**Review Article**

# Ionophores: Their Effects on Ruminal Fermentation, Animal Performance and Carcass Characteristics and Meat Quality

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Abstract | As a result of the increased human population and increased demand for food consumption, there is a need to improve the nutritional value of animal feed. Among the available methods of increasing production is using feed additives. One class of these additives is ionophores, a type of antibiotic that increases the nutritional value of the feed, thereby increasing production by reducing of feed intake, and decreasing the degradability of protein in the rumen, which increases its by-pass to the small intestine and decreasing the ammonia concentration in the rumen. Moreover, ionophores increase propionic acid in the rumen, which is used as an energy source; hence, ionophores increase muscle growth by enhancing the daily weight gain due to the improved feed conversion rate. Studies indicate the effect of ionophores on the characteristics and quality of the carcass have been limited. Ionophoers may be enhanced the concentration of unsaturated fatty acids and conjugated linoleic acid (CLA). The benefits of these acids with respect to human health include lower cholesterol and blood pressure and a reduced incidence of diabetes. There have been few studies on the use of ionophores in the diet of goats. Therefore, more research are needed concerning the influence of ionophores on ruminal fermentation, performance and characteristics of carcass of goats.

**Keywords** | Ionophores, Ruminal Fermentation, Animal Performance, Carcass Characteristics, Meat Quality

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## INTRODUCTION

Ionophores are polyether antibiotics that modulate the composition of rumen microorganisms and rumen fermentation. The result of this manipulation is increased average daily gain and reduced feed intake, resulting improved feed conversion rate. If there is no negative impact on carcass characteristics, the addition of ionophores is an excellent way to increase livestock production.

A long- valued dream of ruminant nutritionists has been to manipulate and improve the efficiency of ruminal fermentation. Specifically, this objective has been pursued by increasing propionic acid in the rumen, depressing methane production, and reducing the fast ruminal proteolysis and protein deamination in the diet. Ionophores, along with monensin, salinomycin, lasalocid, and tetronasin, have been indicated to modify the function of rumen microorganisms (Bergen and Bates, 1984; Russell and Strobel, 1989; Russell et al., 1991; El-Waziry and Kamel, 2001; El-Waziry, 2002). The effects of ionophores on coccidiosis (Merchen and Berger, 1985), bloat, total counts of Gram-positive cocci (Hoshino et al., 1986; Suda et al., 1995), mixed protozoa (Kobayashi et al., 1988; Suda et al., 1995), mixed rumen fungi (Cann et al., 1993), the acidosis (Nagaraja et al., 1985; Suda et al., 1995) and improving body weight gain (Kobayashi et al., 1989) and feed efficiency (Zhao et al., 1995) had been formerly established. Salinomycin (Suda et al., 1993) and monensin (El-Waziry and Kamel, 2001; El-Waziry, 2002) alter the proportions of ruminal VFAs, with a resulting enhance in propionic acid and reduction in acetic acid. The reduction of amino acid deamination in the rumen is important as a means of increasing the ruminal passage of dietary protein. The rate of ruminal amino acid degradation is the way to determine deamination in the rumen. Ionophores effectively decrease amino acid breakdown, resulting in an inhibitory effect on deamination (Hino and Russell, 1985; Newbold et al., 1990; Hoshino et al., 1992; Okuuchi et al., 1993). Yang et al. (2003) showed that the improvement of weight gain of goats when fed lasalocid without any effect on feed intake or nutrient digestion coefficients and increase N retention. Heydari et al. (2008) reported that the average daily gain and final weight of lambs fed ration containing monensin or lasalocid were significantly higher than those of groups fed a control ration. The feed intake of lambs fed a diet containing monensin was significantly lower than that of lambs fed control or lasalocid diets. Carcass qualities were not affected by monensin, but the dressing percentage and boneless meat were higher in lambs fed a diet containing lasalocid (Heydari et al., 2008). Price et al. (2009) reported that dietary treatment with ionophores had no effect on lamb performance. However, the shortage of literature concerning the impact of nutritional ionophore addition on animal performance and meat quality characteristics of intensively fed lambs or goats must be addressed.

## Review Pattern

Ionophore antibiotics, so named because of their ion-carrying property, are members of a big and developing group of compounds that have the ability to make lipid-soluble complexes with cations and mediate their transport across lipid barriers (Nagaraja, 1995). Due to the variety of cyclic ethers in systems of a few ionophores, they may be additionally called "polyether" antibiotics. These ionophores are created by different strains of Streptomyces (Table 1). All of the ionophores currently in use or being tested as increase promotants for ruminants are categorized as carboxylic ionophores (they own a carboxyl group).

The effectiveness of ionophores can be principally attributed to alterations in ruminal fermentation, enhanced feed efficiency, and an improved weight gain rate. The ruminal fermentation is altered when livestock are fed monensin or lasalocid (Russell and Strobel, 1989; Martineau et al., 2007) or other ionophores, although the effect can vary depending on the type of ionophore (Ngaraja et al., 1987). Bergen and Bates (1984) reported alterations in ruminal fermentation due to ionophore additives in three major areas:

1- the enhancement of energy utilization in the rumen and/or host animal due to an increase in propionate and a reduction in methane emission,

2- the enhancement of the nitrogen utilization in the rumen and/or host animal due to a decrease in protein degradability, resulting in a reduction in amino acid deamination,

3- a reduction of ruminal disorders due to a decrease in lactic acid production.

**Table 1:** Ionophore under study for use in ruminant diets

| Ionophore | Producing organism |
|---|---|
| Monensin | *Streptomyces cinnamonesis* |
| Lasalocid | *Streptomyces lasaliensis* |
| Salinomycin | *Streptomyces albus* |
| Tetronasin | *Streptomyces longisporofavus* |
| Narasin | *Streptomyces aureofaciens* |
| Laidlomycin | *Streptoverticillum eurocidicum* |
| Lysocellin | *Streptomyces longwoodensis* |

(Adapted from Nagaraja, 1995)

Most studies have shown that when ruminants are fed ionophores, alterations in rumen fermentation are observed, including an increased of propionate and decreased proportions of acetic and butyric acids (Raun et al., 1976; Singh and Mohini, 1999). The proportional increase in the utilization of energy diet due to the increase in the proportion of propionic acid. The increase in propionic acid is lower in animals that consume a high grain-containing diet (higher energy) compared to animals that consume a high roughage diet (lower energy). In the rumen, the relation improvement is lower in cows eating high energy feeds (high grain) that already have extents of propionic acid than in cows eating low energy feeds (high roughage) (Table 2).

When animals are fed ionophores, the increase in propionate may result in hydrogen utilization due to decreased methane production. Slyter (1979) suggested that some of the enhance in the propionic acid proportion when ruminants are fed monensin is neutral of its influence on methane emission because acetic acid is changed to propionic acid even when methane is not produced in culture. Monensin and salinomycin inhibit biodehydrogenation, resulting in the release of unsaturated fatty acids from the rumen, which are then deposited in body tissues (Wakita et al., 1989; Kobayashi et al., 1992; Barclay et al., 1986). When lasalocid was added to the diet improves propionate rate and decreases methane emission (Fuller and

**Table 2:** Concentration (mM) and Proportion (%) of ruminal volatile fatty acids in cattle fed diets with or without monensin

| | 70% Roughage + 30% Concentrate | | | 50% Roughage + 50% Concentrate | | |
|---|---|---|---|---|---|---|
| **VFA** | **Control** | **Monensin** | **% change from control** | **Control** | **Monensin** | **% change from control** |
| Concentration, mM | | | | | | |
| Acetate | 70 | 61[a] | -13 | 65.8 | 55.9[a] | -15 |
| Propionate | 19 | 23[a] | +21 | 41.1 | 41.9[a] | +2 |
| Butyrate | 10 | 8[a] | -20 | 13.5 | 9.1[a] | -33 |
| Proportion, % | | | | | | |
| Acetate | 71.0 | 66.8[a] | -6 | 53.5 | 51.3[a] | -4 |
| Propionate | 19.1 | 24.7[a] | +29 | 33.4 | 38.4[a] | +15 |
| Butyrate | 9.9 | 8.5[a] | -14 | 11.0 | 8.3[a] | -25 |

[a] Different from control.
(Adapted from Rogers and Davis, 1982; Nagaraja, 1995).

Johnson, 1981). Singh and Mohini (1999) reported that the VFA concentration did not vary among the studied groups, while there was a significant increase in the proportion of propionic acid and a decrease in the proportion of acetic and butyric acids in the rumen of animals fed rumensin. Related findings were informed by Gado (1997) and in agreement with the results of El-Waziry and Kamel (2001) and El-Waziry (2002). These authors found that the proportion of acetate was significantly decreased when monensin was supplemented to the control diet; while supplementation with monensin significantly increased the proportion of propionate, the molar concentration of butyrate was slightly decreased. Kobayashi et al. (1986) reported that when salinomycin was added to animal feed, the ruminal VFA proportions changed to reflect improved propionic acid and reduced acetic acid, although the ruminal pH was not altered. Propionate is utilized more than that of acetate by host tissues (Ørskov et al., 1991). Furthermore, when more propionic acid is produced in the rumen, the efficiency of fermentation is enhanced because of improvements in hydrogen metabolism (Chalupa, 1984) and may due to the propionate gives a lower heat increment than acetate and thus provides more energy (Ørskov et al., 1979). Improving the carbon retention and energy in the rumen results in enhanced animal performance (Hungate, 1966; Chalupa, 1980). Supplementation with monensin allows the host animal to retain approximately 20% more metabolizable energy (Rowe et al., 1981) and results in a 5.6% energy savings for the animal (Richardson et al., 1976). Further researchers have indicated that the lower heat increment may be due to the increase in propionic acid (Blaxter and Wainman, 1964; Smith, 1979), resulting in excess amino acids that are utilized for gluconeogenesis and increase protein synthesis (Leng et al., 1967; Eskeland et al., 1974).

Recently, Martinez et al. (2022) reported that although an interaction between ionophore of monensin and protein supplement was observed on the acetate: propionate ratio, these results remind that the addition of monensin to protein for cattle consuming low quality forage will not give any addition of improving of intake or digestion compared without any additive. In addition, monensin is identified to modify the ratio of acetate:propionate (Linneen et al., 2015; Bell et al., 2017); the propionate molarity increases at the rate of acetate. Propionic acid is a more gluconeogenic VFA; hence, monensin enhances propionate obtainability for glucose creation. Linneen et al. (2015) stated related data with acetate to propionate ratio reducing for steers consuming monensin compared to steers fed diet without monensin.

The ruminal pH did not change when animals were fed ionophores (Saleh, 2002; Garcia et al., 2000; Gado, 1997; McAllister et al., 1994; Newbold et al., 1993) as shown in Table (3).

**Table 3:** Effect of ionophores on ruminal pH

| | **Control** | **Control + Ionophore** | **Reference** |
|---|---|---|---|
| Monensin | 6.73<br>6.8<br>6.45 | 6.75<br>6.9<br>6.54 | Newbold et al., 1993<br>Gado, 1997<br>Garcia et al., 2000 |
| Salinomycin | 7.20 | 7.20 | McAllister et al., 1994 |
| Lasalocid | 5.92 | 6.20 | Saleh, 2002 |
| Tetronasin | 6.73 | 6.75 | Newbold et al., 1993 |

The feed additives of ionophores such as monensin, salinomycin, and lasalocid may inhibit methane production by stimulating hydrogen production (Van Nevel and Demeyer, 1977; Slyter, 1979; Chalupa et al., 1980; Fuller and Johnson 1981; Jalc et al., 1992). Schelling (1984) and Rumpler et al. (1986) observed that methane production in the rumen was decreased by 4 to 31% due to the increasing in propionate and reducing in $H_2$ and formic acid (Van Nevel and Demeyer, 1977; Dellinger and Ferry, 1984). Moreover, the reduction of methane possibly due to a reduction of the nickel concentration by monensin, which reduces the presence of methanogens (Jarrell and Sprott, 1983; Daniels et al., 1984). Contrary, methane production in the rumen of cows was unaffected when diets with or without monensin were supplemented with nickel (Oscar et al., 1987). Van Nevel and Demeyer (1977) and Russell and Martin (1984) demonstrated that the production of methane was unchanged by the addition of monensin when $CO_2$ and $H_2$ were provided (Chen and Wolin, 1979).

Dinius et al. (1976) performed that ruminal ammonia nitrogen ($NH_3$-N) was decreased in cows fed monensin containing a forage diet. Newbold et al. (1993) and El-Waziry (2002) found that ruminal $NH_3$-N concentrations were decreased when tetronasin or monensin was added to the control diet; however, when salinomycin was added to an artificial rumen, the $NH_3$-N concentration increased (McAllister et al., 1994). Gado (1997) confirmed that the $NH_3$-N concentration unchanged with the addition of monensin in the diet. Saleh (2002) found that the same manner of the amount of $NH_3$-N in rumen liquor when lasalocid was added. Goodrich et al. (1984) reported that protein degradability decreased when Rumensin was added to the diet, resulting in reduce in $NH_3$ in the rumen. Monensin is used to prevent bloat in Australia (Lowe et al., 1991; Cameron and Malmo, 1993) hence the results of soluble protein in the rumen was decreased. Zhao et al. (1995) reported that the degradability of protein was declined when salinomycin was added to the diet of goats. The ruminal degradation of DM and CP reduced when monensin was added to a control diet (El-Waziry, 2002). El-Waziry and Kamel (2001) and El-Waziry (2002) observed an increase in microbial nitrogen leaving the rumen with the addition of monensin in the diet. The escape protein from ruminal degradation was increased in the presence of monensin in an in vivo trial (Poos et al., 1979; Owens, 1980; Isichei, 1980). The undegraded dietary protein increased from 22 to 55% in five different experiments using monensin as feed additive . The investigations of Dinius et al. (1976), Van Nevel and Demeyer, 1977; Wallace et al., 1981; Whetstone et al., 1981, Russell and Martin, (1984), Newbold et al. (1990), Wallace et al. (1990), and Chen and Russell (1991) concluded that the decrease in ruminal ammonia nitrogen was primarily caused by a reduction in protein degradability in the rumen. Monensin affected peptide degradation and deamination of amino acid in the rumen more than the breakdown of protein (Van Nevel and Demeyer, 1977; Wallace et al., 1981; Whetstone et al., 1981; Newbold et al., 1990) (Table 4).

The capability of ionophores to inhibit proteolysis is decreased when ionophores unaffected ruminal bacteria (Chen and Wolin, 1979). Yang and Russell (1993) observed that the bypass of amino acids in the rumen was increased when the diet contained monensin, and the quantity of amino acid was dependent on the protein sources. The utilization rate of protein by the animal depends on the deamination process in the rumen, which produces ammonia (Tamminga, 1979).

Ionophores inhibit ammonia-producing bacteria, resulting in a reduction in the breakdown of peptides and deamination of amino acid (Yang and Russell, 1993; Newebold and Wallace, 1989). In the rumen, Starnes et al. (1984) concluded that the addition of ionophores caused a decreasing in urease activity. Hanson and Klopfenstein (1979) reported that changes in nitrogen utilization due to ionophores depend on protein sources in the diet; the highest utilization occurred when the protein in the diet was more fermentable in the rumen.

Supplementation with ionophores is effective at reducing ruminant diseases such as acidosis due to their ability to alter ruminal fermentation (Nagaraja, 1995). Ionophore antibiotics reduce acidosis because they selectively inhibit Gram-positive bacteria but do not have an effect on Gram-negative bacteria, such as those that produce lactic acid (Dennis et al., 1981). Nagaraja et al. (1981) stated that monensin and lasalocid have been helpful at inhibiting lactic acidosis in cows congested with glucose solution or grain. However, lasalocid appeared to be more effective at stating ruminal pH and avoiding lactic acid accretion than monensin. Cattle exposed to experimental acidosis and treated with a diet containing ionophores exhibited more ruminal pH and lesser lactic acid concentrations than those fed a control diet (Nagaraja et al., 1985; Burrin and Britton, 1986). Newbold et al. (1993) mentioned that the concentration of lactic acid observed to be lower in ionophore (monensin or tetronasin)-supplemented animals.

Frothy bloat is a disorder in ruminants caused by eating a diet containing legumes such as alfalfa and a large amount of grain or a mixture of feeds that contain microorganisms that influence digestion in the rumen (Clarke and Reid, 1973). Monensin supplementation is highly effective at reducing the prevalence of feedlot bloat, and this measurable impact is related to a lower in ruminal fluid viscosity (Sakauchi and Hoshino, 1981). Bartley et al. (1983) suggested that all ionophores are similarly effective at reducing bloat. The rate of rumen turnover is reduced when monensin is added to the diet (Lemenager et al., 1978; Allen and Harrison, 1979). The effect of monensin on feed intake is due to a decrease in rumen turnover (Lemenager et al., 1978). The decrease in feed intake might be caused

**Table 4:** Effect of menensin on the extent of escape from ruminal degradation of different protein sources

| | Extent of escape | | |
|---|---|---|---|
| **Diet and protein source** | **Control** | **Monensin** | **Reference** |
| | % | | |
| Feedlot plus brewers dried grain | 100 | 137 | Poos et al.(1979) |
| Feedlot plus urea supplement | 100 | 155 | Poos et al.(1979) |
| Rolled corn plus protein supplement to 16% | 100 | 122 | Owens (1980) |
| Corn silage plus soybean | 100 | 152 | Isichei, (1980) |
| Ground corn, corn silage plus soybean | 100 | 136 | Isichei, (1980) |

**Table 5:** General response of beef cattle to ionophore

| | | **Grain-fed** | | **Pasture-fed** |
|---|---|---|---|---|
| **Ionophore** | **Intake** | **Gain** | **Efficiency** | **Gain** |
| Monensin | ↓ | 0 | ↑ | ↑ |
| Lasalocid | 0, ↑ | ↑ | ↑ | ↑ |
| Salinomysin | 0, ↓ | 0, ↑ | ↑ | ↑ |
| Tetronasin | ↓ | 0, ↑ | ↑ | ↑ |
| Narasin | ↓ | 0 | ↑ | NA |
| Laidlomycin | 0, ↑ | ↑ | ↑ | NA |
| Lysocellin | ↓ | 0, ↑ | ↑ | ↑ |

↑, Increase; ↓, Decrease; 0, No change; NA, Data not available
Adapted from Nagaraja, (1995).

by the testes of ionophores or due to a decrease in rumen motility (Nagaraja, 1995; Deswysen et al., 1987). Nagaraja (1995) reported that ionophore, particularly monensin, has gained varied assent in the cattle feeding industry. Generally, the feed additives ionophores has improved feed conversion but effects on body weight gain and feed intake have been varying. When animals fed grain, ionophores generally lower feed intake, but body weight gain is improved or unaffected and feed conversion is improved. In pasture fed cattle, ionophores do not effect on feed intake but body weight gain is improved, thus resulting in improved feed conversion (Table 5).

A diet containing ionophores increases feed efficiency. When animals are fed grain and ionophore-containing diets, the feed intake decreases, the average daily weight gain increases or is unchanged, and the feed efficiency is enhanced. Van der Merwe et al. (2001) found that the average daily weight gain of cows fed a diet -contained monensin was higher than those fed the control diet; this enhancement was attributed to VFA production. Stock et al. (1995) informed that the growth rate of animals was improved by 2.8% by a monensin-containing diet in four feedlot trails. Nakashima et al. (1982) reported that the addition of salinomycin increased feed conversion by 12%. Gado (1997) found that goats fed monensin-supplemented rations had lower dry matter intake. Xu (2014) reported that the supplementation of monensin with a higher level of 44 mg/kg monenesin than the currently practical level of 28 mg/kg monensin had no effect on growth performance rate, feed efficiency and carcass characteristics, although dry matter intake was decreased. Neumann et al. (2018) suggested that when monensin was added to the diet of young bulls, it improved the production and economic performance without residues in edible tissues. Salinomycin ionophore when fed to Barki sheep diet increased the lean quantity, decreased the fat quantity and decreased meat brightness score (Shaaban et al., 2021). However, there is varying evidence assistant these concerns, whereas ionophores are still an important dietary implement to improve productivity and profitability in beef cattle production systems. However, Studies that indicate the effect of ionophores on the characteristics and quality of the carcass have been limited, and there have been few studies on the use of ionophores in the diet of goats. Therefore, more studies are needed as for the effect of ionophores as feed additives on carcass characteristics and meat quality of goats.

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## CONFLICT OF INTEREST

The authors declare no competing financial interest.

## AUTHORS CONTRIBUTION

The manuscript was written by Ahmed M. El-Waziry, Saeid M. Basmaeil and Gamaleldin M. Suliman, and edited by Ibrahim A. Alhidary, Mutassim M. Abdelrahman and Maged A.Al-Garadi. All authors read and approved the final manuscript.

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