.3390/FOODS13142215

Humma, Z. E., and Patel, P. (2024). *"Moxifloxacin," Kucers the use of Antibiotics: A Clinical Review of Antibacterial, Antifungal, Antiparasitic, and Antiviral Drugs, Seventh Edition* (Petersburg, Florida: StatPearls Publishing LLC). 2085–2109. doi: 10.1201/9781315152110

Inyang, U. E., Akindolu, B. E., and Elijah, A. I. (2019). Nutrient composition, amino acid profile and anti-nutritional factors of nixtamalized maize flour supplemented with sprouted soybean flour. 9, 41–51. doi: 10.9734/EJNFS/2019/46150

Kim, S. Y., Lim, J. A., Choi, J. S., and Joo, C. K. (2006). Comparison of antibiotic effect & Corneal epithelial toxicity between levofloxacin 0.5% (Cravit®) & Moxifloxacin 0.5% (Vigamox®) *in vitro*. *Invest. Ophthalmol. Vis. Sci.* 47, 3565–3565. doi: 10.1097/ICO.0b013e3180515251

Kuriyama, T., Karasawa, T., and Williams, D. W. (2014). "Antimicrobial chemotherapy: significance to healthcare," in *Biofilms in Infection Prevention and Control: A Healthcare Handbook* (San Diego: Academic press), 209–244. doi: 10.1016/B978-0-12-397043-5.00013-X

Loor, N. (2016). Fundamentos de los alimentos peletizados en la nutrición animal. *Dominio. las. Cienc.* 2, 323–333. doi: 10.23857/DC.V2I4.257

López, D. (2017). Caracterización bromatológica de pellets elaborados a partir de subproductos agropecuarios para la alimentación de bovinos. *Rev. Tecnol. en Marcha.* 30, 73–81. doi: 10.18845/TM.V30I5.3226

Lyu, F., van der Poel, A. F. B., Hendriks, W. H., and Thomas, M. (2021). Particle size distribution of hammer-milled maize and soybean meal, its nutrient composition and *in vitro* digestion characteristics. *Anim. Feed. Sci. Technol.* 281, 115095. doi: 10.1016/j.anifeedsci.2021.115095

Magesh, N., Annam, A., and Senthil, P. (2020). Practice on treating pharmaceutical compounds (antibiotics) present in wastewater using biosorption techniques with different biowaste compounds. A review. *Environ. Prog. Sustain. Energy* 39, 1–9. doi: 10.1002/EP.13429

Marín, P. (2008). Aplicación de fluoroquinolonas en Medicina Veterinaria: criterios farmacocinéticos y farmacocinéticos/farmacodinámicos (PK/PD). Available online at: https://dialnet.unirioja.es/servlet/tesis?codigo=18795&info=resumen&idioma=SPA (Accessed Sep. 09, 2024).

Martínez Marín, A. L. (2008).Factores nutricionales que deben considerarse en el diseño de raciones basadas en forrajes secos y concentrados para caballos de ocio alimentados en pesebre. In: *REDVET. Revista electrónica de veterinaria IX (3).* Available online at: http://helvia.uco.es/xmlui/handle/10396/8169 (Accessed Sep. 09, 2024).

Medrano, J. Formas farmacéuticas en veterinaria (I). In: *Farmacia profesional*. 2005 Available online at: https://dialnet.unirioja.es/servlet/articulo?codigo=4583426 (Accessed Sep. 09, 2024). ISSN 0213-9324.

Meena, M., Prajapat, A., Deori, N., Gurjar, T., Patel, P., and Saini, S. (2019). Moxifloxacin and its therapeutic uses in animals: An overview. *J. Entomol. Zool. Stud.* 7, 929–934. Available at: https://www.researchgate.net/publication/360560393 (Accessed November 9, 2024).

Millanao, A. R., Mora, A. Y., Villagra, N. A., Bucarey, S. A., and Hidalgo, A. A. (2021). Biological effects of quinolones: A family of broad-spectrum antimicrobial agents. *Molecules* 26, 7153. doi: 10.3390/MOLECULES26237153

Muhammad, A. (2024). Efficient Pellets. Influencing Production Parameters to make energy efficient pellets. Available online at: https://nmbu.brage.unit.no/nmbu-xmlui/handle/11250/3148372 (Accessed Sep. 12, 2024).

Nahashon,, and Kilonzo, (2011). Advances in soybean and soybean by-products in monogastric nutrition and heatlh. *Soybean Nutr.* 1, 125–158. doi: 10.5772/21135

Odenholt, I., and Cars, O. (2006). Pharmacodynamics of moxifloxacin and levofloxacin against Streptococcus pneumoniae, Staphylococcus aureus, Klebsiella pneumoniae and Escherichia coli: simulation of human plasma concentrations after intravenous dosage in an *in vitro* kinetic model. *J. Antimicrob. Chemother.* 58, 960–965. doi: 10.1093/JAC/DKL356

OMS (2020). Resistencia a los antibióticos. Available online at: https://www.who.int/es/news-room/fact-sheets/detail/antibiotic-resistance (Accessed Sep. 10, 2024).

Ovuchimeru, A. A. (2020). Nutritional effects of full-fat soy flour as an extender on cooked beef sausage quality. *Asian Food Sci. J.* 17, 44–53. doi: 10.9734/AFSJ/2020/V17I330195

Pacheco, W. J., Stark, C. R., Ferket, P. R., and Brake, J. (2013). Evaluation of soybean meal source and particle size on broiler performance, nutrient digestibility, and gizzard development. *Poult. Sci.* 92, 2914–2922. doi: 10.3382/PS.2013-03186

Papich, M. G. (2020). *Papich Handbook of Veterinary Drugs: Small and Large Animal* (North Carolina: Elsevier). doi: 10.1016/B978-0-323-70957-6.01001-3

Pettersson, D., and Pontoppi, K. (2013). "Soybean meal and the potential for upgrading its feeding value by enzyme supplementation," in *Soybean - Bio-Active Compounds* (Egipto: InTech). doi: 10.5772/52607

Pong, A., Thomson, K. S., Moland, E. S., Chartrand, S. A., and Sanders, C. C. (1999). Activity of moxifloxacin against pathogens with decreased susceptibility to ciprofloxacin. *J. Antimicrob. Chemother.* 44, 621–627. doi: 10.1093/JAC/44.5.621

Revest, M., and Tattevin, P. (2014). Fluoroquinolonas. *EMC. - Tratado. Med.* 18, 1–7. doi: 10.1016/S1636-5410(14)67523-1

Rolston, V. I., Frisbee, S., LeBlanc, B., Streeter, H., and Ho, D. H. (2003). *In vitro* antimicrobial activity of moxifloxacin compared to other quinolones against recent clinical bacterial isolates from hospitalized and community-based cancer patients. *Diagn. Microbiol. Infect. Dis.* 47, 441–449. doi: 10.1016/S0732-8893(03)00115-9

Rolston, V. I., Yadegarynia, D., Kontoyiannis, D. P., Raad, I. I., and Ho, D. H. (2006). The spectrum of Gram-positive bloodstream infections in patients with hematologic Malignancies, and the *in vitro* activity of various quinolones against Gram-positive bacteria isolated from cancer patients. *Int. J. Infect. Dis.* 10, 223–230. doi: 10.1016/J.IJID.2005.05.007

Rosero, E. M. I., and Jiménez, R. E. S. (2016). Prevalencia de brucelosis (Brucella Abortus) y factores de riesgo en estudiantes de primero a noveno semestre de la escuela de Desarrollo Integral Agropecuario de la UPEC. *SATHIRI* 11, 303–313. doi: 10.32645/13906925.28

Ryon, W., Mason, A. C., Cross, T. D., Guay, K. A., Raub, R. H., Wellmann, K. B., et al. (2023). Assessment of the palatability and acceptability of hempseed meal pellets in horses compared to mainstream feedstuffs. *J. Equine. Vet. Sci.* 131, 104929. doi: 10.1016/j.jevs.2023.104929

Schedletzky, H., Wiedemann, B., and Heisig, P. (1999). The effect of moxifloxacin on its target topoisomerases from Escherichia coli and Staphylococcus aureus. *J. Antimicrob. Chemother.* 43 Suppl B, 31–37. doi: 10.1093/JAC/43.SUPPL_2.31

Singh, R., Ledesma, K. R., Chang, K. T., Hou, J. G., Prince, R. A., and Tam, V. H. (2009). Pharmacodynamics of moxifloxacin against a high inoculum of Escherichia coli in an *in vitro* infection model. *J. Antimicrob. Chemother.* 64, 556–562. doi: 10.1093/JAC/DKP247

Soto, A. E., and Rojas, A. (2016). "Estudio preliminar sobre el potencial de sustitución de alimento balanceado por pellets de Stylosanthes multilinea en equinos," in *Nutrición animal tropical* (Costa Rica: Universidad de Costa Rica), vol. 10. , 10–23. ISSN-e 2215-3527. doi: 10.15517/nat.v10i1.24397

Stroman, D. W., Dajcs, J. J., Cupp, G. A., and Schlech, B. A. (2005). *In vitro* and *in vivo* potency of moxifloxacin and moxifloxacin ophthalmic solution 0.5%, A new topical fluoroquinolone. *Surv. Ophthalmol.* 50, S16–S31. doi: 10.1016/J.SURVOPHTHAL.2005.06.002

Sumano López, H., Lizárraga, I., Ocampo, L., Obregón, K., Sumano, H., Lizárraga, I., et al. (2020). Reacciones adversas de los fármacos en los equinos. *Vet. México. OA* 7, 1–48. doi: 10.22201/FMVZ.24486760E.2020.3.925

Symoens, A., Westerfeld, R., Vives, B. M., André, V., Moulon, L., Collomb, M., et al. (2024). Steamed hay and alfalfa pellets for the management of severe equine asthma. *Equine. Vet. J.* 1, 1–10. doi: 10.1111/EVJ.14209

Thapa, P., Thapa, R., Choi, D. H., and Jeong, S. H. (2018). Effects of pharmaceutical processes on the quality of ethylcellulose coated pellets: Quality by design approach. *Powder. Technol.* 339, 25–38. doi: 10.1016/J.POWTEC.2018.08.002

Tique, V., González, M., Mattar, S., Velásquez, R., Triana, A., and Vergara, O. D. (2016).Seroprevalencia de brucella sp. en équidos de Córdoba, Colombia. In: *Revista de la Facultad de Ciencias Veterinarias*. Available online at: https://dialnet.unirioja.es/servlet/articulo?codigo=6028945&info=resumen&idioma=ENG (Accessed Sep. 09, 2024). ISSN 0258-6576.

Valdéz-Cruz, M. P., Hernández-Gil, M., Galindo-Rodríguez, L., and Alonso-Díaz, M. Á. (2013). Gastrointestinal nematode burden in working equids from humid tropical areas of central Veracruz, Mexico, and its relationship with body condition and haematological values. *Trop. Anim. Health Prod.* 45, 603–607. doi: 10.1007/s11250-012-0265-3

Van Weyenberg, S., Sales, J., and Janssens, G. P. J. (2006). Passage rate of digesta through the equine gastrointestinal tract: A review. *Livest. Sci.* 99, 3–12. doi: 10.1016/J.LIVPRODSCI.2005.04.008

Westermeyer, H. D., Hendrix, D. V. H., Ward, D. A., and Cox, S. K. (2011). Tear, cornea, and aqueous humor concentrations of ciprofloxacin and moxifloxacin after topical ocular application in ophthalmologically normal horses. *Am. J. Vet. Res.* 72, 398–403. doi: 10.2460/AJVR.72.3.398

Zheng, J., Wang, Y., and Fang, X. (2024). Streptococcus equinus keratitis after small-incision lenticule extraction: A case report and literature review. *Indian J. Ophthalmol. - Case Rep.* 4, 111–113. doi: 10.4103/IJO.IJO_1612_23