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Posted Date: 9 October 2025

doi: 10.20944/preprints202510.0670.v1

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Supplementation of Oregano Essential Oil at Different Phases of Broiler Chicken Production

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Abstract

Supplementation with oregano essential oil is not necessary in all broiler chicken production phases. The aim of study was to evaluate the effect of Mexican oregano essential oil (MOEO) supplementation at each broiler production phase on overall productivity. A total of 300 1-d-old Ross-308 chickens (49.40 ± 1.30 g) were randomly assigned to five experimental groups considering the production phases. The treatments included a control group without MOEO ($MOEO_0$), and four groups receiving 100 mg/kg MOEO during weeks 1-2 ($MOEO_{12}$), 3-4 ($MOEO_{34}$), 5-6 ($MOEO_{56}$) and 1-6 ($MOEO_{16}$). Feed intake (FI) showed a difference ($P < 0.05$) at 14 and 28 d; $MOEO_0$ and $MOEO_{12}$ had the highest FI. Feed conversion ratio (FCR) showed a trend ($P < 0.10$). The FI per phase was different ($P < 0.05$) in the starter phase, while the grower phase showed a trend ($P < 0.10$); $MOEO_{12}$ exhibited the best FI-based on WI. The $MOEO_0$, $MOEO_{34}$, $MOEO_{56}$, and $MOEO_{16}$ exhibited lower FI. In overall productivity, FCRFI was affected ($P < 0.05$); $MOEO_{12}$ improved the FCR. In conclusion, MOEO broiler diet supplementation during the starter or grower phase can be recommended to improve broiler productivity.

Keywords: feed conversion; feed intake; water intake; weeks; weights

1. Introduction

Poultry farming is seeking alternatives to antibiotics during production, as well as to enhance safety and product quality. Chicken meat is low in fat and high in protein [1]. The age of chickens is an important factor for nutrient absorption, and each production phase is characterized by physiological development of the animal (i.e., organ formation, tissue development and deposition of muscle and fat) to meet the marketing requirements of the carcass [2]. Furthermore, the FAO and WHO established decreased use of antibiotics by up to 50% over the next 10 years [3]. Alternatives for replacing antibiotics are probiotics, enzymes, organic acids and essential oils (EO) from aromatic plants (EOAP). The EO of EOAP thyme, rosemary and oregano have been the most evaluated in broiler production [4]. Oregano essential oil (OEO) has shown good effect for reducing pathogenic bacteria in the intestine, improving antioxidant status and reducing blood cholesterol [5], and improving productive parameters and reducing mortality rates [6]. Mexican oregano essential oil (MOEO) has high concentrations of active compounds such as carvacrol and thymol, and *Lippia berlandieri* Schauer and *Poliomintha longiflora* Gray are the MOEO species more sustainably exploited [7]. Lee *et al*. [8] found that EO supplementation can stimulate carbohydrate digestion, fat absorption and protein transformation. Recently, Meligy *et al*. [9] showed that supplementation of 400 mg/kg of

OEO in feed improved antioxidant activity and intestinal health of broiler chickens. Furthermore, productivity parameters were improved with 300 and 600 mg/kg of OEO in diets [10]. However, studies have used EO supplementation throughout all production phases of grow-out (six weeks or 42 days). It is possible that EOAP, such as OEO, supplementation in diets may be effective when applied at certain phases or time periods of production, because the physiology and metabolism of broiler chickens are changing during their growth. In this study, the effect of MOEO supplementation during each of three production phases of broiler chicken grow-out and continuously overall production phases was evaluated for feed intake, water intake, weight gain and feed conversion rate. The results from this study demonstrated that MOEO supplemented per phase influenced production without continuous prevision over all phases of chicken fattening. This option can improve the profitability of production systems using oregano essential oil.

2. Materials and Methods

The study was carried out over 41 days of grow-out at the Marín campus of the Facultad de Agronomía of the Universidad Autónoma de Nuevo León (UANL), Marín, Nuevo León, México. Marín is located between parallels 25° 45′ and 26° 02′ north latitude, meridians - 100° 06′ west longitude, and average altitude of 850 m, with temperature between 18° to 24° C, and annual precipitation of 600-800 mm. The Marin campus borders to the north with the municipalities of Higueras and Cerralvo, to the south with Pesquería, to the east with Doctor González and to the west with General Zuazua [11].

2.1. Experimental Design Through Diets

The experiment was carried out with 300 1-d-old Ross-308 broiler chicks (49.40 ± 1.30 g), which were randomly assigned to five experimental groups considering production phases [starter, weeks 1 (7 d) and 2 (14 d); grower, weeks 3 (21 d) and 4 (28 d); finisher, weeks 5 (35 d) and 6 (41 d)]. Treatments consisted of $MOEO_0$, control diet without MOEO (0 mg/kg of feed); $MOEO_{12}$, diet with MOEO at 100 mg/kg in weeks 1 and 2; $MOEO_{34}$, diet with MOEO at 100 mg/kg in weeks 3 and 4; $MOEO_{56}$, diet with MOEO at 100 mg/kg in weeks 5 and 6; and $MOEO_{16}$, diet with MOEO at 100 mg/kg from weeks 1 to 6. Each treatment group consisted of 6 replicate pens with 10 broilers per pen. The diets were formulated based on the nutritional requirements of broiler chickens (Nutritional specifications for *Ross*-308 broiler chickens) (Table 1). The experiment was approved (ID 0426/2023) by the biosecurity, bioethics and animal welfare committee of the Facultad de Medicina Veterinaria y Zootecnia, UANL. In addition, the NOM-026-ZOO [12] on production, care and use of laboratory animals was considered in the study.

Table 1. Composition of diets supplemented with Mexican oregano essential oil in the production phases during grow-out.

Ingredients (kg/ton)	Production Phase Diets		
	Starter	Grower	Finisher
Corn, ground	523.06	572.92	623.42
Soybean meal	406.00	354.00	302.00
Soybean oil	26.00	32.00	35.00
Calcium carbonate	14.00	12.00	12.00
Monocalcium phosphate	9.75	8.50	7.25
NaCl	4.10	4.40	4.40
L-lysine	1.18	1.00	1.00
DL-methionine	2.98	2.63	2.38
L-Threonine	0.43	0.05	0.05

 doi:10.20944/preprints202510.0670.v1

Starter premix[1]	12.50	0	0
Grower premix[2]	0	12.50	0
Finisher premix[3]	0	0	12.50
Nutrient composition			
Moisture, %	10.34	11.82	11.79
Metabolizable energy, Kcal/kg[4]	3,004	3,081	3,146
Crude protein, %	23.00	21.40	19.00
Crude fiber, %	2.48	2.84	2.64
Ash, %	5.86	5.59	5.30
Crude fat, %	3.91	4.46	5.60
Non-digestible fiber, %	8.55	8.87	9.18
Calcium, %	1.07	0.97	0.88
Phosphorus, %	0.72	0.6	0.56
Magnesium, %	0.27	0.26	0.23
Lysine, %	1.43	1.28	1.17
Digestible lysine, %[4]	1.30	1.16	1.06
Methionine + cysteine, %[4]	1.05	0.98	0.9
Digestible methionine + cysteine, %[4]	0.98	0.91	0.84
Methionine, %[4]	0.68	0.63	0.58
Digestible methionine, %[4]	0.67	0.61	0.56
Threonine, %[4]	0.97	0.87	0.79
Digestible threonine, %[4]	0.86	0.77	0.69

[1]**Starter premix**: Mg, 4.64%; Ca, 4.25; Mn, 9,750 mg/kg; Zn, 8,888 mg/kg; Fe, 1,600 mg/kg; Cu, 1,300 mg/kg; I, 100 mg/kg; Se, 24 mg/kg; vitamin A, 1,040,000 IU/kg; vitamin D3, 400,000; vitamin E, 6,400 IU/kg; vitamin K3, 320 IU/kg; thiamin, 400 mg/kg; riboflavin, 720 mg/kg; niacin, 5,600 mg/kg; pantothenic acid, 2,000 mg/kg; pyridoxine, 400 mg/kg; Biotin, 80 mg/kg; folic acid, 200 mg/kg; vitamin B12, 1.6 mg/kg; choline, 136,000 mg/kg, Phytase, 80,000 PTU/kg. [2]**Grower premix**: Mg, 4.64%%; Ca, 5.61%; Mn, 4,875 mg/kg; Zn, 4,444 mg/kg; Fe, 1,600 mg/kg; Cu, 650 mg/kg; I, 100 mg/kg; Se, 24 mg/kg; vitamin A, 880,000 IU/kg; vitamin D3, 360,000; vitamin E, 5,200 IU/kg; vitamin K3, 288 IU/kg; thiamin, 320 mg/kg; riboflavin, 640 mg/kg; niacin, 5,200 mg/kg; pantothenic acid, 1,600 mg/kg; pyridoxine, 320 mg/kg; Biotin, 22.4 mg/kg; folic acid, 160 mg/kg; vitamin B12, 1.44 mg/kg; choline, 128,000 mg/kg; Phytase, 80,000 PTU/kg. [3]**Finisher premix**: Mg, 4.32%; Ca, 4.5%; Mn, 4,875 mg/kg; Zn, 4,444 mg/kg; Fe, 1,600 mg/kg; Cu, 650 mg/kg; I, 100 mg/kg; Se, 24 mg/kg; vitamin A, 880,000 IU/kg; vitamin D3, 320,000; vitamin E, 4,400 IU/kg; vitamin K3, 256 IU/kg; thiamin, 240 mg/kg; riboflavin, 560 mg/kg; niacin, 4,000 mg/kg; pantothenic acid, 1,200 mg/kg; pyridoxine, 240 mg/kg; Biotin, 17.6 mg/kg; folic acid, 144 mg/kg; vitamin B12, 1.28 mg/kg; choline, 120,000 mg/kg; Phytase, 80,000 PTU/kg. [4]Calculated analyses.

2.2. Productivity Variables

The initial weight (IW) of chickens was recorded at the beginning of the study. Live chicken weights (CW) were determined per week [1 (7 d), 2 (14 d), 3 (21 d), 4 (28 d), 5 (35 d) and 6 (41 d)]. Likewise, feed intake (FI = feed intake per week/number of chickens in the pen), water intake (WI = water intake per week/number of chickens), weight gain (WG = (final weight – previous weight – IW)), and feed conversion ratio (FCR) based on FI (FCR_{FI} = WG/FI) and WI (FCR_{WI} = WG/WI) were determined at weeks 1, 2, 3, 4, 5 and 6. Overall FI, WI, FCR_{FI} and FCR_{WI} were estimated per phase (two weeks each). Finally, total productivity was estimated considering all phases.

2.3. Statistical Analysis

The general linear model (GLM) was used to analyze the production data considering the statistical model: $y_{ijk} = \mu + T_i + \lambda + \varepsilon_{ij}$; where: y_{ijk}= productive variables measured during the experiment; μ= general mean; T_i= effect of the ith-treatment ($MOEO_0$, $MOEO_{12}$, $MOEO_{34}$, $MOEO_{56}$ and $MOEO_{16}$); λ = effect of the IW covariate and ε_{ijk} = experimental error. A significance level of $P < 0.05$ was used to establish difference between treatments in ANOVA. When H_0 was rejected, the means were compared using the Tukey's test at $P < 0.05$ level of significance. A significant trend per variable was considered when the P-value was less than 0.10 ($P < 0.10$), and the comparison of means was performed with the Fischer test ($P < 0.10$). The statistical package Minitab® 17.1.0 [13] was used for data analyses.

3. Results and Discussion

3.1. Chickens Weight

The results of live chicken weight (CW) of broilers supplemented with MOEO are presented in Table 2. The CW showed no difference ($P > 0.05$) between treatments over 41 days. The $MOEO_{12}$ group presented a relatively high weight at 7, 14 and 28 d, while $MOEO_{16}$ at 21 d. The broilers of the $MOEO_{34}$ treatment had a relatively high CW at 35 and 41 d. Similar results in CW were found when feeding Colombian OEO at 100 mg/kg of feed over 35 days [14]. However, Cázares-Gallegos *et al.* [15] obtained differences in CW with MOEO at 400 mg/kg, but with CW being lower than that in the present study where MOEO at 100 mg/kg was used throughout production. In the current study, although CW did not present changes over the study time. $MOEO_{34}$ did show improved CW at 41 d. This finding may indicate that OEO at 100 mg/kg supplemented in weeks 3 and 4 could improve CW. However, Zhang *et al.* [16] showed that high levels of OEO provided in these weeks could improve CW since they found effect on CW with 200 mg/kg over 42 days. The results of the current study indicated that MOEO at 100 mg/kg can improve the CW in weeks 3 and 4, but it is possible that some effect could improve with concentrations greater than 200 mg/kg or higher levels.

Table 2. Weight performance of broiler chickens supplemented with Mexican oregano oil during the different production phases.

Treatment[1]	Starter		Grower		Finisher	
	7	14	21	28	35	41
$MOEO_0$	0.175	0.473	0.949	1.459	1.943	2.442
$MOEO_{12}$	0.177	0.473	0.964	1.500	1.978	2.462
$MOEO_{34}$	0.174	0.469	0.971	1.484	2.005	2.495
$MOEO_{56}$	0.174	0.472	0.964	1.461	1.969	2.486
$MOEO_{16}$	0.172	0.469	0.972	1.467	1.946	2.468
SEM	0.003	0.008	0.012	0.024	0.04	0.066
P-value	0.718	0.917	0.701	0.381	0.896	0.918

[1] $MOEO_0$, control diet without oregano essential oil (0 mg/kg of feed); $MOEO_{12}$, diet with MOEO at 100 mg/kg in weeks 1 and 2; $MOEO_{34}$, diet with MOEO at 100 mg/kg in weeks 3 and 4; $MOEO_{56}$, diet with MOEO at 100 mg/kg in weeks 5 and 6; and $MOEO_{16}$, diet with MOEO at 100 mg/kg from weeks 1 to 6. [a-b] Means weights (kg) (n = 6 replicate pens per treatment with 10 broilers per pen) in columns with different superscripts differ statistically ($P < 0.05$).

3.2. Feed Intake

Feed intake (FI) was different ($P < 0.05$) at 14 and 28 d (Table 3). At both periods, the chickens of the $MOEO_{12}$ group consumed the most feed, while $MOEO_{16}$ and $MOEO_{34}$ had the lowest FI. These results indicated that in the starter and grower phases, FI was affected by MOEO. At 28 d, Méndez-

 doi:10.20944/preprints202510.0670.v1

Zamora *et al*. [17] obtained a similar performance for FI with MOEO at 250 and 400 mg/kg. FI was affected by MOEO at 100 mg/kg, which may be due to the better uptake of nutrients when using levels greater than 50 mg/kg [18]. According to results obtained in that study, FI effects can be seen with MOEO at 100, 250 and 400 mg/kg on day 28 of broiler production, but broilers may exhibit differences at longer periods of supplementation.

Table 3. Feed intake of broiler chickens supplemented with Mexican oregano oil during the different production phases.

Treatment[1]	Starter		Grower		Finisher	
	7	14	21	28	35	41
$MOEO_0$	0.152	0.441^{ab}	0.733	0.961^{ab}	0.931	0.973
$MOEO_{12}$	0.162	0.470^{a}	0.757	0.980^{a}	0.941	0.924
$MOEO_{34}$	0.151	0.453^{ab}	0.771	0.888^{b}	0.962	0.905
$MOEO_{56}$	0.151	0.447^{ab}	0.726	0.897^{b}	0.931	0.937
$MOEO_{16}$	0.147	0.413^{b}	0.725	0.886^{b}	0.902	0.921
SEM	0.004	0.011	0.020	0.021	0.028	0.039
P-value	0.118	0.051	0.444	0.006	0.869	0.653

[1] $MOEO_0$, control diet without oregano essential oil (0 mg/kg of feed); $MOEO_{12}$, diet with MOEO at 100 mg/kg in weeks 1 and 2; $MOEO_{34}$, diet with MOEO at 100 mg/kg in weeks 3 and 4; $MOEO_{56}$, diet with MOEO at 100 mg/kg in weeks 5 and 6; and $MOEO_{16}$, diet with MOEO at 100 mg/kg from weeks 1 to 6. $^{a-b}$ Means (kg) (n = 6 replicate pens per treatment with 10 broilers per pen) in columns with different superscripts differ statistically ($P < 0.05$).

3.3. Water Intake

The water intake (WI) of chickens supplemented with MOEO is shown in Table 4. The treatments did not show differences ($P > 0.05$) in WI. The $MOEO_{12}$ group had relatively high WI at 7 and 21 d, while $MOEO_{34}$ had high WI at 14 and 35 d but low WI on 41 d. The $MOEO_{16}$ group had relatively higher WI at 28 and 41 d. Hernández-Coronado *et al*. [19] found differences in WI when those authors evaluated MOEO at 400 mg/kg at 41 d. This effect on WI can be attributed to the environmental, genetics (breed) and FI factors [20]. The finding showed that WI was not affected by MOEO at 100 mg/kg.

Table 4. Water intake of broiler chickens supplemented with Mexican oregano oil during the different production phases.

Traeatment[1]	Starter		Grower		Finisher	
	7	14	21	28	35	41
$MOEO_0$	0.444	0.921	1.341	1.926	1.993	1.925
$MOEO_{12}$	0.471	0.920	1.528	1.952	1.943	2.063
$MOEO_{34}$	0.448	0.951	1.443	1.910	2.121	1.810
$MOEO_{56}$	0.457	0.939	1.445	1.948	2.018	1.982
$MOEO_{16}$	0.409	0.882	1.430	1.970	1.792	2.069
SEM	0.016	0.040	0.054	0.052	0.138	0.108
P-value	0.209	0.888	0.413	0.903	0.746	0.478

[1] $MOEO_0$, control diet without oregano essential oil (0 mg/kg of feed); $MOEO_{12}$, diet with MOEO at 100 mg/kg in weeks 1 and 2; $MOEO_{34}$, diet with MOEO at 100 mg/kg in weeks 3 and 4; $MOEO_{56}$, diet with MOEO at 100 mg/kg

in weeks 5 and 6; and $MOEO_{16}$, diet with MOEO at 100 mg/kg from weeks 1 to 6. Means (L) (n = 6 replicate pens per treatment with 10 broilers per pen) in columns with different superscripts differ statistically (P < 0.05).

3.4. Feed Conversion Ratio Based on FI

Table 5 presents the feed conversion ratio based on feed intake (FCR_{FI}). The experimental groups showed a trend (P < 0.10) on day 14 of the study. The FCR_{FI} of $MOEO_{16}$ chickens was the highest (least efficient) and $MOEO_{12}$ the lowest (most efficient). The FCR_{FI} at 21 and 35 d remained low for $MOEO_{12}$, while $MOEO_0$ at 28 and 41 d was lower. Results obtained by Chowdhury *et al*. [5] showed differences in FCR_{FI} at 21 d with 400 mg/kg of feed of different essential oils (ajaí, clove and cinnamon). Moharreri *et al*. [21] presented differences in FCR_{FI} with 500 mg/kg of mixture of microencapsulated essential oils (thymol, carvacrol, p-cymene, γ-terpinene and menthol). The results obtained for FCR_{FI} in the current study with 100 mg/kg could be related to the active compounds of MOEO (carvacrol and thymol) for improving feed conversion. Therefore, the essential oils of aromatic plants that contain carvacrol and thymol can promote FCR at doses of 100 to 500 mg/kg of feed.

Table 5. Feed conversion based on feed intake of broiler chickens supplemented with Mexican oregano oil during the different production phases.

Treatment[1]	Starter		Grower		Finisher	
	7	14	21	28	35	41
$MOEO_0$	0.827	0.679^{xy}	0.653	0.532	0.513	0.594
$MOEO_{12}$	0.797	0.630^{y}	0.651	0.547	0.509	0.612
$MOEO_{34}$	0.825	0.657^{xy}	0.656	0.579	0.542	0.631
$MOEO_{56}$	0.817	0.668^{xy}	0.679	0.553	0.543	0.642
$MOEO_{16}$	0.844	0.721^{x}	0.694	0.56	0.528	0.660
SEM	0.021	0.020	0.021	0.020	0.025	0.031
P-value	0.677	0.073	0.577	0.585	0.824	0.697

[1] $MOEO_0$, control diet without oregano essential oil (0 mg/kg of feed); $MOEO_{12}$, diet with MOEO at 100 mg/kg in weeks 1 and 2; $MOEO_{34}$, diet with MOEO at 100 mg/kg in weeks 3 and 4; $MOEO_{56}$, diet with MOEO at 100 mg/kg in weeks 5 and 6; and $MOEO_{16}$, diet with MOEO at 100 mg/kg from weeks 1 to 6. $^{x-y}$ Means (n = 6 replicate pens per treatment with 10 broilers per pen) in columns with different superscripts differ statistically (P < 0.05).

3.5. Feed Conversion Ratio Based on WI

The feed conversion based on water intake (FCR_{WI}) showed no differences (P > 0.05) among treatments (Table 6). The FCR_{WI} was numerically lower in $MOEO_{56}$ at 7 d, $MOEO_{34}$ lower at 14 d, $MOEO_{12}$ lower at 21 and 41 d, while $MOEO_{16}$ was lower at 28 d and $MOEO_0$ lower at 35 d. The current study did not show a change in FCR_{WI}, which may be due to the relationship between feed intake. Due to the lack of information of FCR based on WI, no study has reported FCR_{WI}; hence, this result did not show changes on experimental times but may be related to other variables.

Table 6. Feed conversion ratio based on water intake in broiler chickens supplemented with Mexican oregano oil during the different production phases.

Treatment[1]	Starter		Grower		Finisher	
	7	14	21	28	35	41
$MOEO_0$	0.283	0.327	0.360	0.265	0.242	0.257
$MOEO_{12}$	0.274	0.324	0.329	0.274	0.250	0.243
$MOEO_{34}$	0.278	0.313	0.349	0.269	0.250	0.270
$MOEO_{56}$	0.272	0.320	0.341	0.255	0.253	0.262

 doi:10.20944/preprints202510.0670.v1

$MOEO_{16}$	0.304	0.339	0.351	0.253	0.276	0.257
SEM	0.009	0.013	0.013	0.009	0.018	0.020
P-value	0.190	0.683	0.595	0.436	0.786	0.952

[1] $MOEO_0$, control diet without oregano essential oil (0 mg/kg of feed); $MOEO_{12}$, diet with MOEO at 100 mg/kg in weeks 1 and 2; $MOEO_{34}$, diet with MOEO at 100 mg/kg in weeks 3 and 4; $MOEO_{56}$, diet with MOEO at 100 mg/kg in weeks 5 and 6; and $MOEO_{16}$, diet with MOEO at 100 mg/kg from weeks 1 to 6. [a-b] Means (n = 6 replicate pens per treatment with 10 broilers per pen) in columns with different superscripts differ statistically (P < 0.05).

3.6. Global Effects on Feed and Water Intake by Phase

The global effects of feed and water intake by production phase of chickens supplemented with MOEO are shown in Table 7. The FI showed differences (P < 0.05) for starter and grower phases. In both phases, $MOEO_{12}$ showed the highest FI and WI, while $MOEO_{16}$ the lowest. Numerically (P > 0.05), WI in the grower and finisher phases was high for $MOEO_{12}$ and low for $MOEO_{16}$. Few studies have reported the use of essential oils during the production phases; however, Mousapour *et al*. [22] found differences in FCR_{FI} in the grower phase with savory plant essential oil at 150 mg/kg of feed. These differences may be due to age, animal management, dose supplied, diet composition and environmental factors [23].

Table 7. Overall productivity of feed and water intake in broiler chickens supplemented with Mexican oregano oil during the different production phases.

Variables/Treatments[1]	Starter	Grower	Finisher
FI (kg)			
$MOEO_0$	0.593^{ab}	1.69^{xy}	1.90
$MOEO_{12}$	0.632^{a}	1.74^{x}	1.86
$MOEO_{34}$	0.604^{ab}	1.66^{xy}	1.87
$MOEO_{56}$	0.599^{ab}	1.62^{xy}	1.87
$MOEO_{16}$	0.560^{b}	1.61^{y}	1.82
EEM	0.013	0.032	0.060
P- value	0.029	0.068	0.911
WI (L)			
$MOEO_0$	1.37	3.27	3.92
$MOEO_{12}$	1.39	3.48	4.01
$MOEO_{34}$	1.40	3.35	3.93
$MOEO_{56}$	1.40	3.39	4.00
$MOEO_{16}$	1.29	3.40	3.86
SEM	0.046	0.089	0.198
P- value	0.677	0.581	0.992

[1] FI = Feed intake; WI = water intake (liters); $MOEO_0$, control diet without oregano essential oil (0 mg/kg of feed); $MOEO_{12}$, diet with MOEO at 100 mg/kg in weeks 1 and 2; $MOEO_{34}$, diet with MOEO at 100 mg/kg in weeks 3 and 4; $MOEO_{56}$, diet with MOEO at 100 mg/kg in weeks 5 and 6; and $MOEO_{16}$, diet with MOEO at 100 mg/kg from weeks 1 to 6. [ab] Means (n = 6 replicate pens per treatment with 10 broilers per pen) in columns with different superscripts differ statistically (P < 0.05). [xy] Means (n = 6 replicate pens per treatment with 10 broilers per pen) in columns with different superscripts exhibited a statistical trend (P < 0.10).

3.7. Overall Effect on Feed Conversion Ratio by Phase

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The global effects on FCR_{FI} and FCR_{WI} of chickens supplemented with MOEO were not different ($P > 0.05$) between experimental groups (Table 8). FCR_{FI} for three production phases was high for $MOEO_{16}$. $MOEO_{0}$ was low in the grower and finisher phases. In relation to FCR_{WI}, $MOEO_{16}$ was high in the starter and finisher phases, while the $MOEO_{56}$ group was low in the starter and grower phases. Silva-Vázquez *et al*. [20] obtained similar results for FCR_{FI} at 14 d with MOEO at 400 mg/kg. Similarly, Hernández-Coronado *et al*. [19] did not present differences with MOEOE at 200 mg/kg in the diet and water. This result may be due to the compounds found in MOEO that directly affect microorganism metabolism in the animal's digestive tract [24]. Furthermore, intestinal physiology and metabolic pathways such as glycolysis could be affected by MOEO.

Table 8. Global feed conversion rates of feed and water intake in broilers supplemented with Mexican oregano oil during the different production phases.

Variables/Treatments[1]	Starter	Grower	Finisher
FCR_{FI}			
$MOEO_{0}$	0.753	0.592	0.511
$MOEO_{12}$	0.713	0.599	0.517
$MOEO_{34}$	0.741	0.617	0.541
$MOEO_{56}$	0.743	0.616	0.546
$MOEO_{16}$	0.782	0.627	0.547
SEM	0.017	0.012	0.021
P- value	0.183	0.273	0.702
FCR_{WI}			
$MOEO_{0}$	0.305	0.313	0.249
$MOEO_{12}$	0.299	0.302	0.246
$MOEO_{34}$	0.296	0.309	0.260
$MOEO_{56}$	0.296	0.298	0.257
$MOEO_{16}$	0.321	0.302	0.266
SEM	0.008	0.009	0.014
P- value	0.244	0.798	0.791

[1] FCR_{FI} = feed conversion ratio based in feed intake; FCR_{WI} = feed conversion ratio based in water intake; $MOEO_{0}$, control diet without oregano essential oil (0 mg/kg of feed); $MOEO_{12}$, diet with MOEO at 100 mg/kg in weeks 1 and 2; $MOEO_{34}$, diet with MOEO at 100 mg/kg in weeks 3 and 4; $MOEO_{56}$, diet with MOEO at 100 mg/kg in weeks 5 and 6; and $MOEO_{16}$, diet with MOEO at 100 mg/kg from weeks 1 to 6. [a-b] Means (n = 6 replicate pens per treatment with 10 broilers per pen) in columns with different superscripts differ statistically ($P < 0.05$).

3.8. Overall Productivity

The overall productive efficiency (1 - 41 d) of broilers supplemented with MOEO showed that FCR_{FI} was affected ($P < 0.05$) by the treatments (Table 9). $MOEO_{16}$ had the highest (lowest efficiency) overall FCR_{FI}, while $MOEO_{0}$ and $MOEO_{12}$ the lowest (best efficiency). The overall FCR_{WI} was not affected ($P > 0.05$) by the experimental groups. Hernandez-Coronado *et al*. [19] did not find differences between experimental groups in broilers supplemented with OEO at 200 mg/kg in the diet or water. The FCR_{FI} in the current study was similar to results of Betancourt *et al*. [14] using Colombian oregano at 100 mg/kg. These results confirm that the MOEO added in the different phases can improve productivity without being used continuously over 6 weeks of grow-out and can be used only over the first 2 weeks of grow-out.

Table 9. Feed conversion ratio based on feed intake for broiler chickens supplemented with Mexican oregano oil during the different production phases.

Treatments[1]	Variables[2]			
	FI (kg)	**WI (L)**	**FCR_{FI}**	**FCR_{WI}**
$MOEO_0$	4.191	8.55	0.582[b]	0.285
$MOEO_{12}$	4.234	8.88	0.581[b]	0.279
$MOEO_{34}$	4.129	8.68	0.604[ab]	0.288
$MOEO_{56}$	4.090	8.79	0.607[ab]	0.282
AEO_{16}	3.990	8.55	0.618[a]	0.289
SEM	0.084	0.268	0.008	0.007
P-value	0.333	0.915	0.017	0.731

[1] FI = feed intake; WI = water intake; FCR_{FI} = feed conversion ratio based in feed intake; FCR_{WI} = feed conversion ratio based in water intake; $MOEO_0$, control diet without oregano essential oil (0 mg/kg of feed); $MOEO_{12}$, diet with MOEO at 100 mg/kg in weeks 1 and 2; $MOEO_{34}$, diet with MOEO at 100 mg/kg in weeks 3 and 4; $MOEO_{56}$, diet with MOEO at 100 mg/kg in weeks 5 and 6; and $MOEO_{16}$, diet with MOEO at 100 mg/kg from weeks 1 to 6. [a-b] Means (n = 6 replicate pens per treatment with 10 broilers per pen) in columns with different superscript differ statistically ($P < 0.05$).

4. Conclusions

In conclusion, MOEO at 100 mg/kg in the starter and grower phases ($MOEO_{12}$ and $MOEO_{34}$) improved the productive parameters of broiler chickens. The $MOEO_{12}$ group had the best fed conversion ratio. The $MOEO_{34}$ group had moderate water and feed intake, as well as improved the chicken final weight. The supplementation of MOEO in broiler diets can be recommended in the starter or grower phase to improve profitability and broiler productivity.

Author Contributions: investigation, data curation, writing-original draft preparation, Judith Alejandra S. Cuevas; validation, resources, funding acquisition, Jorge R. Kawas; methodology, investigation, Jimena Martínez-Rojas and Ana C. Hernández-Coronado; validation, data curation, visualization, Daniela S. Rico-Costilla and Victor E. Aguirre-Arzola; resources, visualization, supervision, Adolfo Soto-Domínguez; software, validation, formal analysis, writing-original draft preparation, writing-review and editing, Gerardo Mendez-Zamora.

Funding: This research received no external funding.

Institutional Review Board Statement: The experiment was approved (ID 0426/2023) by the biosecurity, bioethics and animal welfare committee of the Facultad de Medicina Veterinaria y Zootecnia, UANL.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data were not deposited in a repository.

Acknowledgments: Authors acknowledge Michael E. Hume Ph.D. for reviewing and editing the manuscript. Additionally, we acknowledge Facultad de Agronomía, UANL, for supporting this study with experimental areas.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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