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Effects of post-feed restriction of thyme, oregano and probiotics supplementation on growth, carcass characteristics, intestinal morphology and ileal digestibility in broiler chickens

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Abstract

To mitigate metabolic disorders and skeletal abnormalities associated with rapid growth in broilers, and to reduce reliance on antibiotics, strategies involving feed restriction and non-antibiotic dietary additives are increasingly explored. This study investigated the effects of various feeding methods and additives on weight gain, feed intake, feed conversion ratio, carcass characteristics, intestinal morphology and ileal digestibility in broiler chickens. The research involved 480 one-day-old Ross 308 male broiler chickens. A 2 × 5 factorial experiment, arranged in a completely randomized design, incorporating two feeding methods (without and white quantitative restriction) and four types of additives including thyme essential oil (300 g *per* ton), oregano essential oil (300 g *per* ton), equal weight ratio of thyme and oregano essential oil (300 g *per* ton) and probiotic (250 g *per* ton) along with control diets (without additives). Dietary supplementation with oregano essential oil significantly increased weight gain compared to the other additive groups. While the feeding method, additives and their interactions significantly influenced feed intake in chickens and the feed conversion ratio was primarily affected by the type of additive. Supplementation with any of the tested additives led to reduced total feed intake and improved final feed conversion ratio compared to the control group. Histological analysis revealed that chickens receiving oregano exhibited the highest villus height to crypt depth ratio. In conclusion, this research suggested that quantitative feed restriction, particularly when combined with specific dietary additives such as oregano essential oil could significantly improve broiler growth performance, feed efficiency and intestinal morphology, offering potential alternatives to conventional practices.

Introduction

The production of meat in a short time by the poultry industry has made it one of the most important protein producers in the world so that chicken meat has the first place in terms of production in the world. The high growth rate in broilers, despite the reduction of meat production time, leads to the occurrence of diseases and disorders such as cardiovascular disease,[1] ascites, sudden death syndrome, etc.[2] Feed restriction (FR) is an established management strategy employed to mitigate these disorders and associated mortality.[3,4] Previous research indicated that compensatory growth typically followed the re-feeding of restricted broilers.[5,6] Given the global concern regarding antibiotic resistance and its associated health risks, the utilization of effective herbal extracts as non-antibiotic growth promoters is critically important for human and animal health, the use of herbal extracts can be an alternative for antibiotic growth promoters in the re-feeding period of restricted broilers. Incorporating plant-based feed additives into broiler diets enhances intestinal function, increases nitrogen retention and fiber digestibility, promotes better growth performance, reduces inflammation, and improves antioxidant and antimicrobial activities.[7] In addition to the beneficial nutritional effects of plant-based additives, utilizing them in place of synthetic additives also significantly contributes to environmental protection.[8] Therefore, studying the effects of different plant species can lead to the identification of optimal plants for this purpose. Oregano (*Origanum vulgare*) as a medicinal plant is one of the suitable options to be used as an additive in poultry feed. Beyond its antimicrobial properties, oregano enhances the nutrient absorption and feed conservation efficiency by suppressing undesirable intestinal micro-

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organisms.[9] Thyme (*Thymus vulgaris*) is another widely used herbal additive in broilers feed. Previous studies have revealed the antimicrobial, antioxidant, antifungal, anti-coccidial and anti-inflammatory properties of thyme.[10,11] It is also known that thyme is a source of some vitamins (e.g., A, K, E, C and B-complex) and minerals (e.g. Ca, Mg, Fe and K).[11] The current study was conducted to investigate the effects of oregano, thyme, oregano-thyme combination and probiotic (PR) product following FR on growth, feed intake, feed conversion ratio (FCR), carcass characteristics, intestinal morphology and ileal digestibility in broilers.

Materials and Methods

Animals, diets and experiment. A total number of 480 one-day old Ross 308 male broiler chickens were used. We designed a factorial experiment (2 × 5) in a completely randomized design including two feeding methods (full feed and restricted [RE]) and four types of additives (thyme essential oil, 300 g *per* ton of basal diet; oregano essential oil, 300 g *per* ton of basal diet, equal weight ratio of thyme + oregano essential oil , 300 g *per* ton of basal diet, PR protoxin (Probiotics UK International, Somerset, UK) including *Lactobacillus plantarum, L. bulgaricus, L. acidophilus, L. rhamosus, Bifidobacterium bifidum, Streptococcus thermophilus, Enterococcus faecium, Aspergillus oryzae, Candida pintolopesi*, 200 g *per* ton of basal diet) along with control diets (without additives). It should be noted that each treatment was divided into four replicates with 12 chickens in each replicate. The essential oil of thyme and oregano used in this study was purchased from Barij Essence Pharmaceutical Company (Kashan, Iran) with a purity of 85.00%. The basal diet was formulated to meet the nutrient requirements of the broilers as recommended for commercial Ross 308 (Table 1).[12] In the first step of the experiment, the birds were divided into two equal groups. The first group was fed on full feed, but quantitative FR (25.00% lower than the first group) was applied to the second group from 8 to 14 days.[13] After the FR period for second group, the aforementioned herbal additives and PR product were added to the basal diet of both groups until slaughter.

Feed intake and growth performance. The daily feed intake was recorded for each replicate to determine the total feed consumption during the periods of 15 to 24 days, 25 to 35 days, 36 to 42 and for the entire duration of the experiment (8 to 42 days). Weight gain was also measured *per* replicate at the end of each of the mentioned periods using an electrical weighing balance. Finally, feed intake and weight gain values were used to calculate FCR *per* replicate. In line with the diet phasing, which included four periods, comprising a starter phase (days 1 - 10), a grower phase (days 11 - 24), and two finisher phases (days 25 - 35 and 36 - 42), we established three intervals for measuring traits. While the two finisher intervals corresponded with the diet phases, the first interval partially overlapped with the grower phase due to FR applied from days 8 to 14.

Carcass characteristics. On the final day of the experiment (day 42), two broilers from each replicate, which were near the mean weight of that replicate, were selected. Following slaughter, the internal organs of the

Table 1. Composition of diets during starter, grower and finisher (1 and 2) periods.

Ingredients (%)	Starter (1 - 10 days)	Grower (11 - 24 days)	Finisher 1 (25 - 35 days)	Finisher 2 (36 - 42 days)
Corn	55.50	55.74	60.00	61.65
Soybean meal	35.00	36.10	32.40	30.91
Fish meal	3.50	-	-	-
Soybean oil	2.00	3.70	3.65	4.02
Calcium carbonate	1.45	1.60	1.50	1.50
Dicalcium phosphate	1.40	1.70	1.50	1.10
Sodium chloride	0.25	0.25	0.25	0.25
L-Lysine	0.20	0.23	0.10	-
DL-Methionine	0.20	0.18	0.10	0.07
Vitamin supplement*	0.25	0.25	0.25	0.25
Mineral supplement**	0.25	0.25	0.25	0.25
Dry matter	86.48	86.17	86.49	86.75
Metabolisable energy (kcal kg^{-1})	2,927	3,026	3,030	3,126
Crud protein	22.03	20.80	19.54	18.71
Calcium	1.09	1.07	1.00	1.00
Phosphorus	0.50	0.48	0.43	0.46
Methionine	0.59	0.51	0.42	0.39
Lysine	1.40	1.29	1.09	0.93
Methionine + Cystine	0.93	0.85	0.72	0.71

* Supplied *per* kg of feed: 3,500,000 IU of vitamin A, 1,000,000 IU of vitamin D3, 9,000 IU of vitamin E, 1,000 mg of vitamin K3, 900 mg of vitamin B1, 3,300 mg of vitamin B2, 5,000 mg of vitamin B3, 15,000 mg of vitamin B5, 150 mg of vitamin B6, 500 mg of vitamin B9, 7.50 mg of vitamin B12, 250,000 mg of choline and 500 mg of biotin.

** supplied *per* kg of feed: 50,000 mg of manganese, 25,000 mg of iron, 50,000 mg of zinc, 50,000 mg of copper, 500 mg of iodine and 100 mg of selenium.

chickens were removed, and the percentages of whole carcass, thighs, breast and abdominal fat weight were calculated in relation to live body weight.

Intestinal morphology. On the 42nd day of the experiment and following slaughter, one chicken was selected from each replicate and a segment approximately 2.00 cm in length was taken from the middle part of the jejunum. After washing the intestinal segments with saline solution (85.00%), they were fixed in formalin (10.00%) for 24 hr. Once the samples were prepared, an optical microscope connected to a computer was used to measure the villus height (from the top of the villus to the crypt opening), crypt depth (from the base of the crypt to the level of the crypt opening), the villus height to crypt depth (V:C) ratio and the villus width in µm.

Ileal digestibility of nutrients. To determine the digestibility of nutrients, celite (Merck, Darmstadt, Germany) was added as an indigestible marker (10.00 g kg^{-1}) to experimental diets. Acid-insoluble ash was fed to chickens for 3 days (from day 40) along with these diets. At the end of the 3rd day, five chickens *per* replicate were killed by suffocation with carbon dioxide gas and immediately the contents of their ileum were collected and frozen at – 20.00 ˚ C until analysis.[14] Then, the ileum contents after grinding (to pass a 0.50 mm sieve) were analyzed to determine crude protein (nitrogen), crude fat, gross energy, calcium and phosphorus according to standard method.[15] The amount of acid-insoluble ash (as an internal marker) was determined,[16] and the percentage of nutrient digestibility was calculated based on the equations of Scott *et al.* according to the following formula:[17]

Nutrient digestibility (%) = 100 – [(marker in diet (%) / marker in ileum content (%) / nutrient in diet (%)] × 100

Statistical analysis. The data analysis of this study was done using the general linear model procedure of SAS Software (version 9.1; SAS Institute, Cary, USA), software according a completely randomized design with a 2 × 5 factorial arrangements by the following model:

$$Y_{ijk} = \mu + A_i + B_j + AB_{ij} + e_{ijk}$$

where, Y_{ijk}, μ, A_i, B_j, AB_{ij}, and e_{ijk} were evaluated trait, the general mean, the feeding method, the additive type, the interaction of feeding method × additive type and random error, respectively. Finally, Duncan's test was employed to compare the treatment means, with a significance level set at $p \leq 0.05$.

Results

Obtained results revealed that weight gain in different age of studied chickens was affected by the type of feeding method and the additives used in the experiment. Specifically, the weight gains during 15 to 24 and also 25 to 35 days for chickens that had experienced a FR period was significantly greater than in the group that was fed *ad libitum* ($p \leq 0.05$). Additionally, the type of additives affected the weight gain, such that the group fed on the oregano additive experienced greater weight gain compared to the other groups (Table 2).

Table 2. The effects of feeding methods, type of additives and their interaction on weight gain (g) of broiler chickens at different ages.

Parameters	15 - 24 days	25 - 35 days	36 - 42 days	8 - 42 days
Feeding methods				
Free	693.44[b]	918.96[b]	725.89	2,583.67
RE	755.86[a]	990.84[a]	692.52	2,582.65
SEM	17.13	17.35	26.17	25.37
***p*-value**	0.018	0.008	0.378	0.978
Additive types				
No additives	722.97[ab]	906.26[c]	635.06	2,449.68[b]
Thyme	771.88[a]	910.80[bc]	702.80	2,565.66[ab]
Oregano	735.99[a]	1,000.80[a]	755.46	2,688.53[a]
Thyme + Oregano	645.34[b]	994.16[ab]	743.96	2,588.52[a]
PR	747.09[a]	962.48[abc]	708.75	2,623.44[a]
SEM	27.08	27.44	41.38	40.11
***p*-value**	0.038	0.063	0.305	0.007
Interactions				
FR × NO	652.33	897.93	696.78	2,484.96
FR × TH	725.53	862.50	686.67	2,504.91
FR × OR	701.51	962.02	735.61	2,636.15
FR × (TH + OR)	655.14	935.29	770.41	2,610.28
FR × PR	732.71	937.07	740.00	2,682.07
RE × NO	793.61	914.60	573.33	2,414.40
RE × TH	818.22	959.10	718.94	2,626.40
RE × OR	770.47	1,039.57	775.31	2,740.91
RE × (TH + OR)	635.54	1,053.04	717.52	2,566.76
RE × PR	761.47	987.89	677.50	2,564.80
SEM	38.29	38.81	58.52	56.72
***p*-value**	0.310	0.724	0.605	0.168

RE: Restricted; PR: Probiotic; FR: Feed restriction; NO: Without additives; TH: Thyme essential oil; OR: Oregano essential.

While the type of feeding method, additives and their interactions had significant effects on the feed intake in chickens, the FCR was only affected by the type of additives ($p \leq 0.05$). The feed intake in chickens that had undergone a period of FR was higher than in the control group. Adding additives to the diet also resulted in decreased feed consumption and improved FCR compared to the control group (without additives), although different patterns were observed at various ages. Overall, during the experimental period (from 8 to 42 days), chickens that received a combination of oregano and thyme had the lowest feed intake and FCR (Table 3).

Following the impact of treatments on the weight gain of the chickens, the percentage of carcass and various carcass parts were also influenced by them. Except for the breast muscle (%), which was not affected by the type of feeding and additives, the total carcass percentage, the thighs muscle (%), and the amount of abdominal fat were significantly influenced by the type of feeding and additives ($p \leq 0.05$). Notably, the whole carcass (%) and thighs muscles (%) in chickens that underwent a period of FR were higher than those in other group, while the abdominal fat in these chickens was found to be lower (Table 4).

According to the results presented in the Table 5, the chickens that were subjected to a limited feeding period had shorter villus and greater villus depth compared to the control group ($p \leq 0.05$). Additionally, the additives had significant effects on villus length, villus depth and V : C ratio, such that the intestinal villi in chicks consuming PRs were higher and the villus depth was lower than in the other groups ($p \leq 0.05$). Feeding methods had a significant effect only on the ileal digestibility of fat, leading to increased digestion in a group of chicks that experienced FR period. However, the additives had a significant effect on the ileal digestibility of all the examined nutrients ($p \leq 0.05$). The highest ileal digestibility of dry matter (DM), crud protein (CP), gross energy (GE), and fat was observed in the bird's consuming oregano, while thyme resulted in increased digestibility of ash and Ca compared to the other groups.

Discussion

The results of this study were in agreement with Ranjbar *et al.*, who reported that although the daily weight gain during the post-restriction period showed a significant increase compared to the control group, no significant difference in the weight of the chickens related to both groups was observed at the end of the period.[18] Additionally, another researchers reported that chickens under 10.00 and 20.00% quantitative FR had higher growth during the post-restriction period compared to the control group (without restriction).[19]

Table 3. The main effects of the feeding methods, type of additives and their interaction effects on feed intake and feed conversion ratio of broiler chickens at different ages.

Parameters	Feed intake				Feed conversion ratio			
	15 - 24 days	25 - 35 days	36 - 42 days	8 - 42 days	15 -24 days	25 - 35 days	36 - 42 days	8 - 42 days
Feeding methods								
Free	989.11^{b}	1,802.39^{b}	1,943.26	5,071.52	1.43	1.97	2.71	1.97
RE	1,077.03^{a}	1,901.80^{a}	1,945.24	5,176.63	1.42	1.93	2.86	2.01
SEM	24.95	21.39	23.89	40.97	0.02	0.02	0.09	0.02
***p*-value**	0.022	0.004	0.954	0.085	0.821	0.234	0.237	0.098
Additive types								
No additives	1,146.35^{a}	1,911.83^{a}	1,951.67^{ab}	5,302.88^{a}	1.59^{a}	2.11^{a}	3.09	2.16^{a}
Thyme	1,061.93^{ab}	1,779.67^{b}	1,875.33b	5,005.10^{c}	1.38^{b}	1.96^{b}	2.69	1.95^{b}
Oregano	1,001.47^{cb}	1,924.95^{a}	2,009.20^{a}	5,223.09^{ab}	1.36^{b}	1.92^{bc}	2.71	1.95^{b}
Thyme + Oregano	918.89^{c}	1,824.08^{ab}	1,962.91^{ab}	4,995.82^{c}	1.43^{b}	1.84^{c}	2.70	1.93^{b}
PR	1,036.73^{abc}	1,819.97^{ab}	1,922.14^{ab}	5,093.50^{cb}	1.39^{b}	1.90^{cb}	2.73	1.94^{b}
SEM	39.45	33.82	37.78	64.77	0.02	0.04	0.14	0.03
***p*-value**	0.010	0.026	0.184	0.011	≤ 0001	0.0005	0.235	≤ 0001
Interactions								
FR × NO	1,042.70	1,884.00	2,043.33^{a}	5,305.48^{a}	1.60	2.10	2.94	2.13
FR × TH	998.50	1,690.00	1,798.33^{c}	4,816.42^{c}	1.38	1.96	2.63	1.92
FR × OR	960.33	1,835.36	1,978.36^{ab}	5,101.83^{ab}	1.37	1.91	2.75	1.94
FR × (TH + OR)	927.25	1,761.33	1,942.33^{abc}	4,962.31^{bc}	1.42	1.88	2.55	1.90
FR × PR	1,016.79	1841.27	1,953.94^{abc}	5,171.58^{ab}	1.39	1.98	2.68	1.93
RE × NO	1,250.00	1,939.67	1,860.00^{bc}	5,300.28^{a}	1.58	2.12	3.25	2.20
RE × TH	1,125.36	1,869.33	1,952.33^{abc}	5,193.78^{ab}	1.38	1.95	2.75	1.98
RE × OR	1,042.61	2,014.53	2,040.03^{a}	5,344.34^{a}	1.35	1.94	2.67	1.95
RE × (TH + OR)	910.53	1,886.82	1,983.48^{ab}	5,029.33^{bc}	1.43	1.80	2.85	1.97
RE × PR	1,056.67	1,798.67	1,890.33^{abc}	5,015.42^{bc}	1.35	1.83	2.79	1.96
SEM	55.79	47.83	53.43	91.60	0.04	0.05	0.20	0.04
***p*-value**	0.355	0.143	0.047	0.067	0.983	0.387	0.852	0.939

RE: Restricted; PR: Probiotic; FR: Feed restriction; NO: Without additives; TH: Thyme essential oil; OR: Oregano essential.

Table 4. The main effects of the feeding methods, type of additives and their interaction effects on relative weight (%) of broiler chickens.

Parameters	Carcass	Thigh	Breast	Abdominal fat
Feeding methods				
Free	73.10^{b}	22.23^{b}	27.04	2.00^{a}
RE	74.35^{a}	24.38^{a}	28.03	1.67^{b}
SEM	0.31	0.38	0.43	0.05
***p*-value**	0.007	0.041	0.111	≤ 0001
Additive types				
No additives	71.71^{c}	24.20^{ab}	26.64	2.09^{a}
Thyme	73.09^{bc}	23.07^{b}	27.96	1.66^{b}
Oregano	74.27^{ab}	22.70^{b}	27.91	1.86^{ab}
Thyme + Oregano	74.85^{a}	23.69^{ab}	27.66	1.93^{a}
PR	74.73^{a}	25.36^{a}	27.52	1.62^{b}
SEM	0.49	0.60	0.68	0.09
***p*-value**	0.0001	0.029	0.660	0.002
Interactions				
FR × NO	71.66	25.09^{ab}	26.67	2.36
FR × TH	73.09	21.32^{c}	26.58	1.86
FR × OR	73.31	21.29^{c}	27.08	2.03
FR × (TH + OR)	74.04	22.72^{bc}	27.18	2.01
FR × PR	73.41	25.76^{a}	27.71	1.73
RE × NO	71.76	23.32^{abc}	26.62	1.82
RE × TH	73.09	24.82^{ab}	29.33	1.46
RE × OR	75.22	24.11^{ab}	28.74	1.70
RE × (TH + OR)	75.67	24.67^{ab}	28.14	1.85
RE × PR	76.05	24.97^{ab}	27.33	1.52
SEM	0.70	0.86	0.96	0.12
***p*-value**	0.253	0.012	0.486	0.570

RE: Restricted; PR: Probiotic; FR: Feed restriction; NO: Without additives; TH: Thyme essential oil; OR: Oregano essential.

Table 5. The main effects of the feeding methods, type of additives and their interaction effects on intestinal morphology and ileal digestibility of broiler chickens.

Parameters	Intestinal Morphology (µm)				Ileal digestibility (%)						
	Villus height	Villus width	Crypt depth	V : C	DM	Ash	CP	Fat	GE	Ca	P
Feeding methods											
Free	1,518.23^{a}	195.10^{b}	122.40	12.46	74.37	43.92	74.68	77.42^{b}	79.99	51.05	51.01
RE	1,481.53^{b}	215.27^{a}	122.13	12.18	76.06	42.69	77.34	82.05^{a}	81.69	49.58	51.23
SEM	9.63	3.14	1.74	0.18	1.16	0.62	0.98	1.43	1.01	0.40	0.35
***p*-value**	0.014	0.0002	0.92	0.30	0.31	0.177	0.068	0.033	0.251	0.258	0.65
Additive types											
No additives	1,546.75^{a}	202.67^{b}	124.00	12.53^{a}	68.49^{b}	39.36^{b}	70.75^{b}	74.19^{b}	76.74^{b}	44.35^{b}	49.62^{c}
Thyme	1,447.58^{c}	191.25^{b}	127.00	11.47^{b}	75.37^{a}	45.52^{a}	75.17^{ab}	79.45^{ab}	79.29^{ab}	53.75^{a}	50.42^{bc}
Oregano	1,567.50^{a}	205.42^{b}	121.67	12.93^{a}	78.40^{a}	45.09^{a}	78.97^{a}	83.41^{a}	83.91^{a}	52.07^{a}	51.29^{abc}
Thyme + Oregano	1,496.17^{b}	195.33^{b}	119.33	12.56^{a}	77.15^{a}	43.60^{a}	78.96^{a}	80.56^{ab}	82.22^{a}	51.27^{a}	52.55^{a}
PR	1,441.42^{c}	231.25^{a}	119.33	12.10^{ab}	76.67^{a}	42.95^{a}	76.20^{a}	81.09^{ab}	82.05^{a}	50.14^{a}	51.70^{ab}
SEM	15.23	4.97	2.76	0.29	1.83	0.98	1.54	2.26	1.61	0.63	0.55
***p*-value**	≤ 0001	0.0001	0.27	0.021	0.008	0.002	0.007	0.096	0.039	0.002	0.01
Interactions											
FR × NO	1,510.17^{c}	193.50^{cde}	129.33^{ab}	11.68^{bc}	67.24	41.07	70.07	71.00	77.60	48.40	49.33
FR × TH	1,478.50^{cd}	182.83^{de}	124.67^{abc}	11.93^{bc}	75.25	45.25	72.61	77.77	77.77	51.72	50.35
FR × OR	1,523.33^{bc}	203.33^{bcd}	133.00^{de}	13.48^{a}	79.54	47.56	79.15	84.09	85.10	50.45	51.74
FR × (TH + OR)	1,612.67^{a}	179.50^{e}	128.33^{ab}	12.60^{ab}	74.23	43.87	76.78	75.93	79.26	50.66	52.66
FR × PR	1,466.50^{cd}	216.33^{b}	116.67^{cde}	12.57^{ab}	75.58	41.85	74.76	78.32	80.23	51.34	50.95
RE × NO	1,583.33^{ab}	211.83^{bc}	118.67^{bcde}	13.37^{a}	69.74	37.64	71.43	77.37	75.89	48.97	49.92
RE × TH	1,416.67^{de}	199.67^{bcde}	129.33^{ab}	11.00^{c}	75.49	45.79	77.74	81.13	80.80	50.19	50.49
RE × OR	1,611.67^{a}	207.50^{bc}	130.33^{a}	12.37^{ab}	77.26	42.63	78.77	82.72	82.72	50.34	50.84
RE × (TH + OR)	1,379.67^{e}	211.17^{bc}	110.33^{e}	12.52^{ab}	80.07	43.33	81.13	85.17	85.18	51.86	52.44
RE × PR	1,416.33^{de}	246.17^{a}	122.00^{abcd}	11.62^{bc}	77.76	44.05	77.63	83.85	83.86	54.10	52.45
SEM	21.54	7.03	3.90	0.41	2.59	1.39	2.18	3.20	2.27	0.89	0.77
***p*-value**	≤ 0001	0.32	0.002	0.015	0.62	0.107	0.72	0.560	0.321	0.910	0.62

V : C: Villous height to crypt depth ratio; RE: Restricted; PR: Probiotic; FR: Feed restriction; NO: Without additives; TH: Thyme essential oil; OR: Oregano essential, DM: dry matter, CP: crud protein, GE: gross energy.

One possible reason for compensatory growth after a FR period could be attributed to the elevated concentration of growth hormone that has been observed in chickens subjected to feed limitation.[20] The observed higher feed intake in the feed-restricted group was consistent with a study on responds to fasting and refeeding in broiler chickens**.** Following a period of FR, poultry often increased their voluntary feed intake upon the removal of dietary limitations to compensate for the prior deficit.[21] As shown in Table 3, this elevated feed consumption in the restricted group gradually declined over time after the restriction period ended. By 36 to 42 days of age, feed intake levels between the restricted and control groups showed no significant difference.

Since, Oregano and thyme essential oils typically contain monoterpenes such as thymol and carvacrol in different ratios.[22] The reduction in feed intake in the groups receiving thyme + oregano combination may be related to the taste and smell of substances such as carvacrol.[23] However, characteristics such as changes in gut microbiota and the antioxidant properties of these substances,[24] ultimately led to an improvement in the efficiency of the consumed feed.

The results obtained in the present study indicated that the FCR in birds receiving oregano essential oil was somewhat superior to that in chicks receiving thyme essential oil, aligning with the findings of Zaazaa *et al*.[25] In another study, the use of thyme resulted in a significant improvement in FCR in broilers that was consistent with our results.[26] However, several studies have reported no significant effects associated with the inclusion of thyme and oregano essential oil in the diet on weight gain and FCR.[27,28] It appears that factors such as conducting experiments with different poultry strains, applying treatments at various ages, utilizing differing dosages of additives and employing diverse basal diets may contribute to the discrepancies observed in the results of various studies.

The analysis of the effects of additives revealed that the highest percentage of carcass and the lowest amount of abdominal fat belonged to the chickens that were fed on the combination of oregano + thyme and PRs, respectively. Chickens that were not under FR and received no additives had the highest percentage of abdominal fat (2.36%). The findings of the current study, which demonstrated a significant decrease in abdominal fat in poultry given thyme extract were consistent with the results of Abdulkarimi *et al*. who reported that increasing the level of thyme extract (from 0.20 to 0.60%) in the poultry diet significantly reduced abdominal fat.[29] The reduction in abdominal fat observed in birds fed thyme might be attributed to decreased absorption of cholesterol and triglycerides in the intestine or reduced synthesis in the liver as evidenced by a strong correlation between plasma cholesterol levels and abdominal fat accumulation.

Another possible mechanism involves enhanced catabolism of abdominal lipids for gluconeogenesis, supported by reports that crushed thyme supplementation in broilers led to increased serum glucose concentrations.[30] In general, our findings showed that the chickens that were subjected to a one-week nutritional restriction produced less abdominal fat compared to the control group. These results were consistent with the findings of van der Klein *et al.*, Ye *et al*.[5,31] Scientific evidence has shown that consuming *ad libitum* feed leads to the wastage of some energy as abdominal fat. Reasons such as a reduction in the number and volume of adipocyte cells can result in a decrease in abdominal fat due to dietary restriction,[32,33] thereby, improving carcass efficiency.

The group receiving oregano had the highest villus height (1,567.50) and villous height to crypt depth (V : C) ratio (12.93). This result was in accordance with the findings of oregano oil significant effect on increasing villus height, where an increase in the dose of the oil resulted in a noticeable increase in villus height.[34] Crypts are indentations in the mucosal layer located adjacent to the villi, primarily responsible for generating enterocytes and goblet cells. The relationship between villus height and crypt depth is crucial for effective digestion and nutrient absorption in the small intestine. Taller villi provide a greater surface area for nutrient uptake, while shallower crypts indicate lower tissue turnover and reduced secretory demand leading to enhanced absorptive capacity. Therefore, the V : C ratio significantly influences the small intestine digestive efficiency.[35] Generally, a higher V : C ratio has been linked to enhanced digestion and nutrient absorption.[36]

The effects of different herbal additives on the improvement of nutrient digestibility and absorption in poultry have been reported in numerous studies.[37,38] These effects are likely attributable to the stimulating influence of these additives on digestive enzymes leading to enhanced enzymatic efficiency and consequently, increased nutrient digestibility and absorption.[38] The results of the current study, indicating a significant effect of thyme extract and PRs on the intestinal morphology of broilers were inconsistent with the findings of Golshahi *et al.*, who observed that these two additives did not significantly affect intestinal morphology.[39]

The positive effects of thyme extract on ileal digestibility were consistent with previous findings.[38] One of the reasons for these beneficial effects are likely due to the presence of flavonoids in thyme, which may have a spasmolytic activity on smooth muscle. This may improve food transit through the intestines and create favorable conditions for the interaction of digestive enzymes and digestive substrates, thereby, enhancing the digestion of nutrients.[40,41]

The findings of this study indicated that the interaction between FR and additives such as OR significantly optimized overall growth performance. The diet containing OR resulted in a 9.75% improvement in weight gain over the entire period compared to the control diet. Additionally, broilers under FR that received OR gained 10.29% more weight than the control group. The group receiving the thyme essential oil + oregano essential oil combination showed an approximately 10.65% better FCR compared to the control. This diet also led to an increase of about 4.38% in carcass percentage. Although no single additive can be recommended for all measured traits. Given its consistent positive impact across key performance indicators, OR is identified as the most effective single additive for inclusion in feed-restricted broiler programs.

Furthermore, histological measurements revealed that the use of these additives as well as PRs could enhance nutrient digestibility in broilers. Future research is encouraged to investigate the long-term effects of these additives and different feeding strategies.

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Conflict of interest

The authors declare no competing interests.

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