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Impact of Malic Acid Supplementation on the Performance, Rumen Fermentation, Biochemical Parameters and Antioxidant Status in Lambs

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Abstract

DIETARY malic acid (MA) can be used to activate the rumen and participate in fatty acid conversion, which are promising techniques for ruminant nutrition. Therefore, the presented study evaluated the effects of malic acid supplementation on lambs' performance, biochemical, antioxidant status, and rumen fermentation. A total of 30 Barki lambs were randomly assigned to three groups. (i) C, served as the control group. (ii) 0.5% MA and (iii) 1% MA were supplemented with 0.5% and 1.0% malic acid of dry mater, respectively. The results reported that the low dose of MA (0.5% MA) had the highest values of the digestion coefficients of nutrients and a significant increase in the cell wall constituents compared to 1% MA and C. Furthermore, the 0.5%MA was significantly higher nutritive values, including nitrogen consumption, TDN and DCP parameters. In addition, there was a significant decrease in ammonia nitrogen content, NH3-N, while the VFA's were significantly higher in the 0.5% MA than in the C. However, the T3 and T4 concentrations were significantly higher in the 1% MA and 0.5% MA compared to C after 1, 3, and 6 h/day of MA treatment. Also, the GSH-Px concentrations were significantly higher in the 1% MA compared to C and 0.5% MA after 1 and 3 h of MA supplementation. It could be concluded that supplementation with 0. 5% MA of the dry matter improves lambs' performance, biochemical and antioxidant status, and rumen fermentation.

Keywords: malic acid, Barki lambs, lambs' performance, antioxidant status, rumen fermentation.

Introduction

Among all forms of energy, organic acids play an important role in energy supply at the rumen level [1]. Improved rumen activity will also benefit the host by increasing nutrient availability and promoting higher average daily weight gain and improving feed conversion [2]. Thus, efforts are being made to increase the supply of glucose by using metabolic modifiers [3]. An organic acid such as malic acid (MA) is reported to be effective for this purpose [4]. MA is a hydroxycarboxylic acid, and can play an important role in improving rumen fermentation as one of the organic acids present in the rumen [5]. Supplementation of MA is known to increase the efficiency of the microbial production of propionate [6], and the production of propionate and glucose is associated with a decrease in methane emissions from the animal [7]. Furthermore, the external supply of MA encourages inhibited fatty acid oxidation in the liver and suppresses ketogenesis [8]. In sheep, MA has increased the de novo synthesis of glycogen in the liver, influencing the apparent metabolism of propionate [9]. Additionally, feeding MA can increase the benefits of converting feed energy into stimulate microbial production [10]. However, MA plays a vital role to improving metabolism in animal tissue via oxidation by malic dehydrogenase to form free malic acid [11]. Furthermore, MA has been linked to improved microbial N production and microbial efficiency [12], decreased methane production and increased feed digestibility [13], and increased rumen pH [14]. Several studies have reported that malic acid is beneficial for increasing the efficiency of rumen microbial populations and metabolically active bacteria on the in vitro level [13, 15]. Additionally, considering the lower cost of malic acid, compared to commercial buffers and the attention given to the performance of minor feed additives [16]. Therefore, it was necessary to shed light on the use of malic acid as feed additives as a field study and investigation on the performance, biochemical parameters, antioxidant status, and rumen fermentation in lambs. The current study explores the hypothesis that malic

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acid enhances rumen metabolism and serves as an effective experimental instrument.

Material and Methods

Study Location

The present study was conducted at the Noubarian Experimental Station, Animal Production Research Institute, Agricultural Research Centre, Alexandria, Egypt.

Animals and experimental ration

The study included 30 Barki ram lambs (6 months old with an average body weight 21.24±0.69 kg) were divided into three groups (10 lambs each). Before and during the trial, all animals were in good health with typical clinical signs. Before the trial began, each lamb was vaccinated against the majority of the illnesses and dewormed in accordance with veterinary advice. The animals received oxytetracycline LA (1 ml/10 kg) as a preventive therapy against bacterial illness. They were also given Ivermectin® (1 mL/10 kg) to treat ectoparasites and endoparasites. All animals were housed in naturally distinct pens with separate food and watering facilities. All animals were kept at normal photoperiod and temperature. Fresh water was always available. All animals were given a daily meal prepared in accordance with National Research Council (NRC, 2002) guidelines for sheep. Table 1 shows the Chemical composition of concentrate feed mixture, Rice straw and Corn silage.

Experimental design

The ram lambs were randomly assigned to three groups (10 animals in each): (i) C, which served as the control group. (ii) 0.5% MA supplemented group and (iii) 1% MA supplemented group were treated with 0.5% and 1.0% malic acid (MA) of dry matter, respectively. MA (C4H6O5; HOOC-CH2-CHOH2-COOH) in convenient powder form with more than 99.9% purity was obtained from Al-Gomhouria Company, Cairo, Egypt. Throughout 60 days trial, the animals were fed twice a day at 8:00 a.m. and 5:00 p.m., and any leftover food was gathered and weighed. Throughout the trial, feed intake was monitored.

Biological Evaluation

The biological evaluation of the different groups was carried out by determining body weight at the initial (IW) and final weights (FW), as well as determining body weight gain (BWG) using the following formulas: BWG = Final weight - beginning weight.

Apparent digestibility trial

The digestibility trial was conducted at the end of the experiment with three ram lambs of each group and lasted for seven days. Every 24 h, faces were gathered in plastic bags and weighed.

Each animal's daily feces were sampled at 5% at 0, 1, 3, and 6 h after MA treated, with 10% formaldehyde and 10% H2SO4 solution, and kept in an airtight container for chemical analysis. Using the direct approaches, the digestion coefficients of the nutrients for each of the experimental meals were determined.

Chemical analysis

The ration's components were powdered, dried, and sampled before being examined for various nutrients. Over the course of the collection period, the total amount of voided fecal matter per animal was weighed, recorded, and thoroughly mixed. Representative samples were taken from each animal and dried at 60°C for 24 h before being combined, pulverized, and stored until analysis. In accordance with AOAC (2011), the proximate composition of the experimental diets and feces (dry matter, crude protein, ether extract, crude fiber, ash, and nitrogen free extract) was ascertained.

Sampling and analysis of rumen liquor

Rumen fluid specimens (about 100 ml) were collected with a rubber stomach tube and placed in a dry, clean cup before being forwarded to the lab for analysis. Rumen samples were immediately analysed for pH with a digital pH meter. After that, the samples were sieved through four layers of sterile gauze and used in the following methods. Two millilitres fixed in strong acids to measure the concentration of volatile fatty acids, and two millilitres fixed in formal saline to assess the content of ammonia-N. Biochemical analysis included calculations of the concentration of total volatile fatty acids (TVFAs) using the Macro Kjeldahl steam distillation method [17], rumen ammonia nitrogen concentration determined using specialized kits supplied by Spectrum Company, Egypt [18].

Biochemical Assays

A total of 30 blood samples (10 animal × 3 groups × 1 time) were collected from the jugular vein at the end of the experimental after 120 days of the MA supplementation. Blood samples were centrifuged at 3000 x g for 15 min, and the resulting serum samples were obtained and stored at −20 °C until further analysis. Serum triiodothyronine (T3) and thyroxine (T4) concentrations were also analyzed using ELISA kits (Atlas Medical Co, CB4, 0WX United Kingdom; UK). Glutathione peroxidase (GPX) activity was determined according to the protocol described by Paglia and Valentine (1967). Serum glucose and urea were determined according to Caraway and Watts (1987) using assay kits supplied by Diamond Chemical Company, Germany. AST, ALT, cholesterol were determined according to Young (1975 and 1990) using assay kits supplied by Spectrum Chemical Company, Egypt. Total protein and Creatinine were determined according to Tietz

(1986 and 1994) using assay kits supplied by Spectrum Chemical Company, Egypt.

Statistical analysis

The submitted data was statistically analysed using SPSS for Windows 25 (SPSS, Chicago). The Kolmogorov-Smirnov test validated the normal distribution of the data. The data was analysed using a one-way ANOVA, followed by Duncan's multiple range test, according to the following General Linear Model: $Yij = \mu + Ti + Eij$. Where Yij = experimental observation, μ = general mean, Ti = effect of treatments (i = C, 0. 5%, and 1% MA), and eij = experimental error.

Results

Biological Evaluation, Nutrient digestibility and apparent digestibility coefficients

Data in Table 2 shows the biological evaluation, apparent and nutritional digestibility coefficients of lambs treated with MA. Body weight gradually increased ($P \leq 0.05$) in lambs treated with MA (0.5% MA and 1% MA) starting in the 2nd week compared to C. However, the digestion coefficients of nutrients were significantly ($p \leq 0.05$) affected by MA supplementation, and the low dose of MA (0.5% MA) had the highest ($p \leq 0.05$) values of the digestion coefficients of nutrients (DM, OM, CP, CF, and EE). However, there was a significant increase in the cell wall constituents (NDF, ADF, and ADL) in the 0.5% MA compared to the 1% MA and C (Table 3).

Dry matter intake (g/h/d) and nutritive values

Table 4 shows the dry matter intake (g/h/d) and nutritive values of lambs treated with MA. There were no significant changes in the DM consumption of CFM, RS, corn silage, or total feed intake (g/h/d) among the MA-supplemented meals. Furthermore, nutritive values, including TDN% and TDN consumption (g/h/d), reported that 0.5% MA was considerably greater ($P \leq 0.05$) than 1% MA and C, with C having the lowest value. Moreover, compared to the C and the 1% MA, the DCP% and DCP consumption values were considerably higher ($P \leq 0.05$) in the 0. 5% MA.

Nitrogen utilization

Table 5 shows nitrogen utilization in lambs treated with MA. Nitrogen consumption parameters (NI, NA, NB, NBI, and NBA) were significantly higher ($P \leq 0.05$) in the 0.5% MA compared to C and 1% MA.

Ruminal parameters

Tables 6 and 7 show the results of ruminal parameters after 0, 1, 3, and 6 h of lambs treated with MA. The pH of the rumen was no significant difference, but there was a significant ($P \leq 0.05$) decrease in ammonia nitrogen content, NH3-N (mg/100 ml), in the MA supplemented groups (0.5% and 1% MA) compared to the C (Table 5). However, the volatile fatty acid content (VFA's; mmol/100 ml), was significantly higher in the MA supplemented groups (0.5% and 1% MA) than in the C (Table 5). In addition, the 0.5% MA supplemented group was significantly higher ($P \leq 0.05$) in the rumen volume (L), rumen digesta (kg), and microbial protein (MP, g/d), compared to the C and 1% MA groups. In contrast there was a significant decrease in the rate of outflow (% hr) in the 0.5% MA and 1% MA than in the C (Table 6).

Serum Biochemical Parameters

The energy-related indicators showed no significant changes in glucose levels (mg/dl), but cholesterol levels (mg/dl) were significantly higher ($P \leq 0.05$) in the 1% MA supplemented group compared to the C and 0. 5% MA groups (Figure 1). Furthermore, there were no significant variations in creatinine levels (mg/dl) among the groups. While urea and total protein levels (mg/dl) were significantly ($P \leq 0.05$) higher in 0.5% MA and 1% MA compared to C (Figure 2). On the other hand, the data presented in Figure 3 reported that there were no significant differences between groups in ALT and AST levels (U/L).

Serum levels of thyroid hormones

The concentrations of triiodothyronine (T3) and thyroxine (T4) of lambs treated with MA are presented in the Figures 4 and 5. There were no significant increases in T3 and T4 concentrations (ng/ml) at the time of the MA's beginning feeding (0 h/day). However, the T3 and T4 concentrations (ng/ml) were significantly greater ($P \leq 0.05$) in the 1% MA and 0. 5% MA supplemented groups compared to C after 1, 3, and 6 h/day of MA treatment.

Serum levels of glutathione peroxidase

The concentrations of Glutathione peroxidase (GSH-Px; Uml) of lambs treated with MA is presented in Figures 6. There were no significant changes in GSH-Px; (Uml) at the time of the MA's initial feeding (0 h per day). However, GSH-Px concentrations were significantly higher ($P \leq 0.05$) in the 1% MA compared to C and 0. 5% MA after 1, 3 h of MA supplementation, while, after 6 h of MA supplementation, the GSH-Px concentration was significantly higher ($P \leq 0.05$) in the 1% MA and 0. 5% MA groups compared to C.

Discussion

This study effectively sheds insight on the usage of MA as a feed additive to improve lambs' performance. The study's results indicated that MA supplementation markedly improved the rumen fermentation; it improved digestion coefficients of nutrients and caused a significant increase in the cell

wall constituents. In this study, improved rumen activity with MA supplementation was beneficial for the host through increased microbial protein and nitrogen consumption; in addition, there was a decrease in ammonia nitrogen content, NH3-N, and an increase in VFA's. Our study reported that the low dose of MA induced a significant enhancement of the digestion coefficients of nutrients. This result is consistent with earlier research that showed that MA in diet enhances the gastrointestinal tract environment and digestion coefficients in the ruminants [19, 20], while reduced amounts raise questions about low doses of MA' mechanisms of action as metabolic modulators [21, 22].

MA enhances cell wall digestibility in ruminants, particularly those on high-roughage diets [14]. Also, the dry matter consumed by ruminants is in the form of cell wall polysaccharides [23]. The study found significant improvements in the cell wall constituents (NDF, ADF, and ADL) in the 0.5% MA compared to the 1% MA and C. Furthermore, ruminants rely on cellulolytic bacteria and ciliated protozoa for energy and protein [24].

In the presented study, nitrogen consumption parameters (NI, NA, NB, NBI, and NBA) were significantly higher in the 0. 5% MA compared to the C. These results can be supported by the fact that MA reduces ammonia volatilization or compounds that increase microbial nitrogen synthesis in the diet [25], as a salt generated in the cycle of tricarboxylic acid can lower the ruminal pH and increase the utilization of nitrogen by the organism [26].This study showed a significant decrease in ammonia nitrogen content, NH3-N; in the MA-treated group compared to the C group. This result agrees with Burchill et al. [27] reported that, using organic acid has a high ammonia concentration in NH3-N decreased by 22% and nitrogen excretion decreased by 14.9% and was successfully applied to dairy cattle. Also, minimal levels of NH3-N in the rumen support the growth of both beneficial bacteria and bacteria that produce organic acids [28].

However, this study reported that the VFAs were significantly higher in the C+MA than in the C. This result agrees with Liu et al. [29] found that the malic acid caused an increase in the total rumen VFA concentrations in early lactating cows. VFAs are the primary energy source for the host and are also essential in gluconeogenesis and the maintenance and improvement of tissues [30, 31]. This study found that the T3 and T4 concentrations were significantly greater in the lambs treated with MA compared to C. Hamdon et al. [32] reported that the lambs' thyroid hormone levels were higher, while Mousa et al. [33] revealed that probiotic supplementation increased the lambs' T3 and T4 hormone levels. Also, T3 and T4, the two main thyroid hormones, are important modulators of the body's energy metabolism [34].

In the presented study, GSH-Px concentrations were significantly higher in the 1% MA compared to C and 0. 5% MA groups after 1–3 h of MA treatment, while after 6 h, they were significantly higher in the 1% MA and 0.5% MA groups compared to C. GSH-Px consists of a group of enzymes that help protect body tissue from damage due to oxidation [35, 36]. According to Yousefi et al. [37], the activity of GSH-Px was significantly increased by feeding 0.5 and 1% of MA. A prospective acidifying agent with a potent antioxidant capability is malic acid, an intermediary of the tricarboxylic acid cycle [38].

Conclusion

This study concluded that the low dose of MA (0.5% MA) may improve the nutritional digestibility coefficients and cell wall constituents; additionally, it enhanced dry matter intake, nutritive values (TDN and DCP), and nitrogen consumption. Furthermore, the ruminal fermentation may be improved by being treated with MA (0.5% or 1% MA), resulting in a decrease in ammonia nitrogen content (NH3-N) and an increase in volatile fatty acid content (VFA's). Additionally, treatment with MA may enhance serum biochemical parameters, thyroid hormones, and antioxidant biometric parameters. The study's findings support the idea that the technique that uses supplementation with MA can subsequently improve the performance of lambs. Finally, the presented study recommends the use of a low dose of MA (0.5% MA) as a feed additive for ram lambs to improve their performance.

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Funding statement

Not applicable.

Declaration of Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest

Ethical of approval

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to. This study was conducted in accordance with institutional and national guidelines for the care and use of animals, according to the Egyptian Medical Research Ethics Committee (no. 14–126).

TABLE 1. Chemical composition of concentrate feed mixture, Rice straw and Corn silage.

Chemical Composition, %	Concentrate feed mixture	Rice Straw	Corn Silage
Dry matter, DM	88.58	89.52	32.98
Organic matter, OM	94.31	90.42	94.03
Crude protein, CP	13.62	3.71	7.82
Crude fiber, CF	7.31	39.18	25.64
Ether extract, EE	2.53	1.06	1.98
Nitrogen-free extract, NFE	70.85	46.47	58.59
Ash	5.69	9.58	5.97
Neutral detergent fiber, NDF	33.49	69.06	57.06
Acid detergent fiber, ADF	19.37	53.72	27.49
Acid detergent lignin, ADL	3.29	9.01	3.36

Mineral–vitamin premix provided the following per kilogram of diet: vitamin A, 150 000 UI; vitamin E, 100 mg; vitamin K3, 21 mg; vitamin B1, 10 mg; vitamin B2, 40 mg; vitamin B6, 15 mg; pantothenic acid, 100 mg; vitamin B12, 0.1 mg; niacin, 200 mg; folic acid, 10 mg; biotin, 0.5 mg; choline chloride, 5000 mg; Fe, 0.3 mg; Mn, 600 mg; Cu, 50 mg; Co, 2 mg; Se, 1 mg; and Zn, 450 mg.

TABLE 2. Chemical composition of concentrate feed mixture, Rice straw and Corn silage. Where FCR

Items	Malic acid		
	C	0.5%MA	1%MA
		Body Weight (Kg.)	
Initial weight	21.24±0.69	22.09±1.37	22.94±0.91
1st Week	22.65±0.69	26.08±1.31	25.33±1.10
2nd Week	23.95±0.74[b]	28.32±1.63[a]	27.34±1.27[a]
3rd Week	25.18±0.84[b]	30.12±1.45[a]	29.09±1.40[a]
4st Week	26.48±0.88[b]	32.35±1.77[a]	31.09±1.56[a]
Final Weight	27.36±0.96[b]	33.64±1.64[a]	32.34±1.68[a]
Body Weight Gain (BWG)	6.11±0.33 [b]	9.54±0.30 [a]	9.40±0.80 [a]
Total feed intake	1028.73±41.88	1066.93±31.77	1009.97±54.15

[ab] Means within rows with different superscript are significantly differ (P ≤ 0.05).

TABLE 3. Effects of MA treatment on apparent digestibility coefficients.

Items	Malic acid		
	C	0.5%MA	1%MA
Dry matter (DM)	59.41±0.86[b]	63.27±0.63 [a]	59.15±1.07 [b]
Organic matter (OM)	60.90±1.69 [b]	65.71±0.44 [a]	62.16±1.63 [b]
Crude protein (CP)	57.77±1.07 [b]	64.42±0.52 [a]	58.98±1.11 [b]
Crude fiber (CF)	55.86±2.51 [b]	60.58±0.86 [a]	57.22±1.08 [b]
Ether extract (EE)	70.81±1.86 [b]	80.74±1.64 [a]	76.96±0.75 [b]
Nitrogen free extract (NFE)	62.11±1.53 [b]	66.93±0.84 [a]	63.56±1.42 [b]
	Cell wall constituents %		
Neutral detergent fiber (NDF)	55.36±1.06 [b]	59.06±0.69 [a]	54.81±0.85 [b]
Acid detergent fiber (ADF)	53.16±0.88 [b]	56.72±0.36 [a]	53.01±0.24 [b]
Acid detergent lignin (ADL)	36.04±0.73 [b]	39.41±0.27 [a]	35.88±0.66 [b]

[ab] Means within rows with different superscript are significantly differ (P ≤ 0.05).

TABLE 4. Effects of MA treatment on dry matter intake (g/h/d) and nutritive values.

Items	Malic acid		
	C-MA	0.5%MA	1%MA
DM intake, g/h/d			
CFM	531.48±0.00	531.48±0.00	531.48±0.00
RS	152.18±19.97	159.35±22.06	136.07±23.96
Corn silage	345.67±29.55	376.08±25.76	342.43±35.07
Total feed intake	1028.73±41.88	1066.93±31.77	1009.97±54.15
	Nutritive values %		
TDN	58.65±1.57 [b]	63.66±0.78 [a]	60.31±1.83 [b]
TDN intake (g/h/d)	603.35±7.87 [b]	679.21±11.06 [a]	609.11±5.66 [b]
DCP	5.89±0.22 [b]	6.50±0.14 [a]	6.08±0.17 [b]
DCP intake (g/h/d)	60.59±0.95 [b]	69.35±0.76 [a]	61.41±1.06 [b]

[ab] Means within rows with different superscript are significantly differ (P ≤ 0.05).

TABLE 5. Effects of MA treatment on nitrogen utilization.

Items	Malic acid		
	Control	**1 % MA**	**2 % MA**
Nitrogen intake (NI)	16.80±0.18 [b]	17.23±0.14 [a]	16.67±0.25 [b]
Nitrogen absorbed (NA)	9.71±0.13 [b]	11.10±0.16 [a]	9.83±0.09 [b]
Nitrogen balance (NB)	3.58±0.45 [b]	6.14±0.11 [a]	3.99±0.38 [b]
NB as percentage of NI (NBI)	21.33±2.69 [b]	35.65±0.57 [a]	23.97±1.07 [b]
NB as percentage of NA (NBA)	36.93±4.33 [b]	55.34±1.64 [a]	40.64±3.84 [b]

[ab] Means within rows with different superscript are significantly differ ($P \leq 0.05$).

TABLE 6. Effects of MA treatment on pH, Ammonia nitrogen concentration and Volatile fatty acids concentration.

Items	Malic acid		
	Control	**0.5 % MA**	**1 % MA**
PH			
0 h	6.67±0.05	6.69±0.02	6.73±0.01
1 h	6.41±0.09	6.46±0.03	6.52±0.12
3 h	6.29±0.08	6.34±0.12	6.39±0.09
6 h	6.61±0.05	6.63±0.06	6.70±0.01
Overall mean	6.49±0.09	6.53±0.06	6.58±0.11
Ammonia nitrogen concentration, NH_3-N (mg/100 ml)			
0 h	12.44±0.26 [a]	10.21±0.16 [b]	10.12±0.23 [b]
1 h	13.88±0.36 [a]	12.11±0.16 [b]	12.09±0.25 [b]
3 h	15.69±0.32 [a]	13.88±0.44 [b]	13.74±0.37 [b]
6 h	14.21±0.29 [a]	11.86±0.32 [b]	11.70±0.28 [b]
Overall mean	14.06±0.31 [a]	12.01±0.17 [b]	11.91±0.24 [b]
Volatile fatty acids concentration, (VFA's) (mmol/100 ml)			
0 h	9.32±0.09 [b]	10.21±0.18 [a]	10.17±0.21 [a]
1 h	10.45±0.15 [b]	11.68±0.19 [a]	11.58±0.33 [a]
3 h	12.11±0.11 [b]	13.74±0.25 [a]	13.69±0.15 [a]
6 h	9.92±0.33 [b]	11.01±0.22 [a]	10.89±0.21 [a]
Overall mean	10.45±0.15 [b]	11.66±0.17 [a]	11.58±0.25 [a]

[ab] Means within rows with different superscript are significantly differ ($P \leq 0.05$).

TABLE 7. Effects of MA treatment on rumen volume (L), rate of out flow (% hr), rumen digesta (kg) and microbial protein (MP, g/d).

Items	Malic acid		
	Control	**1 % MA**	**2 % MA**
Rumen volume (L)			
0	3.28±0.12 [b]	4.35±0.09 [a]	3.31±0.11 [b]
3	3.13±0.10 [b]	4.11±0.12 [a]	3.11±0.12 [b]
6	2.91±0.13 [b]	3.65±0.17 [a]	2.95±0.09 [b]
Overall mean	3.11±0.05 [b]	4.03±0.12 [a]	3.12±0.11 [b]
Rate of out flow (% hr)			
0	5.68±0.21 [a]	4.49±0.31 [b]	4.21±0.37 [b]
3	6.88±0.15 [a]	5.35±0.18 [b]	5.26±0.46 [b]
6	8.23±0.12 [a]	6.47±0.27 [b]	6.33±0.32 [b]
Overall mean	6.93±0.36 [a]	5.44±0.23 [b]	5.26±0.28 [b]
Rumen digesta (kg)			
0	3.71±0.11 [b]	5.01±0.06 [a]	3.76±0.09 [b]
3	3.57±0.09 [b]	4.65±0.05 [a]	3.93±0.10 [b]
6	3.29±0.08 [b]	4.19±0.10 [a]	3.79±0.07 [b]
Overall mean	3.52±0.25 [b]	4.61±0.16 [a]	3.83±0.31 [b]
microbial protein (MP, g/d)	57.85±0.28 [b]	68.44±0.31 [a]	58.42±0.24 [b]

[ab] Means within rows with different superscript are significantly differ ($P \leq 0.05$).

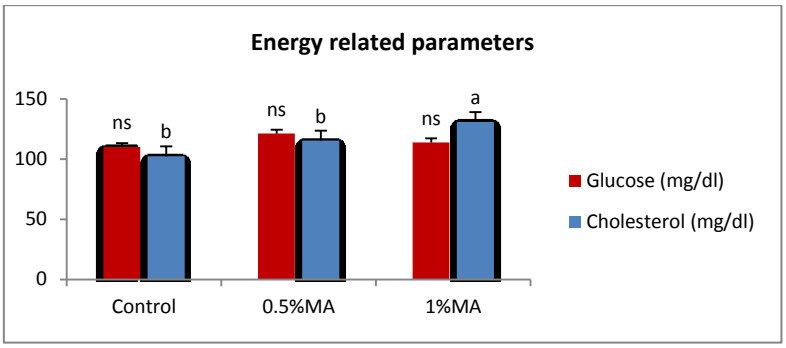

Fig. 1. Effects of MA treatment on blood biochemical (Energy related parameters). ab Means within rows with different superscript are significantly differ (P ≤ 0.05).

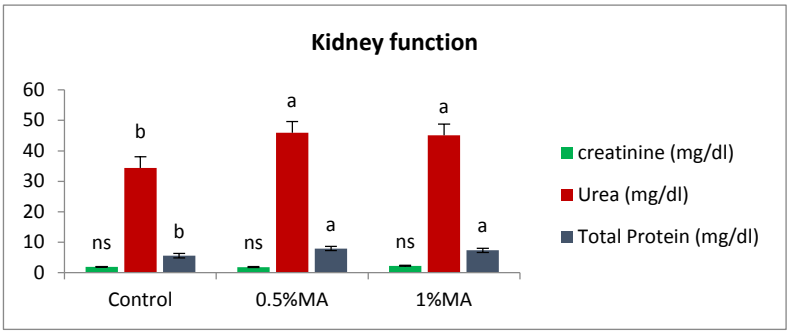

Fig. 2. Effects of MA treatment on blood biochemical (Kidney function). ab Means within rows with different superscript are significantly differ (P ≤ 0.05).

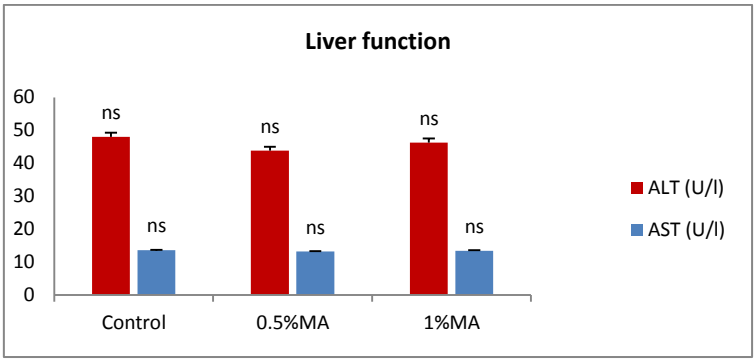

Fig. 3. Effects of MA treatment on blood biochemical (Liver function). [ab] Means within rows with different superscript are significantly differ (P ≤ 0.05).

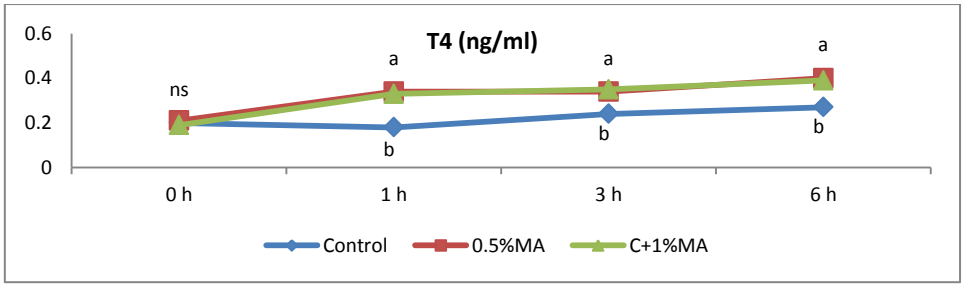

Fig. 4. Effects of MA treatment on the serum levels of thyroid hormones (T4). [ab] Means within rows with different superscript are significantly differ (P ≤ 0.05).

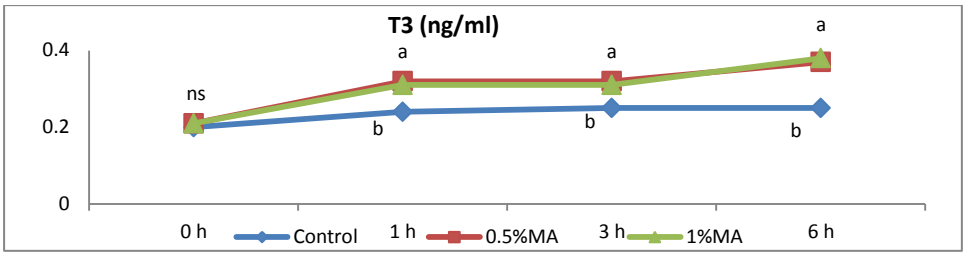

Fig. 5. Effects of MA treatment on the serum levels of thyroid hormones (T3). [ab] Means within rows with different superscript are significantly differ (P ≤ 0.05).

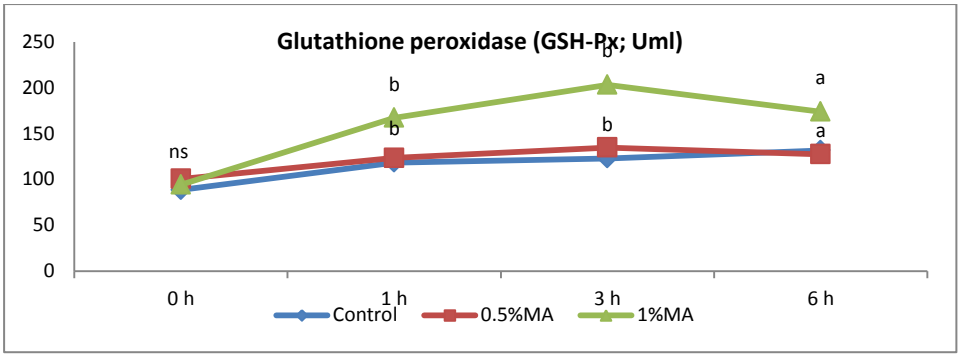

Fig. 6. Effects of MA treatment on Glutathione peroxidase GSH-Px; Uml. [ab] Means within rows with different superscript are sign

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تأثير إضافة حامض الماليك على أداء الحملان ومعاير الدم الكيميائية وحالة مضادات الأكسدة

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الملخص

يمكن استخدام حمض الماليك لتنشيط الكرش والمشاركة في تحويل الأحماض الدهنية، وهي تقنيات واعدة لتغذية المجترات. لذلك، استهدفت هذه الدراسة تقييم آثار مكملات حمض الماليك على أداء الحملان وبعض معايير الدم البيوكيميائية ومضادات الأكسدة وتخمر الكرش. تم تقسيم 30 حمل برقي عشوائيًا إلى ثلاث مجموعات. مجموعة التحكم، مجموعة حمض المالك 0.5٪، مجموعة حمض المالك 1٪. أظهرت النتائج أن الجرعة المنخفضة من حمض المالك (0.5%) كان لها أعلى قيم لمعاملات هضم العناصر الغذائية وزيادة كبيرة في مكونات جدار الخلية مقارنة بمجموعة من حمض المالك 1٪. علاوة على ذلك، كانت نسبة 0.5٪ من حمض المالك أعلى معنوياً في القيم الغذائية، بما في ذلك استهلاك النيتروجين ومعايير TDN وDCP. بالإضافة إلى ذلك، كان هناك انخفاض في محتوى NH3-N وVFA في مجموعة حمض المالك 0.5٪ مقارنة بمجموعة التحكم. ومع ذلك، كانت تركيزات T3 وT4 أعلى بكثير في مجموعة حمض المالك، أيضًا كانت تركيزات GSH-Px أعلى معنوياً في مجموعة حمض المالك 1٪ مقارنة بمجموعة التحكم. يمكن أن نستنتج أن المكملات التي تحتوي على 0.5٪ من حمض الماليك تعمل على تحسين أداء الحملان وتخمر الكرش.

الكلمات المفتاحية: حمض الماليك، حملان البرقي، أداء الحملان، حالة مضادات الأكسدة، تخمر الكرش.