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Original Articles

Performance, Carcass Variables, and Meat Quality of Broilers Supplemented with Dietary Mexican Oregano Oil

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ABSTRACT

The current study was conducted to evaluate the dietary supplementation of Mexican oregano essential oil (MOO; *Lippiaberlandieri* Schauer) on broiler performance, carcass variables, meat quality, and sensory evaluation. One-day-old mixed-sex broilers were distributed in the following treatment groups, according to MOO supplementation levels: 0 = control diet; 200 = diet + 2200 mg of MOO/kg; 400 = diet + 4200 mg of MOO/kg; 600 = diet + 6200 mg of MOO/kg; 800 = diet + 8200 mg of MOO/kg; 1000 = diet + 1000 mg of MOO/kg. MOO affected ($p<0.05$) body weight, feed and water intake, and feed conversion ratio. The 200 and 400 mg/kg formulations gave better results at 7, 14 and 28 d than the other diets. MOO at 1000 mg/kg increased ($p<0.05$) slaughter weight and hot carcass yield, and decreased meat pH and cooking loss. The 200 and 400 treatments increased breast meat redness (a*), but reduced yellowness (b*). Meat hardness, cohesiveness and resilience were affected ($p<0.05$) by MOO, but not ($p>0.05$) the sensory parameters evaluated. Mexican oregano oil presents positive qualities as a plant-derived performance enhancer in broiler diets and improves of the meat quality of broilers at the levels of 200, 400 and 600 mg/kg of diet.

INTRODUCTION

Resistance of pathogenic bacteria to antibiotics used in broilers is widely known. Human health can be directly affected by residues of antibiotic growth promoters (AGP)in the meat or by the development of antibiotic-resistant pathogenic bacteria that may spread to humans (Chowdhury *et al*., 2018). In recent years, natural strategies are being studied for application in poultry production.

Leaves of the oregano plant and its essential oils are considered phytogenic replacers for AGPs in broiler diets (Toghyani *et al*., 2011), as well as growth promoters, natural antibiotics, and improvers of broiler meat quality. Two plants commonly used fall under the common name oregano. There are the oregano varieties *Origanum* spp. (common name Greek oregano, a member of the mint family Lamiaceae), which are native to Eurasia and the Mediterranean. There is also the oregano variety *Lippiaberlandieri* Schauer (common name Mexican oregano, a member of family Verbenaceae), which is native to Mexico, Central America, and southwestern United States. The dried leaves and inflorescences of Mexican oregano, similar to the Greek varieties, are used as condiments and treatment for respiratory and digestive diseases (Rivero-Cruz *et al*., 2011). The main constituents of essential oils from Mexican oregano are carvacrol, thymol, β-myrcene, α-terpinene, ɤ-terpinene, *p*-cymene and ceneol (Silva Vazquez & Dunford, 2005).

Some studies have evaluated the performance and meat quality of broilers given diets supplemented with natural extracts (Cho *et al*., 2014; Park *et al*., 2014; Mpofu *et al*., 2016; Chowdhury *et al*., 2018), and Greek (OEO) and Mexican (MOO) oregano essential oils (Silva Vázquez *et al*., 2015; Peng *et al*., 2016; Méndez-Zamora *et al*., 2017; Reyer *et al*., 2017), demonstrating their effects on feed intake, growth promotion, blood profile, and meat quality. *Origanum vulgare* L. and *Origanumonites* sp. and A. *sativum* L. are the most frequently phytogenic additives used in broiler production. However, a limited number of studies have been reported regarding Mexican oregano essential oils from *Lippiaberlandieri* in broiler diets (Méndez-Zamora *et al*., 2015a, 2015b; Silva-Vazquez *et al*., 2015; Méndez-Zamora *et al*., 2017). The use of Mexican oregano essential oils may be a value-added phytogenic alternative to traditional antibiotics in broiler production.

The current study was carried out to evaluate the effects of the MOO supplementation in broiler diets on their growth performance, carcass traits, and meat physicochemical variables, texture analysis and meat sensory evaluation.

MATERIALS AND METHODS

Birds and experimental diets

The study was carried out at the Marin Experimental Farm of the Universidad Autonoma de Nuevo Leon (UANL), located at Marin, Nuevo Leon, Mexico. The study site is located between 25° 45′ and 26° 2′ N and 99° 48′ 100° 6′ W, at an altitude between 200 and 1500 m, with a mean temperature 21°C, annual precipitation between 600-800 mm, and is in a semi-warm sub humid climate (INEGI, 2017).

The experimental procedures complied with the Mexican standards on animal use (NOM-062-ZOO, 1999), and were approved by the local animal care and welfare committee of the Universidad Autonoma de Nuevo Leon.

In total, 360 one-day-old Ross308 mixed-sex broiler chicks (49.92 ± 1.33 g) were obtained from a local hatchery and distributed into 30 floor pens with 12 birds each (1.20 x 1.20 x 0.80 m) on fresh wood-shavings litter. Five pens were randomly assigned to one of six treatments (diets): 0 = control diet (CD), no MOO; 200 = CD + 200 mg of MOO/kg; 400 = CD + 400 mg of MOO/kg; 600 = CD + 600 mg of MOO/kg; 800 = CD + 800 mg of MOO/kg; and 1000 = CD + 1000 mg of MOO/kg.

The Mexican oregano oil was prepared by steam distillation of dry leaves (Natural Solutions Company SMI, Jimenez, Chihuahua, Mexico), and was incorporated into the diets with canola oil as carrier and by mixing for 8 min. The main components of MOO (60.02% carvacrol, 23.63% 1,8-cineole, 9.57% *p*-cymene, 3.96% thymol, 0.11%gamma-terpinene, and 2.71% others) were determined by gas chromatography (Clarus 600 and MS SQ8 PerkinElmer Inc., Waltham, MA, USA), according to Silva-Vazquez *et al*. (2017).

Starter (1-21 d) and finisher (22-40 d) diets were formulated according to the NRC (1994) and as used by Silva-Vázquez *et al*. (2015) and Méndez-Zamora *et al*. (2017). The ingredients and analyzed chemical composition of the control starter and finisher diets are shown in Table 1. Feed and water were provided *ad libitum* throughout the experiment. Husbandry practices were applied according to above-mentioned authors. House temperature was set at 34°C on the first day, followed by 32°C over the remainder of the first week, and then was reduced by 3°C per week until it reached 23°C. The relative humidity fluctuated between 65 and 85%. Lighting was provided 22 h/d.

Table 1 – Ingredients of the starter and finisher diets for broilers.

Items	Diets[2]	
	Starter (0-21 d)	Finisher (22-40 d)
Ingredients (g kg^{-1})[1]		
Corn	467.2	556.4
Soybean (48% CP)	392.2	312.9
Corn gluten	53.3	44.4
Vitamins and mineral premix	11.7	13.3
Calcium carbonate	14.4	21.4
Dicalcium phosphate	21.3	22.2
Sodiumchloride	6.0	6.4
DL-Methionine	1.9	0.8
Canolaoil®[3]	32.0	22.2
Chemical analysis (%)		
Crudeprotein	26.73	24.26
Etherextract	5.86	4.33
Crudefiber	3.96	4.89
Ash	7.57	9.96

[1] Ingredients were incorporated per kg of the experimental diet (expressed on dry--matter basis).

[2] Diets were formulated according to the nutrient requirements for broilers as recommended by NRC (1994).

[3] Canola oil was purchased from the company Industrial Patrona, S.A. de C.V., Mexico.

Growth performance evaluation

The initial body weight (IBW; g) was determined at the beginning of the experiment. Broiler body weight (BW), feed intake (FI; g intake of feed per week/

number of broilers per pen), and water intake (WI; g intake of water per week/number of broilers per pen) were evaluated on d 7, 14, 21, 28, 35, and 40. These variables were used to estimate weekly body weight gain (WBWG; g ($BW_{current}$-$BW_{previous}$)/day) and feed conversion ratio (FCR; FI/WBWG) and were determined at the same periods. Offered and rejected feed weights were recorded to estimate these variables.

Slaughter variables

The slaughter process was carried out according to the Official Mexican Standard (NOM-033-SAG/ZOO, 2014) and the method of Méndez-Zamora *et al*. (2015a). Thirty 40-day-old chicks from each treatment (six birds per pen) were randomly selected for slaughter by cervical dislocation. Slaughter weight (SW), and hot (HCW; after removal of the head, feathers, and internal organs) and cold (CCW; 24 h *post mortem*) carcass weights were recorded to calculate hot (HCY; (HCW/SW) × 100) and cold (CCY; (CCW/SW) × 100) carcass yields. Breast meat yield (BY = (BrW/SW) × 100) was estimated as breast meat weight (BrW) relative to SW (two birds per pen per treatment).

Meat physicochemical variables

Breast meat (*pectoralis major*) pH, color, water holding capacity (WHC), and cooking loss (CL) were measured 24 h *post mortem*. These variables were measured in duplicate in ten breasts from each treatment, randomly selected, two breasts/pen/treatment. Meat pH was determined with a puncture electrode (HI 99163, Hanna Instruments WoonSocket, RI, USA). Meat color values for lightness (L*), redness (a*), yellowness (b*), Chroma (saturation index) and Hue angle were measured with a colorimeter (CR-400 Konica Minolta®, Tokyo, Japan; Illuminant/Observer: D65/10), set on the CIE Lab System (CIE, 1976) on the breast surfaces. Values for L*, a* and b* were used to estimate total color change (ΔE) and browning index (BI), according to Ledesma *et al*. (2016), using the colorimeter calibration values L^*_0 = 94.18, a^*_0 = -0.43 and b^*_0 = 3.98. The equipment was calibrated with a standard white plate. Breast meat WHC was determined using the compression method according to Tsai & Ockerman (1981) and Méndez-Zamora *et al*. (2015b). Approximately 300 ± 0.1 mg of meat sample were placed between two pieces of filter paper, between two acrylic-plastic plates, applying a force of 4 kg for 20 min, and obtaining the final weight: WHC = 100 – {[(initial weight – final weight)/initial weight] x 100}. To determine CL, the breast meat was vacuum-packed (Koch 800, Kansas City, MO, USA) in vacuum bags (Zubex Industrial SA de CV, Monterrey, Nuevo Leon, Mexico) and cooked by immersion in water at 75.0 ± 0.1°C for 1 h. Then the samples were cooled by immersion in water at 4°C for 20 min. The pieces were removed from the bags, carefully drained, and weighed. Raw and cooked weights of each breast meat sample were recorded to evaluate CL percentage as [(raw weight -cooked weight)/raw weight piece] × 100.

Meat texture analysis

Breast meat shear force (SF) and texture profile analysis (TPA) were carried out with a TA.XT. Plustexturometer (Stable Micro Systems, Serrey, England) in two sections per replicate (2 breasts/pen/treatment). SF (N, Newtons) was measured using a Warner-Bratzler shear blade with a triangular slot cutting edge. Rectangular meat slices (3.5 cm long x 1.0 cm wide x 1.0 cm high for each breast) were used to evaluate SF. Samples were cut parallelly to the direction of the muscle fibers. Test conditions used in the instrument were velocities of 2 mm/s pre-test, 2 mms/s during the test, 10 mm/s post-test, and a distance of 15 mm. The SF value was calculated from the maximum point of the curve generated. TPA was determined using standardized cylinders (1.5 cm high and 2.5 cm in diameter), oriented perpendicular to the direction of the muscle fibers. A cylindrical piston (75 mm in diameter) was used to compress the sample during two test cycles, compressing the sample up to 60% of the original height within a time span of 5 s between the cycles. Force-time curves of deformation were obtained from the conditions established in the texturometer. The velocities used were 2.0 mm/s pre-test, 5.0 mm/s during the test, and 5.0 mm/s post-test. The following parameters were recorded according to Bourne (1978): hardness (Hard; N), adhesiveness (Adhes; g/s), springiness (Spring; mm), cohesiveness (Cohes; dimensionless), gumminess (Gum; g), chewiness (Chew; g mm), and resilience (Resil; dimensionless).

Sensory evaluation

The most important meat attributes are appearance and texture, since they exert the most influence on consumer initial selection and ultimate satisfaction with traditional poultry meat products (Fletcher, 2002). An affective sensory test of breast meat attributes was conducted to measure the satisfaction level of 30 consumers. The breasts (1 breast/pen/treatment) were vacuum-packed and cooked by immersion in water at 75.0 ± 0.1°C for 1 h. Each consumer evaluated four 1.5-cm cut cubes chosen at random per treatment.

Samples for evaluation were maintained at 30°C and were presented in small plastic cups codified with three random numbers. The attributes evaluated were odor, taste, tenderness and overall acceptability. A 7-point hedonic scale was used, where 7 = liked very much and 1 = disliked very much (Anzaldúa-Morales, 1994; Meilgaard *et al*., 2006).

Statistical analysis

The growth performance data were analyzed using the MIXED procedure of SAS (2006) and the following statistical model (Wang & Goonewardene, 2004): $y_{ijk} = \mu + T_i + \delta_j + (T\delta)_{ij} + \Phi_{k(ij)} + \lambda + \varepsilon_{ijk}$;where y_{ijk} = production variables measured during the experiment, μ = general mean, T_i = effect of the *i*th treatment (0, 200, 400, 600, 800, and 1000), δ_j = effect of the *j*th day of fattening (7, 14, 21, 28, 35 and 40 d), $(T\delta)_{ij}$ = fixed effect of the interaction between *i*th treatment and *j*th day of fattening, $\Phi_{k(ij)}$ = nested effect of the *i*th treatment in each pen where the chickens remained for the *j*th day of fattening, λ = effect of the covariate IW, and ε_{ijk} = random error normally distributed with mean zero and variance $\sigma^2\varepsilon_{ijk} \sim N(0, \sigma^2)$. A significance level of $p<0.05$ was used to detect significant statistical difference, and when the *p*-value was less than 0.05 in fixed effects and its interaction, the means were compared using Adjust = Tukey (SAS, 2006).

Carcass parameters and meat physicochemical and texture variables were analyzed with the GLM procedure (SAS, 2006), according to the following statistical model: $y_{ij} = \mu + T_i + \lambda + \varepsilon_{ij}$; where y_{ij} = variables evaluated; μ = general mean; T_i = effect of the i^{th} treatment (0, 200, 400, 600, 800, and 1000); λ = effect of the covariate IW, and ε_{ij} = random error normally distributed with mean zero and variance σ^2 ($\varepsilon_{ij} \sim N(0, \sigma^2)$). When the fixed effect had significant effect ($p<0.05$), the means were compared using the Tukey's test (SAS, 2006).

The sensorial data were analyzed with a complete random block design according to the statistical model $y_{ij} = \mu + T_i + \beta_j + \varepsilon j$. The treatments ($T_i$) represented the fixed effects and each consumer was the block (β_j). A significance level of $p<0.05$ was used to assess significant differences among treatment applying Tukey's test (SAS, 2006).

RESULTS

The statistical model was significant ($p<0.001$) for growth performance variables, and the interaction effect was statistically significant ($p<0.001$) for WBWG and FCR. Specifically, treatments were different ($p<0.05$) and days were significant ($p<0.001$) for performance variables.

Body weight and feed intake

On d 28, BW was different ($p<0.05$) among treatments, with 400 mg/kg being highest and 800 mg/kg lowest (Table 2). At 40 d, BW was not different ($p>0.05$) by treatment, although the400 mg/kg treatment BW was slightly higher. BW did increase for all treatments over time, being highest at 40 d. FI was affected ($p<0.05$) at 7, 14 and 21 d (starter period), presenting higher FI with 0, 400, and 600(at 21 d) mg/kg, while200, 600 (at 7 and 14 d), 800, and 1000 mg of MOO/kg showed lower values (Table 2). Somewhat similar performance values were found over the fattening period (1-40 d); however, broilers given 400mg/kg did consumed more feed (FI), although at levels not significantly different from broilers given the other MOO formulations. Due to the period between 35 d and 40 d accounting for only 5 d and not 7 d, the FI values statistically and numerically were lower more specifically when compared to 28 d and 35 d. Overall, FI increased ($p<0.05$) incrementally during the period from 7 d to 35 d. WI was different ($p<0.05$) at 28 d and 1-40 d. During these periods, 400 and 600 mg/kg promoted the highest ($p<0.05$) WI, while that 200 and 800 mg/kg presented lower ($p<0.05$) WI values.

Weekly body weight gain and feed conversion ratio

Production efficiencies of broilers fed MOO in the diet are given in Table 3. Effects of MOO levels on WBWG were different ($p<0.05$) at 21 and 28 d, with higher values obtained with400 and 600 mg/kg ($p<0.05$). At 21 d (starter period), birds fed 200 mg/kg had the lowest ($p<0.05$) WBWG value and at 28 d (finisher period), those fed 800 mg/kg had the lowest ($p<0.05$) value. During the other evaluated periods, there were no WBWG differences ($p>0.05$). Throughout the trial (1-40 d), there were no WBWG or FCR differences ($p<0.05$) among treatment groups. There were FCR differences ($p<0.05$) among treatments during the starter period (7 to 21 d), when the control group (0 mg/kg) presented the highest FCR. However, at 14 and 21 d, the FCR of the control group was not different ($p>0.05$) from those of groups 200, 400, and 1000mg of MOO/kg.

Slaughter variables

The effects of MOO on slaughter variables are shown in Table 4. SW and HCY were affected ($p<0.05$) by MOO levels, with the highest SW in broilers given 400

Table 2 – Performance parameters of broilers supplemented with Mexican oregano essential oil.

Treatment[1]	Days						
	1 (PI)	7	14	21	28	35	40
				Body Weight (g)			
0	48.67	138.31^{F}	413.98^{E}	736.23^{D}	1218.64$^{ab;C}$	1723.23^{B}	2070.65^{A}
200	49.33	152.14^{F}	425.72^{E}	739.22^{D}	1222.40$^{ab;C}$	1722.25^{B}	2025.80^{A}
400	50.58	177.42^{F}	457.83^{E}	791.25^{D}	1289.50$^{a;C}$	1796.09^{B}	2146.59^{A}
600	49.69	149.48^{F}	422.08^{E}	759.03^{D}	1247.12$^{a;C}$	1759.29^{B}	2095.32^{A}
800	50.17	152.49^{F}	434.17^{E}	761.86^{D}	1166.73$^{b;C}$	1675.23^{B}	2017.30^{A}
1000	50.25	159.25^{F}	429.00^{E}	757.37^{D}	1216.46$^{ab;C}$	1702.62^{B}	2050.47^{A}
SEM	0.53	4.73	9.24	10.56	19.25	32.69	39.05
				Feed Intake (g)			
	7	14	21	28	35	40	1-40
0	127.13$^{a;E}$	389.71$^{a;D}$	678.72$^{a;C}$	937.63^{AB}	1078.41^{A}	829.88^{B}	4038.77
200	108.89$^{b;F}$	342.89$^{b;E}$	588.97$^{b;D}$	903.20^{B}	1104.85^{A}	760.36^{C}	3808.06
400	126.47$^{a;E}$	366.30$^{ab;D}$	643.30$^{ab;C}$	988.05^{B}	1187.72^{A}	838.89^{BC}	4152.67
600	112.33$^{b;F}$	344.48$^{b;E}$	629.11$^{ab;D}$	981.71^{B}	1097.95^{A}	757.89^{C}	3923.26
800	115.38$^{b;E}$	344.68$^{b;D}$	611.07$^{b;C}$	965.68^{A}	1077.03^{A}	820.46^{B}	4035.25
1000	112.59$^{b;E}$	342.26$^{b;D}$	610.64$^{b;C}$	992.40^{AB}	1113.93^{A}	829.83^{B}	4002.78
SEM	4.10	9.89	14.07	50.69	63.17	40.35	93.64
				Water Intake (g)			
	7	14	21	28	35	40	1-40
0	330.11^{E}	984.19^{D}	1841.52^{C}	1969.44$^{ab;C}$	2459.05^{A}	2182.49^{B}	9766.78^{ab}
200	344.01^{E}	1004.00^{D}	1781.51^{C}	1860.02$^{ab;BC}$	2467.51^{A}	2025.82^{B}	9482.87^{ab}
400	365.31^{E}	1063.48^{D}	1965.06^{C}	2097.15$^{a;BC}$	2515.31^{A}	2142.23^{B}	10148.55^{a}
600	315.42^{E}	1002.80^{D}	1903.10^{C}	2064.03$^{a;BC}$	2608.03^{A}	2218.96^{B}	10112.34^{a}
800	293.42^{E}	956.32^{D}	1748.17^{C}	1772.05$^{b;C}$	2426.82^{A}	2085.24^{B}	9282.02^{b}
1000	334.40^{D}	1029.99^{C}	1913.64^{B}	1931.71$^{ab;B}$	2371.20^{A}	2199.60^{A}	9780.55^{ab}
SEM	15.65	24.48	53.49	55.93	66.02	71.02	192.54

[1]Treatments 0 = control diet; 200 = diet + 200 mg Mexican oregano essential oil (MOO)/kg; 400 = diet + 400 mg/kg MOO; 600 = diet + 600 mg/kg MOO; 800 = diet + 800 mg MOO /kg; and 1000 = diet + 1000 mg MOO/kg. BW = Broiler body weight; FI = feed intake; WI = water intake. SEM = standard error of the mean.

$^{a-b}$ Means (n = five replicate pens with 12 chicks per treatment) in rows followed by different lowercase superscripts are significantly different (p<0.05).

$^{A-F}$ Means (n = five replicate pens with 12 chicks per treatment) in columns followed by different uppercase superscripts are significantly different (p<0.05).

Table 3 – Production efficiency of broilers supplemented with Mexican oregano essential oil.

Treatment[1]	Days						
	7	14	21	28	35	40	1-40
				WBWG (g)			
0	102.16^{D}	269.75^{C}	316.33$^{ab;BC}$	476.49$^{a;A}$	498.66^{A}	341.51^{B}	334.15
200	107.86^{C}	271.19^{B}	311.11$^{b;B}$	480.79$^{a;A}$	497.46^{A}	301.15^{B}	328.26
400	117.84^{D}	284.67^{C}	337.67$^{a;BC}$	502.51$^{a;A}$	510.84^{A}	354.76^{B}	351.38
600	100.80^{D}	272.12^{C}	336.48$^{a;B}$	487.62$^{a;A}$	511.69^{A}	335.56^{B}	340.71
800	98.01^{E}	283.73^{D}	329.73$^{ab;C}$	451.91$^{b;B}$	510.54^{A}	344.11^{C}	328.84
1000	103.74^{D}	272.24^{C}	330.86$^{ab;B}$	461.57$^{ab;A}$	488.65^{A}	350.34^{B}	334.57
SEM	4.73	6.93	6.91	14.28	19.19	15.87	6.51
				FCR			
0	1.27$^{a;C}$	1.45$^{a;C}$	2.14$^{a;AB}$	1.96^{B}	2.16^{AB}	2.42^{A}	1.91
200	1.02$^{b;C}$	1.27$^{ab;C}$	1.90$^{ab;B}$	1.88^{B}	2.24^{AB}	2.52^{A}	1.81
400	1.06$^{b;D}$	1.28$^{ab;D}$	1.92$^{ab;C}$	1.98^{BC}	2.32^{AB}	2.37^{A}	1.82
600	1.12$^{ab;C}$	1.27$^{ab;C}$	1.87$^{b;B}$	2.01^{AB}	2.16^{A}	2.26^{A}	1.78
800	1.18$^{ab;C}$	1.21$^{b;C}$	1.86$^{b;B}$	2.12^{B}	2.11^{AB}	2.40^{A}	1.86
1000	1.08$^{ab;C}$	1.26$^{ab;C}$	1.85$^{b;B}$	2.16^{AB}	2.10^{AB}	2.39^{A}	1.84
SEM	0.05	0.04	0.06	0.12	0.11	0.09	0.04

[1]Treatments 0 = control diet; 200 = diet + 200 mg Mexican oregano essential oil (MOO)/kg; 400 = diet + 400 mg/kg MOO; 600 = diet + 600 mg/kg MOO; 800 = diet + 800 mg MOO /kg; and 1000 = diet + 1000 mg MOO/kg. WBWG = weekly body weight gain; FCR = feed efficiency. SEM = standard error of the mean.

$^{a-b}$ Means (n = five replicate pens with 12 chicks per treatment) in columns followed by different lowercase superscripts are significantly different (p<0.05).

$^{A-F}$ Means (n = five replicate pens with 12 chicks per treatment) in rows followed by different uppercase superscripts are significantly different (p<0.05).

mg/kg. Although, the 400 mg/kg treatment promoted the highest (p<0.05) comparative SW, its value was similar to those presented by broilers given MOO at 0, 200 and 600 mg/kg. The highest HCY values (p<0.05) were obtained in broilers given 0 and 200 mg/kg and the lowest (p<0.05) in broilers given 400 mg of MOO/kg. However, the HCY obtained with the 0 and 200 mg/kg treatments and the 400 mg/kg treatment were not statistically different (p>0.05) from the 600 to 1000 mg/kg treatments. CCY and BY values were not different (p>0.05) among treatments.

Table 4 – Slaughter variables of broilers supplemented with Mexican oregano essential oil.

Treatment[1]	Variables[2]			
	SW (g)	HCY (%)	CCY (%)	BY (%)
0	2292.68^{ab}	72.95^{a}	71.85	26.66
200	2244.67^{ab}	72.92^{a}	71.67	27.62
400	2319.29^{a}	71.01^{b}	70.62	27.56
600	2225.00^{ab}	72.53^{ab}	71.28	27.62
800	2156.25^{b}	71.48^{ab}	70.85	28.56
1000	2163.13^{b}	72.10^{ab}	71.19	26.12
SEM	38.13	0.38	0.32	0.59
p-values	0.0160	0.0012	0.0607	0.0845

[1]Treatments 0 = control diet; 200 = diet + 200 mg Mexican oregano essential oil (MOO)/kg; 400 = diet + 400 mg/kg MOO; 600 = diet + 600 mg/kg MOO; 800 = diet + 800 mg MOO /kg; and 1000 = diet + 1000 mg MOO/kg. SEM = standard error of the mean.

[2] SW = slaughter weight; HCY = hot carcass yield; CCY = cold carcass yield; BY = breast yield.

[a-b] Means (n = 30 birds per treatment) in columns followed by different superscripts are significantly different (p<0.05).

Breast meat physicochemical properties

Table 5 presents the effects of MOO on breast meat physicochemical properties. The pH values were different (p<0.05), with broilers given 0 mg/kg MOO having the highest (p<0.05) and those given 1000 mg/kg the lowest (p<0.05) values. WHC values were not different among treatments (p>0.05); however, there was an increasing trend to hold water as the level of MOO increased. Broilers fed 400 of MOO mg/kg had the highest (p<0.05) CL, while those fed 1000 mg/kg had the lowest (p<0.05) CL. However, CL was not different (p>0.05) among broilers given 0 to 800 mg of MOO /kg, and between broilers given 1000 mg/kg and the other treatments, with the exception of the 400 mg/kg treatment.

Table 5 – Breast meat pH, water holding capacity and cooking loss in breast meat from broilers supplemented with Mexican oregano essential oil.

Treatment[1]	Traits		
	pH	WHC (%)[2]	CL (%)
0	5.98^{a}	56.32	22.81^{ab}
200	5.87^{b}	56.67	21.25^{ab}
400	5.82^{bc}	58.00	23.51^{a}
600	5.79^{cd}	58.04	21.28^{ab}
800	5.84^{bc}	58.72	22.32^{ab}
1000	5.72^{d}	60.32	19.87^{b}
SEM	0.02	1.29	0.73
p-values	<0.0001	0.2953	0.0141

[1]Treatments 0 = control diet; 200 = diet + 200 mg Mexican oregano essential oil (MOO)/kg; 400 = diet + 400 mg/kg MOO; 600 = diet + 600 mg/kg MOO; 800 = diet + 800 mg MOO /kg; and 1000 = diet + 1000 mg MOO/kg. SEM = standard error of the mean.

[2] WHC = water holding capacity; CL = cooking loss.

[a-d]Means (n = 10 breasts per treatment, two per replicate pen) in columns followed by different superscripts are significantly different (p<0.05).

Broiler breast meat color parameters were affected (p<0.05) by dietary MOO concentrations (Table 6). Parameters L* and Hue angle were higher (p<0.05) in 1000 mg/kg breast meat samples than for the other concentrations, although L* values for 0 and 1000 mg/kg were not different (p>0.05). Otherwise, no single MOO concentration across b*, Chroma, ΔE, and BI color parameters demonstrated consistent statistically high or low values.

Shear force and texture analysis

Breast meat SF and TPA from broilers supplemented with MOO are shown in Table 7. Values of SF, Adhes, Spring, Gum, and Chew did not present any differences (p>0.05) over the range of MOO concentrations in broiler feeds. However, there was a tendency for SF and adhesiveness values to decrease as the MOO concentration increased. In contrast, Hard, Cohes and Resilwere different (p<0.05) among treatments. Higher Hardvalues (p<0.05) were detected in the breast meat of broilers given 600, 800 and 1000 mg of MOO/kg, while the meat from the control treatment presented lower values (p<0.05), but not different from those obtained with 200 and 400 mg of MOO/kg. These results indicated that hardness improved with increasing MOO concentrations in broiler diets. Conversely, Cohes and Resil decreased (p<0.05) as MOO levels increased, to the extent that the values obtained in broilers fed 0 mg/kg were higher (p<0.05) than those at 1000 mg/kg.

Sensory attributes

The sensory attribute scores for odor (5.04 ± 0.18), taste (5.06 ± 0.21), tenderness (5.34 ± 0.23) and overall acceptability (5.34 ± 0.19) were not different (p>0.05) among treatments. However, numerically the consumers gave a higher overall score (5.23) for the breast meat of broilers supplemented with MOO than for those of the control group (5.04).

Table 6 – Color parameters of breast meat from broilers supplemented with Mexican oregano essential oil.

Treatment[1]	Variables[2]						
	L*	a*	b*	Hue	Chroma	ΔE	BI
0	68.80 ^{ab}	12.29^{a}	11.24^{c}	42.68^{d}	16.73^{b}	29.29^{bc}	30.42^{c}
200	67.22^{b}	13.32^{a}	12.43^{bc}	43.07^{d}	18.33^{ab}	31.48^{ab}	34.50^{abc}
400	64.20^{c}	12.88^{a}	12.68^{bc}	44.50^{cd}	18.18^{ab}	34.00^{a}	36.28^{ab}
600	66.58^{bc}	12.48^{a}	14.78^{a}	50.01^{bc}	19.47^{a}	32.41^{a}	38.50^{a}
800	66.92^{b}	11.89^{a}	14.81^{a}	50.83^{b}	18.88^{ab}	31.94^{ab}	37.67^{a}
1000	69.74^{a}	9.19^{b}	14.17^{ab}	57.95^{a}	16.92^{b}	28.23^{c}	32.35^{bc}
SEM	0.58	0.48	0.49	1.44	0.52	0.68	1.26
p-values	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.0017	< 0.0001	< 0.0001

[1]Treatments 0 = control diet; 200 = diet + 200 mg Mexican oregano essential oil (MOO)/kg; 400 = diet + 400 mg/kg MOO; 600 = diet + 600 mg/kg MOO; 800 = diet + 800 mg MOO /kg; and 1000 = diet + 1000 mg MOO/kg. SEM = standard error of the mean.

[2] L* = lightness; a* = redness; b* = yellowness; Hue = Hue angle; Chroma = saturation index; ΔE = total color change; BI = browning index.

[a-d]Means (n = 10 breasts per treatment, two per replicate pen) in columns followed by different superscripts are significantly different (p<0.05).

Table 7 – Shear force and texture analysis of breast meat from broilers supplemented with Mexican oregano essential oil.

Treatment[1]	Variables[2]							
	SF (N)	Hard (N)	Adhes (g s^{-1})	Spring (mm)	Cohes	Gum (g)	Chew (g mm)	Resil
0	17.00	86.93^{b}	-22.43	0.50	0.40^{a}	35.10	17.55	0.14^{a}
200	13.36	94.24^{ab}	-27.99	0.48	0.38^{ab}	35.48	16.99	0.13^{ab}
400	13.14	103.52^{ab}	-34.14	0.49	0.35^{ab}	36.68	17.82	0.12^{ab}
600	11.35	110.66^{a}	-24.96	0.49	0.36^{ab}	41.12	19.82	0.12^{ab}
800	11.13	108.75^{a}	-23.55	0.51	0.35^{b}	38.06	19.58	0.12^{ab}
1000	11.86	105.12^{a}	-26.63	0.50	0.33^{b}	35.00	17.66	0.11^{b}
SEM	1.79	5.91	6.67	0.012	0.01	2.73	1.42	0.01
p-values	0.2109	0.0466	0.8373	0.4042	0.0047	0.5887	0.6386	0.0260

[1]Treatments 0 = control diet; 200 = diet + 200 mg Mexican oregano essential oil (MOO)/kg; 400 = diet + 400 mg/kg MOO; 600 = diet + 600 mg/kg MOO; 800 = diet + 800 mg MOO /kg; and 1000 = diet + 1000 mg MOO/kg. SEM = standard error of the mean.

[2] SF = shear force; Hard = hardness; Adhes = adhesiveness; Spring = springiness; Cohes = cohesiveness (dimensionless); Gum = gumminess; Chew = chewiness; Resil = resilience (dimensionless).

[a-b] Means (n = 10 breasts per treatment, two per replicate pen) in columns followed by different superscripts are significantly different (p<0.05).

DISCUSSION

The null hypothesis (MOO treatment effects on breast meat quality are equal to the no-MOO control treatment) is based on the *p*-value according to a significance level determined at$\alpha = 0.05$. Several studies have evaluated oregano essential oil supplementation at various levels (mg/kg) in feed: 300 (Alp *et al*., 2012; Skoufos *et al*., 2016), 65 (Bozkurt *et al*., 2012; Sun *et al*., 2015), 125 (Hong *et al*., 2012), 0, 60, 100 and 200 (Hashemipour *et al*., 2013), 15-60 (Khattak *et al*., 2014), 250 (Ghazi *et al*., 2015), 300 and 500 (Mohiti-Asli & Ghanaatparast-Rashti, 2015), 400-1600 (Silva Vazquez *et al*., 2015), 300 and 600 (Peng *et al*., 2016) and 400 (Méndez-Zamora *et al*., 2017). These studies obtained significant effects with all the OEO levels evaluated in broilers regarding, for example, BW, FI and FCR.

Contrary to results in the current study, Skoufos *et al*. (2016) did not find any differences in BW of 28-d-old broilers fed0 or 15 mg oregano essential oil (OEO)/kg feed. Peng *et al*. (2016) obtained higher BW in broilers fed 300 and 600 mg OEO /kg diet in the grower (1-21 d) and finisher (22-42 d) phases, which are similar to results observed in the current study with 200 to 1000 mg MOO/kg. Contrasting results were obtained by Sun *et al*. (2015), who obtained lower BW and higher FI at 14 and 21 d in broilers fed 60 mg OEO /kg in broiler diets on BW and FI compared with results of the current study using MOO. Hence, similar to improvements with OEO, broiler performance can be improved with MOO from *Lippiaberlandieri* Schauer, which may translate into higher market value. Peng *et al*. (2016), using 600 mg/kg of supplement, did not find differences in FI at 1 to 21 d, while from 22 to 42 d and 1 to 42 d, the supplement promoted higher FI. In contrast, Hashemipour *et al*. (2016) did observed any FI differences at 42 d in broilers fed 100 or 200 mg/kg of thymol+carvacrol, major components of OEO and MOO. The controversy represented by these results is whether treatment during the fattening period would result in higher production expenditures for growers, and therefore, much consideration is needed

to determine the optimal OEO, including MOO, levels required to enhance broiler performance.

Few studies have reported and measured the effect on the water intake (WI) of broilers supplemented with OEO, and to a lesser degree with MOO. Differently from the results of the present study, Silva Vázquez *et al*. (2015), evaluating two MOO levels in the starter and/or finisher broiler diets, did not obtainany WI differences in at overall period (0-39 d). These differences may be due to broilers' physiological status, population density, room temperature, and feed intake (Manning *et al*., 2007), as well as to the thymol and carvacrol levels in the MOO used as growth promoter (Silva Vázquez *et al*., 2015). Results from the current study again demonstrated that WI can be affected in broilers supplemented with dietary MOO.

Hashemipour *et al*. (2016) found significantly higher average daily weight gain at 10, 24 and 42 d and throughout the experiment (0-42 d) when supplementing broiler diets with 100 and 200 mg of thymol + carvacrol /kg. Similarly, Mohiti-Asli & Ghanaatparast-Rashti (2015) found higher weight gain at 28 din broilers supplemented with 300 and 500 mg of OEO/kg. These results are consistent with those in the current study with 200, 400 and 600 mg of MOO /kg. Ghazi *et al*. (2015), supplementing broilers with 250 mg of OEO/kg, obtained similar average daily weight gain and FCR throughout that trial (1-40 d) as those observed in the current study.

Slaughter variables results (p<0.05 for SW and HCY) of the current study do not agree with those of Alp *et al*. (2012) and Kırkpınar *et al*. (2014), who fed broilers with up to 300 mg of OEO/kg and did not find any SW or carcass yield differences. In contrast, Méndez-Zamora *et al*. (2017), feeding broilers with 400 mg of OEO/kg, did not find SW or HCY differences, while Méndez-Zamora *et al*. (2015a) observe higher SW and HCY when using 400 and 800 mg of MOO/kg. According to these authors, increased levels of the active molecules carvacrol and thymol, as essential oil components, may have reduced offal weight. Khattak *et al*. (2014) and Peng *et al*. (2016) found higher CY and BY values with broiler diet supplementation of 0 to 500 g/t and 300 and 600 mg/kg of a natural blend of essential oils and OEO, respectively. The previous analyses and data from the current study revealed that the effects on CY and BY may be attributed to dietary essential oil concentrations, in addition to breed, sex and diet. In the current study, CCY and BY were not different among treatments, but CCY and BY were numerically higher when broilers were fed 0 and 200mg MOO/kg and 800 1000 mg MOO/kg, respectively, which may increase carcass market value.

Fletcher (2002) indicated that myoglobin content, its chemical state and pH contribute to broiler meat color. Broiler breast meat pH in the current study decreased with increasing MOO levels. Similar pH values in broiler breast meat were obtained by Kirkpinar *et al*. (2014) and Méndez-Zamora *et al*. (2015b), using 150 and 300 mg of Greek oregano and garlic essential oils/kg diet, and 1600 mg MOO/kg, respectively. The breast meat pH variation obtained in the current study could be explained according to Roofchaee *et al*. (2011), in which the high antioxidant activity of thymol, present in Greek and Mexican oregano essential oils, is due to the presence of phenolic OH groups, which act as hydrogen donors. Hence, increasing OEO or MOO dietary levels diets enhances the donation of OH groups, potentially lowering the pH value detected in breast meat. Méndez-Zamora *et al*. (2015b) indicated that the synergism between carvacrol and thymol in MOO could equilibrate the charge distributions in the breast meat.

Few studies have evaluated CL when supplementing essential oils in broiler diets. Park *et al*. (2014) did not find any influence of the inclusion of 0.2% (w/v) of three plant extracts in broiler diets on CL. In the current study, CL was significantly lower when broilers were fed 1000 mg MOO/kg diet relative to 400 mg MOO/kg.

Differences in L* and a* values when testing OEO and garlic essential oil were found by Kirkpinar *et al*. (2014) obtained higher breast meat L* and a* values in broiler fed 150 mg garlic essential oil or OEO/kg and 300 mg of both EO/kg, respectively. However, these values are lower than those determined in the current study with MOO. The b* results of the current study were similar to those obtained by Young *et al*. (2003) with 3 % of Turkish oregano; however, Méndez-Zamora *et al*. (2015b) found higher L* and b* values when feeding broilers with400, 800 and 1600 mg of MOO/kg. Those authors indicated that the increase in b* are likely due to high carotenoid content of MOO. This observation could explain the results obtained in the current study, because higher b* values were obtained at high MOO concentrations. Symeon *et al*. (2009) found significant statistical differences in a* and b* when 100 and 250 mg of OEO /kg were fed to broilers, and stated that these parameters may present inconsistent performance due to dosage or genetic effects. Few studies have reported data on ΔE and BI, variables that can help explain L*, a* and b* behavior

in broiler breast meat as affected by OEO inclusion in the diet. The results of the current study indicate that the changes in color parameters may be attributed to the effects of 400 and 600 mg of MOO /kg on ΔE, and of 600 and 800 mg/kg on BI. Other authors (Hong *et al*., 2012; Park *et al*., 2014), however, did not find any effect of broiler diet supplementation OEO on meat color parameters.

Meat texture is evaluated with textural profile analysis (TPA) and shear force (SF) as affected by myofibril structure. Recently, studies on the meat quality or carcass traits of broilers supplemented with plant extracts in diets have been carried out (Méndez-Zamora *et al*., 2015a, 2015b; Hashemipour *et al*., 2016; Mpofu *et al*., 2016; Peng *et al*., 2016; Sadeghi *et al*., 2016; Soltani *et al*., 2016; Chowdhury *et al*., 2018), but with little attention have been given to TPA. Park *et al*. (2014) did not find effects on SF, Spring, Gum and Chew when evaluating 0.2% (w/v) of the inclusion of extracts of the plants *Saposhnikoviadivaricata*, *Lonicera japonica* and *Chelidoniummajus*in broiler diets. Compared with the current study, those authors found contrasting results for Adhes, but similar results for Hard, Cohes and Resil. Results obtained by Park *et al*. (2014) and data from the current study indicate that essential oil extracts in diets may influence texture properties of broiler meat. In the current study, 200, 400 and 600 mg/kg increased the Hard, Cohes and Resil qualities of broiler breast meat.

The main poultry meat quality attributes are appearance, texture, juiciness, flavor, and functionality (Fletcher, 2002). Contrary to the sensory results obtained in the breast meat of broilers fed MOO in the current study), Hong *et al*. (2012) obtained lower tenderness and overall acceptability scores in broiler fed 125 mg of OEO/kg diet. In addition, those authors obtained lower (4.04-4.52) preference values compared with the current study, using a seven-point hedonic scale, indicating that the improved overall acceptability may be due to the antioxidant properties of polyphenols and flavonoids in OEO, which limit lipid and protein oxidation. Kirkpinar *et al*. (2014) carried out a sensory evaluation with a trained panel of the breast meat from broilers supplemented with 300 mg of OEO and garlic/kg diet, where the panel detected significant statistical differences with slightly higher scores for oxidized flavor, juiciness, flavor and overall acceptability at 1, 15 and 30 d of broiler age. The authors stated that the essential oils in the diet may improve flavor and texture in breast meat. This observation may be reflected by the inclusion of 200 to 1000 mg of MOO/kg tested in the current study.

CONCLUSIONS

Mexican oregano essential oil from *Lippiaberlandieri* Schauer at 200 and 400 mg/kg diet as broiler dietary supplement improved body weight, feed and water intake, weekly body weight gain and feed conversion ratio at 7, 14 and 28 d. Furthermore, dietary Mexican oregano essential oil supplementation at 1000 mg/kg increased slaughter weight, hot carcass yield, and reduced breast meat pH and cooking loss. Mexican oregano oil influenced color parameters, hardness, cohesiveness and resilience, but did not have any adverse effects on the sensory evaluation.

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