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Rare Earth Elements in Agriculture with Emphasis on Animal Husbandry

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ABSTRACT:
There is a requirement for newer feed additives thanks to legal prohibition on inclusion of growth promoting antibiotics in livestock diets in several countries thanks to antimicrobial resistance. During this context, rare-earth element elements (REE) have gained attention among animal nutritionists as potential growth promoters. Currently, several studies have reported better weight gain, milk production, laying capacity and feed conversion efficiency among different breeds of livestock following supplementation with REE, with however largely inconsistent results. Furthermore, REE supplementation has also shown to enhance ruminal fibrolytic and proteolytic activities also as flavor of meat with negligible residues in edible tissue, however the mechanism behind this action remains unclear. Consistent with existing research, thanks to their poor absorption and similarity with calcium REE might exert their action locally on gut microbial populations within the alimentary canal (GIT). Moreover, REE have also shown anti-inflammatory, anti-oxidative also as immune stimulating effects. This review aims to broaden the knowledge about use of REE as feed additives for livestock and sum up efficacy of REE supplementation on performance and health of animals by comparing the findings. Till date, researches with REE have shown properties that make them a promising, new and safe alternative feed additive but further exploration is suggested to optimize effects and clarify discrepancy of varied results before practical proposals are often drafted.
KEYWORDS: *Rare-earth elements, Farming, Antimicrobial Resistance, Livestock Production.*

I. INTRODUCTION

Feed additives are ingredients/chemical compounds or combinations thereof which are added to the basal ration to satisfy specific requirement or to enhance weight gain, feed efficiency and control diseases in livestock. Feed additives are often broadly classified into nutrient (amino acids, minerals, and vitamins) and non nutrient (antibiotics, hormones, enzymes, prebiotics, yeast culture, pellet binder, antioxidants etc.) feed additive [1]. Antimicrobial compounds like antibiotics were previously utilized in feeds for therapeutic purposes to cure and stop infectious diseases. But soon the expansion promoting effect of antibiotics came into limelight under intensive animal rearing system; thereafter these were added at sub therapeutic doses to animal feeds as an additive for nearly 6 decades. These compounds also improved feed utilization (2% to 5%) and reduced morbidity also as mortality thanks to clinical and subclinical diseases [2,3]. However, extensive use of antibiotics at therapeutic or subtherapeutic doses over long period of your time provides favorable conditions for proliferation of antimicrobial resistant microorganisms in animals, plants and soil [1].

At present global concern regarding antimicrobial resistance and transference of resistant strains gene from animal to human is rising [4–6]. Therefore, the potential risks related to development of antibiotic resistant bacteria and its transmission led to the ban on use of feed antibiotics as growth promoters in European Union since 2006. This ban endorsed scientific community and animal feed industry to actively explore alternatives for feed antibiotics which could improve feed efficiency, weight gain and manipulate rumen fermentation [7]. As a result, the rare-earth element elements (REE) have gained interest among animal nutrition research for its efficacy as a feed additive in substitution to antibiotics.

The REE aren't a more moderen feed additive as these are successfully used as fertilisers in plant production and as growth promoter in animal production for several decades in China [8]. Till date numerous scientific reports indicated that alittle amount of REE mixtures within the diet of livestock increased live weight gain, feed efficiency and milk/egg production [9,10]. The REE are naturally occurs within the environment and contains three members of group IIIB, namely scandium (Sc; number 21), yttrium (Y; number 39), lanthanum (La; number 57) and 14 chemical elements from group IIIA of the table called lanthanoids (atomic numbers 58–71) viz. cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), and therefore the elements Y and Sc. These are frequently divided into two subgroups: the sunshine or Ce group and therefore the heavy or Y group. The Ce group consists of the weather La, Ce, Pr, Nd, Pm, Sm, and Eu, whereas Y group comprises the weather Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Y [11]. The importance of varied inorganic elements (commonly referred to as minerals) in human, animal and plant nutrition are very familiar and are required for various metabolic functions [12–14]. Now, among inorganic elements, REE emerges as new generation growth promoter feed additive alternative to feed antibiotics for livestock. The aim of present review is to broaden the knowledge about use of REE as feed additive in livestock, its effect on health and performance of animals also as its accumulation in tissue.

II. BACKGROUND OF RARE-EARTH ELEMENTS

The history of the invention of REE is extremely old and first element to be discovered was in 1788, by the Swedish army lieutenant Karl Axel Arrhenius, who collected the black mineral ytterbite (named after the nearby Swedish town). Then, Gadolin in 1794, isolated ytterbia from the mineral ytterbite using fractional crystallization and explained their chemical properties. This created the interest among many scientists and with development of varied technology like spectroscopic methods of study and therefore the exploration of electrochemical separation led to discovery of varied REE. the newest REE discovered was Pm in 1947 through the utilization of natural process chromatography from fission fragments of uranium.

III. TECHNIQUES

The term rare earths may be a misnomer as these elements are neither rare nor earths. The word rare, relates to the considerable difficulties in separating one REE from another due to their close similarity in physical and chemical properties. All REE are more common than Ag or Hg [11] and Tm, the rarest of the REE, are found more often than gold, platinum or iodine [15]. The term earths was utilized in the 18th century for describing alkali metal oxides, as they were first identified as rare-earth element oxides. Rare-earth element elements are cosmopolitan and mainly occur as phosphates because they need strong affinity for phosphate. Moreover, oxides, silicates, carbonate and halogen compounds of REE also are present in mineral deposits under natural conditions [16]. There are quite 2 hundred mineral deposits known to contain REE and among which few of them are useful for industrial production.

Several methods of separating rare earths are identified, but none are considered to be universal. Usually there are choices between either acidic (using sulphuric acid) or alkaline (using caustic soda) methods of breakdown, which are temperature dependent. High purity isolates for commercial purposes are mainly obtained by solvent extraction while natural process resins are utilized in special cases [15].

IV. MECHANISM

The scientific literature and evidences on the mechanism of REE which reinforces the performance of animals are limited and not well established. However, various biological effects supported results of various feeding trials on supplementation of REE within the diet of animals are proposed (Figure 1) viz. antibacterial property, antioxidant nature, increased hormonal, and enzyme activities, proliferation of specific cells, stimulation of system , enhancement of digestibility and nutrient utilization [10,17]. These effects of REE are often either thanks to their similarity with calcium (radius of Ca is extremely on the brink of lanthanoids) or poor absorption from the alimentary canal (GIT) [18]. Moreover, it's believed that the small amount of absorbed REE affected various physiological process like hormonal concentration, enzyme activity, activation of system , metabolism of nutrients (protein or lipids) and cell proliferation [19,20]. Further, REE are alleged to have hormetic effect on microbes i.e. concentration-related effects, by improvements in biological events at low levels, followed by inhibitory effects at increasing concentrations [21–22].

V. INTERACTION WITH INTERMEDIATE METABOLISM

Muroma [23], first observed the antibacterial effect of REE and reported its dose dependent activity i.e. at higher concentrations (10-4 to 10-2 mol/L) these elements inhibit bacterial growth mainly Gram negative, whereas at lower concentrations (10-5 mol/L) bacterial growth was stimulated. Similarly, Zhang et al [24] concluded that the expansion of Escherichia coli (E. coli), Bacillus pyocyaneus, Staphyloccous aureus, Leuconostoc, and Streptococcus faecalis were inhibited by Ce (10-3 mol/L to 10-2 mol/L). Zhao et al [25] also reported that Ce ions at concentrations below 350 µg/mL had a stimulatory effect on the expansion of E. coli, whereas concentrations at or above 400 µg/mL had an inhibitory effect. Stimulatory effect of REE was explained by Talburt and Johnson [26] as they reported that ethanedioic acid produced by Aspergillus niger combines with REE to make insoluble oxalates and leading to detoxification mechanism permitting further growth of this microbes. More recently, Liu et al [27] explained inhibitory of REE using La nitrate effect on the expansion of E. coli B. They observed that there was an abnormal “eruption of heat” phenomenon at high concentration (500 mg/L) led to wreck the outer cell wall and increases its permeability along side reduced proton-electron P.E. across the cell wall. Further, the expansion of the cells was inhibited thanks to scarceness of energy ATP (ATP) as energy couldn't be translated into ATP effectively within the course of organic process and resulted in additional heat release. Therefore, from above studies it are often considered that REE has hormetic properties so use of REE in feed might enhance animal performance by influencing the event of desired bacterial species within the GIT selectively during a dose dependent manner.

VI. ROLE OF RARE-EARTH ELEMENTS IN FARMING

Supplementation of animal feeds with REE has been practiced in China for several decades. After the ban on antibiotic growth promoters, these elements have inherit focus as newer natural feed additives in substitution to antimicrobials. Numerous studies reported that certain dose of REE within the diet of animals could improve their health, weight (BW) gain, feed conversion efficiency, milk and egg production [9,28].

Poultry

Effect of REE supplementation in poultry diets are summarized in Table 1. Addition of REE to layer diets (30 to 1,000 mg/kg feed) resulted in increased egg production (3% to 15%), hatchability (5% to 15%) and improved feed conversion efficiency (2% to 22%) also as BW gain (4% to 14%) [29,30]. Recently, Cai et al [31] observed that supplementation of RY at 1,500 mg/kg (containing 42.3 mg/kg La, and 70.65 mg/kg Ce) during starter and growing period resulted in improved nutrient digestibility and meat quality. However, there was no significant influence on growth performance, relative organ weight and excreta microflora.

Table 1 : Literature summary of effect of REE supplementation in poultry

Dose	Results and conclusions	Reference
250 mg/kg (La 100 mg, Ce 150 mg) and 500 mg/kg (La 200, Ce 300 mg) of REE in the diet of laying hen	• Significant increase in plasma Ca and P levels at first and second month when supplemented group treated with REE at 250 mg/kg • Whereas in group supplemented with 500 mg/kg REE plasma Ca and P had significantly increased only during first month of the trial • No significant changes were reported in second month of the trial • Non-significant effect on total protein, albumin and globulin level	Reka et al [34]
Lanthanum oxide (La_2O_3; having 85.3% La) at 100 (85.3 ppm La), 200 (171 ppm La) and 300 (256 ppm La) ppm to starter and finisher diet of broiler	• Improvement in the total weight gain over the control on supplementation of La at 171 ppm • Relatively lower counts of bacteria were obtained in group supplemented with 85.3 ppm La	Agbede et al [35]
Lanthanum oxide at 0, 100, 200, 300, or 400 mg/kg) in the diet of laying hen	• Significant increase in Haugh unit and eggshell breaking strength • Significantly decreased thiobarbituric acid reactive substance (TBARS) values in egg yolk • Non-significant effect on SOD and GPx values • Significant decrease in serum MDA concentration • Non-significant difference in serum Ca and P level	Durmus and Bolukbası [36]
Cerium oxide at 0, 100, 200, 300, or 400 mg/kg in the diet of laying hen	• Non-significant effect on feed intake and egg weight • Egg production and feed conversion rate were improved by maximum level of cerium oxide (at 400 ppm) • Significant decrease in SOD and MDA concentration • Significant increase in serum Ca and P concentration	Bolukbası et al [37]

Ruminants

Studies regarding the effect of REE on production performance of ruminants are summarized in Table 2. REE supplementation in ruminants had variable effect on ADG, feed intake, rumen fermentation and milk production. Literature summarized by Redling [10] reported that addition of rare-earth element oxides (mainly La 22%, Ce 45%, and Nd 15% oxides) and rare-earth element nitrates consisting of (38%) rare-earth element oxides (22% La_2O_3, 45% Ce_2O_3, 15% Nd_2O_3) at 600 and 800 ppm within the diet of fattening cattle and dairy cows improved daily gain and milk production, respectively.

Table 2 :Literature summary of effect of REE supplementation in ruminants

Dose	Results and conclusions	Reference
REE-citrate at 100, 200, and 300 mg/kg DM (having Ce 57.9%, La 34.0%, and Pr 6.5%) in the diet of fattening bulls.	• Non-significant effect in feed-to-gain ratio, ME-to-gain ratio and digestibility of nutrients due supplementation of REE	Schwabe et al [7]

REE-citrate at 100, 200, and 300 mg/kg DM (having Ce 57.9%, La 34.0%, and Pr 6.5%) in the diet of fattening bulls.	● Significantly linear increase the concentrations of REE (lanthanum [La], cerium [Ce], and praseodymium [Pr]) in the liver, kidneys and rib bone ● While, the concentration in muscle was not influenced ● Risk to humans from consuming of edible tissue of REE supplemented animals can be regarded as negligible	Schwabe et al [19]
REE-citrate (Ce 56.8%, La 35.0%, and Pr 6.5%) at 100, 200, and 300 mg/kg DM in diet of sheep	● Significantly decrease in ruminal pH ● Quadratically decreased in ruminal ammonia content with increasing REE supplementation ● Other ruminal parameters like total volatile fatty acids concentration and acetate to propionate ratio were also affected by REE supplementation ● Negative effect on growth of several rumen bacteria ● Digestibility of various nutrients and urinary excretion of purine derivatives were also increased with increasing REE addition	Xun et al [38]
$LaCl_3$, $CeCl_3$, or $PrCl_3$ at 204 mg/kg DM to the basal ration of beef cattle	● Linear increase in NDF digestibility and reduced enteric CH_4 emissions ● Significant decreased in total N excretion and urinary N excretion, increased N retention ● Total urinary PD were linearly increase ● Non-significant effect in N retention, urinary PD, microbial N flow and plasma biochemical parameters	Lin et al [935]
Cerium chloride ($CeCl_3$) at 0, 80, 160, and 240 mg/kg DM in beef cattle	● Significant increase in NDF digestibility and N retention ● Significantly decreased the molar ratio of rumen acetate to propionate, total N excretion, urinary N excretion and CH_4/kg DMI	Lin et al [40]
Lanthanum oxide at 100, 200, and 300 mg/kg in the diet of sheep	● Significant improvement in daily weight gain and total weight gain ● Non-significant effect on AST, ALT, cholesterol, urea, total protein, albumin, and globulin ●	Adu et al [41]

VII. SAFETY ASPECTS OF RARE-EARTH ELEMENT ELEMENTS

Results of varied studies reported that concentrations of REE in liver and muscle is weakly suffering from the dose of REE supplementation in diets of poultry and fattening bull [21,32,19]. Moreover, RE aren't highly toxic as LD50 values for IV-injected REE are 10 to 100 mg/kg/BW and people of IP-injected REE are 150 to 700 mg/kg/BW. Toxicity of REE through oral route is extremely low as only very small amounts of REE are absorbed within the GIT [33]. When rats got higher levels of REE ($LaCl_3 \cdot 7H_2O$ at 1,000 mg/kg BW/d for 28 days) orally, it induced hepatotoxic effect and caused irritation to the stomach mucosa [24]. Hence, it are often supposed that oral supplementation of REE within the diet of animals may pose similar health risk like that of salt. Further, either thanks to poor absorption or rapid elimination of REEs from the body of animals the health risks to humans consuming edible tissues from these animals are often considered negligible. However, thanks to limited scientific information there's controversy regarding health benefits and toxic effects of REE on human health [23].

VIII. CONCLUSION

After reviewing the complied and cited literature, it's difficult to clarify the biological role of REE on animal performance as there's huge discrepancy among the results of varied trials conducted on poultry and ruminants. just in case of poultry, REE- citrate mixture supplementation up to 100 ppm in diet of broiler birds improved weight gain and FCR by 5% and 3.4%, while the supplementation of RRE-chloride mixture showed no effect. Supplementation of REE-chlorides, nitrates, oxide up to 900 ppm and REE-citrate up to 300 ppm within the diet of cattle and sheep respectively, had positive impact on animal performance by improving rumen fermentation and nutrient digestibility. But, REE-citrate supplementation up to 300 ppm had no impact on rumen fermentation and performance of cattle. Aside from above findings, there are few studies which reported that REE had similar impact on fecal micro-biota and growth performance in animals in comparison antibiotics supplementation. Moreover, it had been also observed that the concentration of REE in various edible tissues wasn't suffering from dose of REE within the diet. Hence, REE could be considered as an alternate to antimicrobial compounds as these are capable of augmenting performance in both ruminants and non-ruminants with none residual effect on edible tissue. Although, there's a requirement of further research to elucidate the pathways through which REE exerts its action on various physiological processes.

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