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RESEARCH ARTICLE

The Influence of *Artichoke Aqueous* extract on the growth performance, feed utilization, carcass characteristics, and health status of growing rabbits

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Abstract

The present study was conducted to evaluate the effect of different levels of dietary artichoke aqueous extract (AAE) on the growth performance, and physiological, immune, and oxidative responses of black Baladi rabbits. An experiment of 84 days was conducted with 36 growing male rabbits at 5 weeks of age with an initial live body weight (LBW) of 666.75g. A completely randomized design (with 4 treatments and 3 replicates/treatment) was used in the present study. Rabbits in the control group (D_0) received a free AAE-basal diet. Rabbits in the treatments D_1, D_2, and D_3 received a based diet supplemented with different levels of AAE at 10, 20, and 40 mg/kg diet, respectively. The results indicated that rabbits in D_1 had higher LBW, weight gain, performance index, lower feed intake, and better feed conversion ratio than those in D_0. A better significant effect on carcass characteristics was detected in D_1 than in D_0 rabbits in terms of carcass weight and edible giblets. Rabbits in D_1 had the best hematological (erythrocyte and leucocyte counts) and serum biochemical parameters, including blood protein, liver and kidney functions, redox balance, and cellular immunity compared to rabbits in D_0. It may be concluded that the dietary supplementation of 10mg AAE/kg diet (D_1) could have resulted in considerable improvement in the growth performance and feed efficiency without adverse effects on either carcass characteristics or constituents of blood serum of treated rabbits.

Keywords: Artichoke; Feed additive; Growth performance; Rabbits

1. Introduction

There is a direct relationship between animal and human populations; hence contaminated food is the possible transmission route for diseases among animals and humans (Fong, 2017). In recent years, farmers have been looking for ways to improve feeding techniques and find new by-products that could increase the productivity of animals, while improving animal conditions and keeping them in good health status (Dawkins, 2021). In this context, Terzic et al. (2012) noticed that approximately 80% of domestic animals have been fed synthetic compounds thus, residual amounts of nutritional of either antibiotics or synthetic hormones in animal products (meat, milk, eggs) have caused great caution in their use in the animal industry. Herbs, spices, and essential oils are an alternative to nutrition in livestock farming (Tajodini et al., 2015). These by-products have positive effects on improving animal performance, quality, and shelf life of livestock products. Hence, among plants, an alternative nutritional is the artichoke (Cynara scolymus L.). It is widely used in the culinary and pharmaceutical industries. Its extract is rich in biologically active substances such as flavonoids (cynarin, luteolin, apigenin), tannins, inulin, and pectin, as well as which are of interest to the feed

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industry (Salman et al., 2014). Furthermore, Salman et al. (2014) found that the main polyphenolic compounds of C. scolymus (caffeic acid and its derivatives; flavonoids cynarin, apigenin, and luteolin; tannins) have antioxidant properties and polyphenolic compounds that affected cholesterolemia by modulate cholesterol absorption. The tuber of an artichoke is rich in the carbohydrate inulin, which is converted to a fructooligosaccharide (FOS). Hence, the addition of FOS to the diet of monogastric animals brings about several metabolic and physiological changes, including improvements in feed efficiency, reduced diarrhea, and reduced smell in feces that have been attributed to a change in the make-up of the intestinal microflora population (García et al., 2016). Artichoke is a rich source of minerals a low amount of lipids, dietary fiber, and a high proportion of phenolics, and its crude protein (CP) content is near to alfalfa hay (15%) and has low crude fiber content of up to14.5% (Farhan et al., 2018). It is a good source of natural antioxidants such as vitamin C, carotenoids, polyphenols, hydroxyl cinnamic acid, and flavones (Gotardoa et al., 2019). It is a rich source of inulin and oligofructose, which belong to a class of carbohydrates known as fructose (Abadjieva et al., 2020). In addition, many researchers have reported the positive effects of extracts of herbal medicines on the function and growth of livestock (Kuralkar and Kuralkar, 2021; Al- Masari and Al-Himdany, 2022; Abdel-Wahab et al., 2023). In this respect, Karimi et al. (2020) reported that artichoke is the oldest known herbal medicine; it has phenolic compounds that prove the antioxidant function results from its radical-scavenging properties. Artichoke could be a good ingredient in rabbit diets from the view of the digestion and health status of growing rabbits (Havlíček et al., 2023), where its contents of oligosaccharides, such as inulin, and oligofructose, are possible substitutes for antibiotics and can improve gut health and reduce the mortality of rabbits. Despite the wide use of artichoke in many domestic animals, there is very few investigations have been done to use aqueous extract of artichoke on the growth performance in rabbits. Therefore, the present study was conducted to evaluate the effect of different levels of dietary artichoke aqueous extract (AAE) on the growth performance, and physiological, immune, oxidative responses, and histological properties of black Baladi rabbits.

Materials and methods

The present study was carried out from September 2022 to April 2023 at EL-Serw Research Station, Animal Production Research Institute (APRI), Agricultural Research Center, Ministry of Agriculture, Egypt.

Providing the artichoke aqueous extract

A weight of 200 milligrams of artichoke powder (purchased from AB Chemical Company, Mansoura, Egypt) was dissolved in 5 mL distilled water. The mixture was stirred for up to one hour. The solid deposit of the mixture was removed by centrifugation at 2500 rpm for 15 min. Then, the solution was recovered to get AAE. Finally, the extract was filtered and kept in a dark sterilized bottle at 4°C until use. Before the use of AAE, it was put in a water bath and kept at a temperature of 37°C.

Animals, housing, and quaffed artichoke aqueous extract

Randomized black Baladi rabbits were used with four treatments replicated three times with 3 rabbits per replicate making a total of 36 male rabbits to form D0, D1, D2, and D3 treatments. At the beginning of the experiment, the average initial live body weight (LBW) was 666.75± 0.31g. All rabbits were individually weighed weekly using a digital electric scale before offering the experimental diets in the morning until the 17th week of age. In a well-ventilated barn, each replicate was placed in a separate cage its dimensions at 50 cm3 length × 50 cm3 width × 35 cm3 height. Each cage has a feeder and free access to fresh water via automatic drinkers with nipples. All replicates were housed under standard conditions controlled by an automatic heating system (16 – 18 °C) and the light: dark cycle was 12 h: 12 h. Rabbits in the control treatment (D0) were given a free AAE-basal diet for 84 days. While, those in D1, D2, and D3 received 10, 20, and 40 mg AAE/kg diet, respectively. Rabbits in all treatments were monitored daily and managed under the same environmental and hygienic conditions and were given the appropriate vaccinations. Feces and urine were cleaned every morning when dropped from the cages on the ground.

Experimental feeding analysis:

The composition and chemical analysis of the experimental basal diet and artichoke contents are presented in Tables 1 and 2, respectively according to Salman et al. (2014). The amino acid concentrations (g/100g sample) of artichoke are explained in Table 3 according to Salman et al. (2014). In addition, the composition of minerals in artichoke aquas leaf extracts is shown in Table 4 according to Biel et al. (2020). The basal diet covered the nutrient requirements of growing rabbits from 5 to 12 weeks of age according to NRC (1994). The chemical analysis of the basal diet was explained according to Feed Composition for Animal and Poultry Feedstuffs used in Egypt (2001). Furthermore, the chemical analysis of the basal diet and premix was performed according to AOAC (2007).

The experimental measurements:

Growth performance and feed efficiency

The growth performance and feed efficiency parameters of the experimental rabbits were calculated according to the following equations;

Total weight gain (TWG, g) = Final weight - Initial weight.

Average daily gain (ADG, g/rabbit/day) = TWG/the experimental period (day).

Feed intake (FI, g/rabbit) = Feed offered (g) – Leftover (g).

Feed conversion ratio (FCR) = Average daily feed intake / average body weight gain.

Performance index (PI, %) = [Final weight (kg)/FCR × 100].

Carcass characteristics and internal organs

At the end of the experiment (12 weeks), a total of 12 rabbits (*n* = 3 in each treatment) were randomly chosen and fasted for 12 hours before slaughter according to El-Raghi et al. (2023). Then, the rabbits were individually weighed and the pre-slaughter weight was recorded. After slaughter, the abdominal cavity was opened to expose the visceral organs. Then, the carcass characteristics were evaluated after complete skinning and bleeding, the empty hot carcass with head, heart, kidneys, and liver were separately weighed. Then, the carcass characteristics percentages were determined according to the following equations;

Edible giblets (%) = [Liver (g)+kidney (g)+heart (g)/Pre-slaughter weight (g)] ×100.

Dressing percentage (%) = [Hot carcass weight including the head (g)/ Pre-slaughter weight (g)] ×100.

Blood sampling:

In the 12th week of the experiment, a total of 12 rabbits (*n*=3 males/treatment) were randomly chosen to collect the whole blood samples to assay the hematological parameters. Other blood samples were also collected in the heparinized tubes to get the serum to determine the serum biochemical measurements.

Table 1: Composition and chemical analyses of the basal diet

Ingredient	Content
Yellow Corn	8.00
Barley	20.00
Wheat barley	23.00
Soybean meal (44% CP)	16.00
Alfalfa hay	24.00
Mint straw	5.00
Di-calcium phosphate	1.30
Limestone	1.00
Vitamins and minerals premix*	0.30
NaCl	0.40
Di-methionine (99%)	1.00
Total	100.00
Calculated chemical composition (% on dry matter basis)	
Organic matter (OM)	91.06
Crude protein (CP)	18.17
Crude fiber (CF)	13.44
Ether extract (EE)	2.57
Nitrogen-free extract (NFE)	56.88
Ash	8.94
Neutral detergent fiber (NDF)	37.75
Acid detergent fiber (ADF)	21.69
Non-fiber carbohydrates (NFC)	32.87
Calcium	1.11
Available phosphate	0.49
Lysine	0.89
Methionine	0.42
Methionine + calcium	0.66
Digestible energy (Kcal /Kg)	2784.15

* Vitamins and premix/kg diet included Vitamin A 160000IU, Vitamin E 125 mg, Vitamin K 17 mg, Vitamin B_1 13 mg, vitamin B_2 43 mg, Vitamin B_6 18 mg, pantothenic acid 85 mg, Vitamin B_{12} 0.17 mg, Niacin 230mg, Folic acid 12 mg, Biotin, 0.60mg, Choline Chloride 4300mg, Fe 0.34 mg, Mn 670mg, Cu 56 mg, Co 3mg, Se 2.2 mg and Zn 480 mg.

Nuetral detergent fiber (NDF %) = 28.924 + (0.657×CF %) and Acid detergent fiber (ADF %) = 9.432+ (0.912× CF %) according to Cheeke (1987).

Non-fiber carbohydrates (NFC) = 100 – (CP + NDF + EE + ash) according to Calsamiglia *et al.* (1995).

Table 2: Chemical composition and fiber fraction of artichoke

Item	Composition (% on dry matter basis)
Dry matter (DM)	92.30
Organic matter (OM)	87.34
Crude protein (CP)	16.61
Crude fiber (CF)	24.22
Ether extract (EE)	5.46
Nitrogen-free extract (NFE)	41.05
Ash	12.66
Fiber fraction	
Neutral detergent fiber (NDF)	42.90
Acid detergent fiber, ADF	30.00
Acid detergent (ADL)	10.10
*Hemicellulose	12.90
**Cellulose	19.90

*****Hemicellulose = NDF–ADF.

**Cellulose =ADF–ADL.

Table 3: Amino acids concentration (g/100g) of artichoke

Item	Amino acid concentration
Essential amino acids	
Threonine	0.14
Valine	0.55
Methionine	0.36
Isoleucine	0.25
Leucine	0.59
Phenylalanine	0.56
Histidine	0.36
Lysine	0.14
Arginine	0.26
Proline	0.51
Non-essential amino acids	
Aspartic acid	0.63
Serine	0.27
Glutamic acid	0.67
Glycine	0.15
Alanine	0.37
Cystine	0.26
Tyrosine	0.22

Table 4: Composition of minerals in aquas artichoke leaves extract in 100 g of DM.

Item	Mineral concentration
Microelements (mg)	
K	506.3
P	414.0
Ca	386.9
Mg	220.7
Na	194.4
Microelements	
Zn (mg)	2.10
Fe (mg)	1.60
Mn (mg)	0.80
Cr (µg)	1.50

Hematological parameters:

It was used 3.0 mL of whole blood was collected in clean and sterilized bottles to determine the hematological parameters. Where, the concentration of hemoglobin (Hb), hematocrit (Hct), red blood cells (RBCs), white blood cells (WBCs), and platelets (PLT) count were assayed. While, the mean corpuscular volume (MCV), and mean corpuscular hemoglobin concentration (MCHC) were calculated. The fraction of WBCs including the percentage of lymphocytes, monocytes, neutrophils, and basophils was also determined using an automated hematology analyzer (Hema Screen 18, Hospitex diagnostics, Sesto Fiorentino, Italy).

Serum biochemical parameters:

It was used 10 mL of blood which collected in a clean and sterilized bottle without an anti-coagulant. Then, within one hour of collection, the samples were centrifuged at 3000 *rpm* for 5 min to get the serum samples. The serum in each treatment was stored at –20°C until analysis of the biochemical parameters. Where, serum glucose, total protein, albumin, globulin, total cholesterol, triglyceride, high-density lipoprotein (HDL), and low-density lipoprotein (LDL) were determined using commercial kits (Bio-diagnostic, Giza, Egypt). Both liver function enzymes as serum aspartate aminotransferase (AST), alanine aminotransferase (ALT), and total bilirubin, as well as renal function biomarkers such as uric acid and creatinine, were also measured using spectrophotometrically according to the manufacturer's protocol using commercial kits (Bio-diagnostic, Giza, Egypt).

Oxidative capability

Serum oxidative capability such as total antioxidant capacity (TAC), and lipid peroxidation was evaluated through measurement of malondialdehyde (MDA), superoxide dismutase (SOD), and catalase (CAT) using commercial kits (Shmadzu, Kyoto, Japan) according to the manufacturer's instructions.

Immune response parameters

The immune response parameters were measured as immunoglobulins G (IgG) and M (IgM) using commercial kits (number of kits as CSB-E06950RB).

Adrenal gland hormone

Serum cortisol was evaluated as an adrenal gland hormone using the commercial kits (the cortisol ELISA Kit quantitatively).

Statistical analysis:

The statistical analysis of all the obtained data as mean and standard errors of the mean (± SEM) was performed by ANOVA followed by the Duncan *post hoc* test to determine the significant differences at ($P < 0.05$) among all treatments using the SPSS/PC program (**SPSS Statistics version 2020**) by the following fixed model:

$$Y_{ie} = \mu + T_i + R_e$$

Where Y_{ie} = the individual observation;

μ = is the general mean.

T_i = is the fixed effect of the oral doses (0, 10, 20 and 40mg).

R_e = is the residual error component assumed to be normally distributed.

Results

Changes in body weight (g/week)

The average body weight (BW) during 12 weeks of trial rabbits in D0, D1, D2, and D3 was shown in Figure 1. The D1 rabbits obtained a higher (P < 0.05) final weight than those in D0. While rabbits fed AAE in D2 have higher (P < 0.05) final body weight than rabbits in D3. Furthermore, no significant difference (P > 0.05) between D0 and D3 in final body weight through the experimental intervals period. Constructively, high doses of AAE created negative changes in the body weight of treated rabbits.

Changes in feed consumption (g/week):

Average feed consumption during 12 weeks of D_0, D_1, D_2, and D_3 rabbits was explained in Figure 2. The feed consumption of rabbits fed AAE was significantly different ($P < 0.05$) compared to those in the control treatment (D_0) during the experiment weeks. At 12 weeks of the experiment, the D_1 rabbits had lower ($P < 0.05$) final feed consumption than the D_0 rabbits. While D_2 rabbits have less (P > 0.05) feed consumption than D_3 rabbits. Furthermore, a significant difference (P < 0.05) in feed consumption of rabbits in D_0 and D_3 was observed at 12 weeks of trial. Constructively, AAE at low doses created an improvement in the feed consumption of treated rabbits.

Measurements of growth performance and feed efficiency

The values of TWG, ADG, total feed intake, daily feed intake, FCR, PI, and metabolic weight (MW) are presented in Table 5. Both TWG and ADG were different among D_0, D_1, D_2, and D_3 rabbits. The D_1 and D_2 were heavier weight ($P < 0.05$) than those in D_0 and D_3. In general, ADG decreased ($P < 0.05$) during the growth period in D_0 and D_3 rabbits, except for the D1 rabbits which recorded heavier weight ($P > 0.05$) than D_2 rabbits. Feed intake decreased in D_1 and D_2 rabbits compared to those in D_0 and D_3 (Table 5). The values of FCR for D_1 were the best ($P < 0.05$) compared to either D_2 or D_3 rabbits. The obtained results indicated that D_1 and D_2 rabbits were more efficient in feeding utilization than those in D_0 or

D_3. The value of PI differed ($P < 0.05$) in D_1 and D_2 rabbits compared to those in D_0 and D_3. Improving the PI in D_1 and D_2 rabbits may be the consequence of the increment ($P < 0.05$) of their final body weight and the decrease of the corresponding FCR compared to those in the D_0 and D_3. Likewise, D_1 and D_2 rabbits could result in an improvement ($P < 0.05$) MW compared to those in D_0 and D_3, which depended on the final body weight of the treated rabbits.

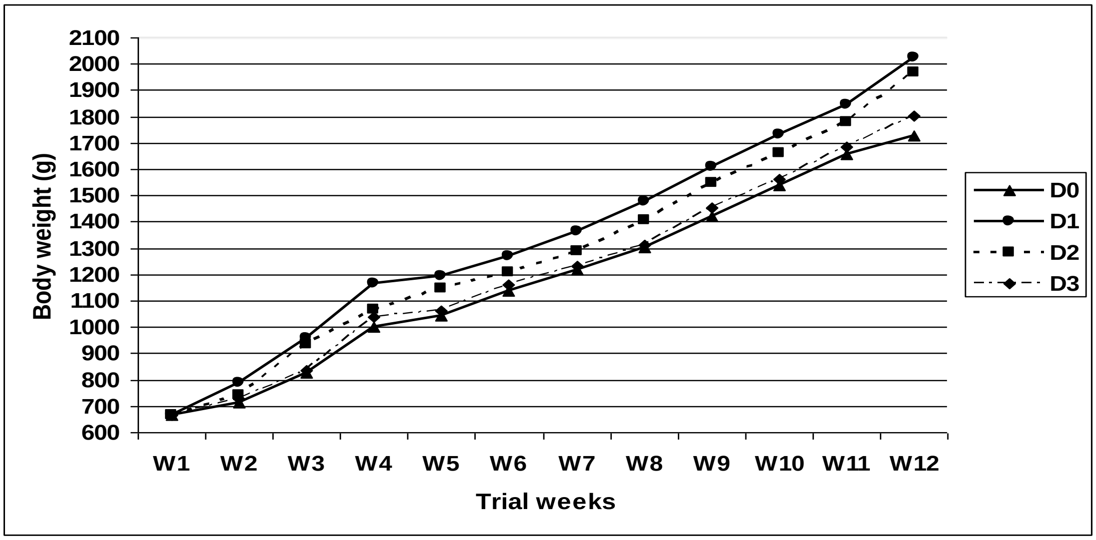

Figure 1. Changes in body weight (g) of D_0, D_1, D_2, and D_3 rabbits during the 12^{th} weeks of the experiment

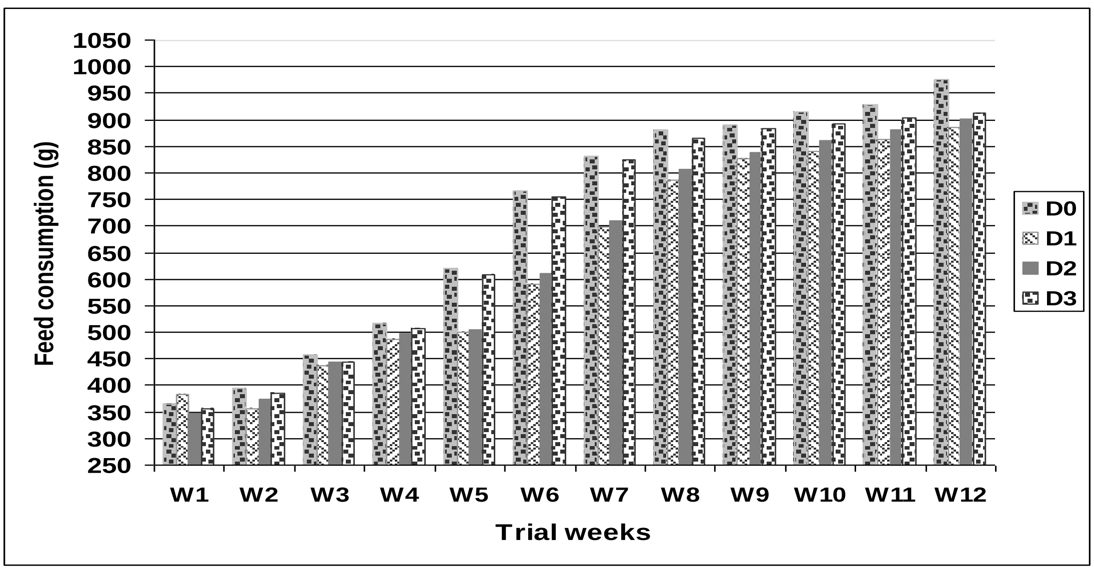

Figure 2. Changes in feed consumption (g) of D0, D1, D2, and D3 rabbits during the 12th weeks of the experiment

Carcass characteristics and internal organs

Results of carcass traits in Table (6) showed that D1 rabbits had significantly (P<0.05) higher weight of empty carcass with head, kidneys, liver, heart, edible giblets % and dressing % than those in D0, D2, and D3 rabbits. However, there were insignificant differences (P>0.05) in edible giblets % and dressing % between D0, D2 and D3 rabbits. Likewise, D1 rabbits could achieve the best (P < 0.05) carcass characteristics compared with D0, D2 and D3 rabbits.

Hematological parameters

Values of hematological parameters of D0, D1, D2, and D3 rabbits are presented in Table (7). It is well-known that hematology testing can detect changes in the nutritional, physiological, and pathological status of animals caused by diet and other variables. In D1 and D2 rabbits, the concentration of hemoglobin (Hb), red blood cell count (RBC) and platelet counts (Pit) were significantly (P < 0.05) higher than those placed in D0 and D3 rabbits. The WBCs were significantly lower (P<0.05) in D0 rabbits than those placed in D2 and D3 rabbits then, superior (P>0.05) for D1 rabbits. On the other hand, the leukogram fraction (%) of D1 rabbits was observed higher (P>0.05) values in neutrophils, lymphocytes, monocytes, and basophils than those values in D0, D2, and D3 rabbits.

Table 5. The growth performance and feed efficiency parameters of rabbits as affected by artichoke aqueous extract

Parameter	**Artichoke aqueous extract doses**			
	D_0	D_1	D_2	D_3
Total weight gain (g)	1058.67±28.26^b	1360.00±14.30^a	1300.00±20.50^a	1134.67±46.84^b
Daily weight gain (g)	12.60±0.65^b	16.19±0.75^a	15.48±0.77^a	13.51±0.84^b
Total feed intake (g)	8538.60±73.45^a	7601.16±24.77^b	7775.04±42.31^b	8350.44±63.81^a
daily feed intake (g)	101.65±1.55^a	90.49±1.47^b	92.56±1.64^b	99.41±1.65^a
Feed conversion ratio	8.08±1.0^a	5.71±.0.95^c	5.98±0.88^c	7.38±.97^b
Performance index (%)	21.41±1.84^b	35.53±1.70^a	32.95±1.31^a	24.45±1.48^b
Metabolic weight	1.38±0.08^b	1.48±0.04^a	1.46±0.07^a	1.40±0.06^b

Means in the same row within each classification bearing different letters are significantly different (*P* < 0.05).
* Metabolic weight (MW) = (Initial body weight (kg) + Final body weight (kg) ÷ 2)$^{0.75}$ was calculated according to Willems *et al.* (2013).

Serum biochemical parameters:

The blood biochemical indices, renal function, enzyme activity, oxidative capacity, immunity strength and adrenal gland hormone of D0, D1, D2, and D3 rabbits fed various tested diets were measured in Table (8).

The biochemical indices, including total protein and HDL, were obtained significantly higher (P<0.05) for D1 rabbits than for D0, D2, and D3 rabbits. However, glucose was lower (P>0.05) in D1 rabbits than in D0, D2 and D3 rabbits. The highest (P>0.05) levels of globulin were observed in D1 rabbits compared with D0, D2, and D3 rabbits. The serum blood of albumin, cholesterol, and triglycerides observed greater (P>0.05) levels in D0, D2, and D3 rabbits than in those rabbits placed on the D1 treatment. The lowest (P<0.05) levels of LDL were indicated in D1 and D2 rabbits compared with those rabbits in D0 and D3 treatments. In terms of renal function, rabbits in D1 and D2 had substantially lower levels ($P < 0.05$) of uric acid and creatinine than rabbits in D0 and D3 treatments. The concentration of all determined liver enzyme values as ALT, AST, and TSB were lower considerably ($P < 0.05$) in D1, D2, and D3 rabbits than in D0 rabbits. The D0 rabbits obtained susceptible lesser oxidative capacity than the D1, D2, and D3 rabbits. Immunity strength in D1 and D2 rabbits was positively ($P < 0.05$) affected compared with D0 and D3 rabbits the best obtained with D1 treatments. While cortisol concentration was decreased ($P < 0.05$) by artichoke aqueous extract plus diets fed to D1 and D2 rabbits compared with D0 and D3 rabbits.

Table 6. Measurements of carcass characteristics of D0, D1, D2 and D3 rabbits as affected by artichoke aqueous extract doses

Parameter	**Artichoke aqueous extract doses**			
	D0	D1	D2	D3
Pre-slaughter weight (kg)	1.73±0.03^{b}	2.03±0.1^{a}	1.97±0.02^{a}	1.80±0.05^{b}
Hot carcass weight + head (kg)	0.95±0.05^{b}	1.50±0.05^{a}	1.27±0.09^{a}	1.06±0.07^{b}
Kidneys (g)	11.33±0.88^{b}	16.00±0.57^{a}	14.67±0.33^{ab}	13.00±10.57^{b}
Liver(g)	49.00±4.04^{b}	69.00±.4.05^{a}	50.90±0.78^{b}	51.07±2.25^{b}
Heart (g)	4.38±0.36a^{b}	6.14±0.20^{a}	5.17±0.61^{ab}	4.67±0.44^{b}
Carcass characteristics percentages				
Edible giblets (%)	3.74±0.78^{b}	4.49±0.48^{a}	3.59±0.59^{b}	3.82±0.54^{b}
Dressing (%)	54.91±2.40 ^{b}	73.89±2.11^{a}	64.47±4.89^{b}	58.88±2.36 ^{b}

Means in the same row within each classification bearing different letters are significantly different ($P<0.05$).

Table 7. Hematological parameters of D0, D1, D2 and D3 rabbits as affected by artichoke aqueous extract

Parameter	**Artichoke aqueous extract doses**			
	D0	D1	D2	D3
Erythrogram				
RBCs, (100^{3} cell/µL)	4.28±0.20^{b}	6.69±0.31^{a}	6.59±0.65^{a}	4.53±0.37^{b}
Hb, g/dL	9.79±0.26^{b}	12.92±0.45 ^{a}	11.11±0.28^{ab}	9.54±0.28^{b}
HCT, %	33.80±0.80	37.17±4.07	31.15±2.13	31.71±1.05
MCV, fL/cell	71.99±1.32	70.48±3.82	70.98±5.47	69.91±4.01
MCHC, g/dL	34.58±0.83	33.53±1.01	33.34±0.75	34.30±0.85
PLT, 10^{3}/mm^{3}	280.70±3.26$^{a\,b}$	300.41±2.79 ^{a}	293.81±5.81 ^{a}	263.28±8.94^{b}
WBCs, 10^{3}/mm^{3}	5.48±0.06^{b}	6.67±0.29^{a}	6.51±0.05^{a}	6.36±0.57^{b}
Leukogram fraction %				
Neutrophils	37.85±0.45	46.08±8.69	36.63±0.91	33.89±1.72
Lymphocytes	52.78±1.31	54.14±2.25	53.28±1.17	53.21±1.35
Monocytes	7.13±1.47	7.72±1.67	7.71±1.93	7.57±1.23
Basophils	2.33±0.33	2.67±0.33	2.33±0.31	3.33±0.33

Means in the same row within each classification bearing different letters are significantly different ($P<0.05$).

Table 8: Serum biochemical parameters of rabbits fed different levels of artichoke aqueous extract

Parameter	Artichoke aqueous extract doses			
	D0	D1	D2	D3
Total protein (g/dL)	5.63±0.15^{c}	6.67±0.31^{a}	6.27±0.09^{ab}	6.05±0.08^{b}
Albumin (g/dL)	3.14±0.29	3.21±0.29	3.41±0.15	3.24±0.04^{b}
Globulin (g/dL)	2.49±0.15	2.89±0.26	2.85±0.14	2.81±0.06
Lipid profile				
Total cholesterol (mg/dL)	102.04±5.78^{a}	80.10±1.89^{b}	83.57±0.52^{b}	97.20±4.30^{a}
Triglycerides (mg/dL)	57.20±1.87	50.07±1.29	53.57±2.79	54.03±1.58
HDL (mg/dL)	50.97±3.41^{b}	57.40±1.60^{a}	54.53±1.11^{ab}	51.03±1.19^{b}
LDL (mg/dL)	31.30±2.16^{a}	22.97±1.79^{b}	23.51±2.57^{b}	28.90±1.53^{ab}
Renal function				
Uric acid (mg/dL)	1.63±0.06^{a}	1.17±0.03^{b}	1.27±0.04^{b}	1.50±0.12^{a}
Creatinine (mg/dL)	1.22±0.05^{a}	0.75±0.07^{b}	1.01±0.16^{b}	1.15±0.09^{a}
Liver function enzymes				
ALT (U/L)	81.46±1.63^{a}	61.55±1.94^{c}	70.11±1.81^{bc}	73.00±3.62^{b}
AST (UL)	38.17±1.55^{a}	28.54±2.17^{c}	34.58±2.97^{bc}	33.56±1.23^{b}
Total bilirubin, mg/dL	0.89±0.05^{a}	0.68±0.01^{b}	0.77±0.02^{b}	0.80±0.04^{ab}
Oxidative capacity				
MDA (nmol/mL)	15.63±0.45^{a}	9.88±0.71^{b}	11.09±0.61^{b}	10.43±0.53^{b}
TAC (ng/mL)	1.15±0.05^{c}	1.91±0.02^{a}	1.71±0.04^{b}	1.73±0.05^{b}
SOD (μ/mL)	0.17±0.01^{b}	0.24±0.02^{a}	0.23±0.01^{a}	0.16±0.001^{b}
CAT (U/g)	437.34±2.64^{c}	606.02±16.09^{a}	558.45±26.67^{ab}	537.18±10.59^{b}
Immune responses				
lgG (mg/dL)	31.64±1.79^{c}	47.94±1.95^{a}	43.54±2.80^{a}	37.30±1.89^{b}
lgM (mg/dL)	49.89±0.20^{b}	59.95±1.79^{a}	51.57±0.76^{a}	49.00±2.42^{b}
Adrenal gland hormone				
Cortisol (μg/dL)	14.23±1.05^{a}	10.40±0.49^{b}	11.76±0.73^{b}	13.07±0.43$^{a b}$

Means in the same row within each classification bearing different letters are significantly different (P<0.05).

Discussion

Effects of artichoke extract (AE) on changes in body weight of D0, D1, D2, and D3 rabbits through the trial period are presented in Figure (1). The D1 rabbits showed higher ($P < 0.05$) body weight than D0, D2 and D3 rabbits. In this context, Dabbou *et al.* (2013) concluded that artichoke by-product is a valid feed ingredient due to its good chemical composition and it could be used satisfactorily as a supplement for rabbits at levels of up to 10% of basal diet, even though the best digestibility was found in rabbits fed diet with 5%. Also, Dabbou *et al.* (2014) indicated that dried artichoke bracts (AB) in growing rabbits were able to utilize diets supplemented with artichoke. Hence, the same authors defined that 50% of Artichoke bracts achieved a higher final in body weight at 3208 g than 3191 g in control rabbits. According to Dokoupilová *et al.* (2019), 20% of Jerusalem artichoke tubers can improve live body weight up to 2594 g compared with 2570 g in control rabbits after 84 days of feeding. On the other hand, the positive effect of AE on changes in body weight was explained by Lertpatarakomol *et al.* (2015) who determined that supplementation of 75 *ppm* of artichoke extract in drinking water on days 1-7 and 15-24 of age may improve growth performance of broiler chickens. At that same time, Karimi *et al.* (2020) noticed that the change in the body weight of broilers that received artichoke extract was 952.78 g compared with 943.79g in control during a trial period from 21 to 35 days. Also, Al-Masari and Al-Himdany (2022) found that artichoke leaf extract powder at 0, 0.5, and 1.0 g/kg diet led to changes in body weight of broilers up to 2154, 2239, and 2236 g at 5th weeks of age, respectively.

The D1 rabbits were lower (P < 0.05) final feed consumption than the D0 rabbits (Figure 2). Our results concurred with Dabbou *et al.* (2014[a]) who observed that rabbit diets supplied with dried artichoke bracts at 50 and 100% had lower feed consumption at 134 and 130 g than 146g in control rabbits. Also, Dokoupilová *et al.* (2019) reported that feed consumption was 140.83 and 132.81 g/day in control and trial rabbits given 20% of Jerusalem artichoke tubers, respectively. Similarly, Zdeněk *et al.* (2023) stated that the average feed intake in control and tested rabbits given 10% of Jerusalem artichoke tubers were 127.8 and 119.1g/day, respectively. The artichoke extract has some beneficial effects on reduced consumption of basal diet intake which helps to protect the abdominal cavity from fat deposition in broiler chickens (Nateghi *et al.*, 2013). The findings of Abbasi and Samadi (2014) indicated that artichoke extract which has an essential oil and the main components of essential oil could be less feed intake in Japanese quail. Similarly, Al-Masari and Al-Himdany (2022) during 5th weeks of rearing broiler hens adding either 0.5 or 1.0g of artichoke leaves extract powder/kg basal diet occurred respectively feed intake at 1158 and 1326 g compared with 1705g in control basal diet. The present study corresponded with former studies that showed significant improvements in growth performance and feed utilization as a response to dietary inclusion of natural antioxidants in the basal diet of growing rabbits (Ismail et al., 2023; Ragab et al., 2023).

The D1 rabbits had the best values of weight gain (WG) and less feed conversion ratio (FCR) compared with the D0 rabbits are presented in Table (5). These results corresponded with the results of Dabbou *et al.* (2014[a]) who recorded that WG in rabbits fed 0%, 50 and 100% of dried artichoke bracts was 36.7, 37.2, and 36.9 g, however, FCR was 4.02, 3.60 and 3.56, respectively. In the experiment conducted by Dokoupilová *et al.* (2019) which fed Jerusalem artichoke tubers in amounts of 20% they observed the best WG (40.21 g/day) and FCR (3.17) compared with 39.56 g/day and 3.56 in control rabbits, respectively. In harmonize with our findings, Zdeněk *et al.* (2023) observed that 25% of Jerusalem artichoke tubers had WG and FCR up to 42.37 g/day and 2.95 compared with 36.42 g/day and 3.25 in control rabbits, respectively. Several researchers have shown that the artichoke extract had some beneficial effects on growth performance (Dabbou *et al.*, 2013, Nateghi *et al.*, 2013, Tajodini *et al.*, 2014 and Abbasi & Samadi, 2014). In this context, Lertpatarakomol *et al.* (2015) stated that using 300 *ppm* of artichoke extract in drinking water could attained more WG and FCR up to 65.01 g / d and 1.63 than 60.09 g/d and 1.57 in control broiler chickens from 1 to 42 days of age, respectively. Furthermore, Karimi *et al.* (2020) showed that chicks fed basal diets supplemented with artichoke extract had an improvement in the FCR (1.94) compared to the control (2.19) during 21-28 days of the experimental period. According to, Al- Masari and Al-Himdany (2022) showed that the effect of adding artichoke leaf extract powder at 0.5 g/kg diet has significantly (P<0.05) excelled in WG (775.49g) and FCR (1.49) compared with 729.06 (WG) and 1.61 (FCR) in control broiler at 5 weeks of age. The performance index (PI) % was improved (P< 0.05) higher with added AE to rabbits than control rabbits. Confirmation by, El-Abd (2016) who supplemented Jerusalem artichoke with a basal diet of Japanese quail at 30 and 60 g/ kg diet indicated respectively higher performance index up to 5.70 and 5.97% compared with 5.38% in the control diet. The supplementation of 10 g of artichoke/kg basal diet improved FCR in laying hens (Ürüşan, 2023).

Data on carcass traits of slaughtered D0, D1, D2, and D3 rabbits are presented in Table (6). The results revealed that significantly higher (P<0.05) differences were observed in carcass traits and internal organ weights with D1 rabbits compared with D0, D2, and D3 rabbits. The obtained results indicated that the weights of the empty carcass (with head), giblets, and dressing (total edible parts) were more ($P < 0.05$) for both D1 and D2 rabbits than those of the D0 and D3 diet. A similar trend among the dietary treatments was observed for liver, heart, and kidney weights, with the highest values found in the D1 diet and the low ones associated with the D0 and D3 rabbits. This improvement induced by the D1 diet might be due to the ability of AE in the production of meat by increasing longissimus dorsi (LD) muscles. This result has been confirmed by Dabbou *et al.* (2014[a]) who supplied that 0%, 5%, and 10 % of dried artichoke bracts to rabbit diets can improve slaughter weight at 2934, 3034, and 3033 g and dressing out 59.8, 60.0 and 59.9%, respectively. Also these results are in line with those found by Dabbou *et al.* (2014[b]) who concluded that enrichment of the rabbit's diet with artichoke bracts (AB) could allow the best production of rabbit meat quality with a good degree of longissimus dorsi (LD) muscles. On the other hand, the artichoke as a natural antioxidant may have beneficial effects on chicken carcass traits (Sritiawthai *et al.*, 2013) who reported that the performance of laying hens was influenced by adding Jerusalem artichoke up to 50 and 100 *ppm* in the diet. The current results are in agreement with the results of Tajodini *et al.* (2015) who revealed that artichoke powder had significant differences ($P \leq 0.05$) for carcass, breast, thigh, and pancreas weights in broiler chickens. Also, the results of the current study are confirmed to those reported by (El-Abd, 2016) in which dietary addition of 3% of Jerusalem artichoke has higher carcass traits such as pre-slaughter weight, dressing weight, dressing and liver up to 203g, 184 g, 90.6% and 3.0% than 201.0g, 171.0 g, and 85.1% in control Japanese quail, respectively. The findings of Al- Masari and Al-Himdany (2022) results indicate that supplementing artichoke leaf extract powder to the diet showed a significant in improving the productive performance of the broiler hence, the final carcass broiler weight pre-slaughter was 2913, 3020, and 3036 g at 0, 0.5 and 1.0 g of artichoke leaves /kg feed, respectively.

Both treatment groups of D1 and D2 rabbits showed improvement in hematological parameters (as, Hb content, Pit values, WBCs and RBCs count) the best observed with D1 rabbits (Table 7). The blood pictures of animals might be influenced by certain factors one of which is nutrition thus; the processing of feed could affect haematological parameters of farm animals (Aya *et al.,* 2013). Hence, use of artichoke extract with a basal diet may be achieve more haematological parameters including Hb, Pit, WBCs and RBCs than the control basal diet thus; dietary content affects the blood profile of healthy animals. These results are compatible with results obtained by Al-Kassie (2008) who reported that the use of Jerusalem artichoke in the diet of broiler improved PCV%, Hb content, and RBCs count compared with the control group. Similarly, Al-Kassie and Al-Qaraghuli (2013) recorded that treatment of broiler chicks with Jerusalem artichoke improved all hematological parameters (Hb content, PCV%, WBCs and RBCs counts). In addition, Isaac *et al.* (2013) stated that haematological parameters like hematocrit value, hemoglobin concentration, white blood cell count and red blood cell count are used in routine screening for the health and physiological status of livestock. Besides, El-Maddawy and Ibraheim (2019) showed that administration of Jerusalem artichoke has improved ($P<0.05$) in Hb (13.80 g/dL), RBCs (1.81×10^6) and WBCs (33.67×10^3) compared with Hb (12.53), RBCs (1.70) and WBCs (24.45) in control broiler chicks. The best haematological traits especially Hb (is correlated with the nutritional status of the animal) and RBCs (is involved in the transport of oxygen and absorbed nutrient) in rabbits may be affected body performance and health positively (Ali and Mikail, 2021) similar results obtained in the current study in D1 rabbits.

The values of blood biochemical obtained in this study were symmetrical with the results of El-Sayaad *et al.* (1995) who reported that the incorporation of artichoke bracts (AB) in New Zealand White rabbit's diets up to 20% had no significant effect on some blood components. Regarding glucose level, the AE indicated more glucose (P<0.05) in D1 rabbits than in D0 rabbits. These results are in agreement with the results of El-Abd (2016) who showed that glucose concentration in blood serum was 239, 240, and 145 mg/dL in Japanese quail fed 0, 3, and 6% of Jerusalem artichoke, respectively. Total protein and globulin were lower in D0 rabbits than in all artichoke extract rabbits. These findings are in agreement with the results of Tajodini *et al.* (2015) who demonstrated that supplementation of 1.5% artichoke powder to a basal diet of boiler has total protein and globulin up to 5.38 and 3.14 mg/dI compared with 5.27 and 2.48 mg/dI in-control boiler, respectively. On the contrary, Tajodini *et al.* (2015) reported that the supplementation broiler diet with artichoke had higher (P>0.05) values of albumin than control. They revealed that artichoke concentration at 0, 1.5 and 3% of indicated albumin levels at 2.78, 2.24 and 2.05mg/dL, respectively. In this context, Dokoupilová *et al.* (2019) mentioned that albumin is one of the important protein fractions that keep the osmotic pressure stable in the blood. Both albumin and globulin results reflect the ability of animals to store reserve proteins even after their bodies have reached the maximum capacity of depositing tissues (Ali and Mikail, 2021). In addition, El-Abd (2016) found that artichoke inulin plays a role in the modulation of serum cholesterol and triglyceride thus, cholesterol was 130, 125 and 121 mg/dI, but triglyceride was 45, 42 and 41 mg/dL when Japanese quail received 0, 3 and 6% of Jerusalem artichoke, respectively. The current results observed that the lowest cholesterol and triglyceride levels were in the D1 rabbit compared with other trial rabbits. In coordination with our findings El-Maddawy and Ibraheim (2019) defined that the control boiler the cholesterol and triglyceride were greater up to 100.90 and 88.83mg/dI than 79.40 and 77.97mg/dI in the artichoke boiler, respectively. This is Confirmed by Karimi *et al.* (2020) who reported that cholesterol and triglyceride concentration were more in the control boiler were 121.90 and 94.69 mg/dL than 110.67 and 90.72mg/dL in the artichoke boiler, respectively. The lowest LDL was observed in D1 rabbits compared with all other rabbits, then the same trend was recorded by Fallah *et al.* (2013) who reported that LDL was 34.06 and 32.16 mgdI^{-1}in control and artichoke broiler, respectively. The current results observed that the uric acid in serum blood of all rabbits was in the normal range in all trial rabbits reported by Njidda and Isidahomen (2010) who recorded that uric acid levels of the serum blood rabbits ranged from 4.53 to 7.9 mmol/l. The values in this study were ranged from 1.63 to 1.50 mmol/l. The lowest was observed in D1 rabbits (1.17 mg/dL) compared with all rabbits. the same trend was observed by Fallah *et al.* (2013) who recorded that urea was 2.44 and 2.11 mgdI^{-1} in control and artichoke broiler, respectively. Similar results were observed by Abadjieva *et al.* (2020) who noticed that greater serum blood urea at 1.21 mmol/L in the control group than 0.94 mmol/L of laying hens given 3 g/kg of dried and milled artichoke. Regarding creatinine concentration in serum blood, the D1 rabbits have lower (P<0.05) creatinine than other rabbits. El-Maddawy and Ibraheim (2019) suggested that control broiler chicks had more creatinine levels at 0.38 mg/dI than 0.35 mg /dI in Jerusalem artichoke broiler chicks. In contrast to our results, El-Abd (2016) reported that creatinine concentration in serum blood was 0.6, 0.6 and 0.7 mg/dI when fed diet supplied with 0, 3% and 6% of Jerusalem artichoke in Japanese quail, respectively. Concentrations of AST and ALT enzymes were detected lower (P<0.05) in D1 rabbits compared with those of the other rabbits. The ALT and AST are widely known that layers show a changeable activity as a result of the continued metabolic load (El-Maddawy and Ibraheim, 2019). Additionally, the decreasing level of the liver enzymes (D1 rabbits) in the current study may reflect the decreased level of glucose (Noordam *et al.*, 2017) revealing that the scientific concentrations of liver enzymes have been associated with glycaemia. Karimi *et al.* (2020) found that lower AST and ALT in artichoke boiler were 72.41and 4.28 IU/L than 141.11 and 5.94 IU/L in the control group, respectively. Also, Abadjieva *et al.* (2020) recorded that ALT and AST had more concentration in control up to 11.9 and 182.0 U/L than 10.9 and 160.0U/L in laying hens received 3 g/kg of milled artichoke. Regarding total serum bilirubin (TSB), the lowest value was observed in D1 rabbits compared with all rabbits. These results are in agreement with the results of El-Maddawy and Ibraheim (2019) who said that total bilirubin was 0.23 and 0.13 mg/dL in boiler chickens received control and Jerusalem artichoke diets, respectively. Artichoke has been used in traditional medicine for its antioxidant properties (Tajodini *et al.,* 2015) defined the effects of adding artichoke meal in livestock feeds and obtained definite positive effects on the performance and antioxidant capacity of broiler. Generally, these results are compatible with Abdel-Wahab *et al.* (2023) who concluded that the addition of AE at 400 *ppm* followed by 200 *ppm* improved the productive performance, antioxidant capacity, and blood biochemical and immunological indices in growing Japanese quails. Besides, Ürüşan (2023) revealed that the addition of artichoke to the diet reduced the serum triglyceride, LDL, and VLDL concentration, and also, the GSH, CAT, and GPx values which are enzymatic antioxidants in serum were found to be the highest in artichoke group which given 5 g/kg diet. The observed improvements in the hemato-biochemical attributes in this study can be attributed to the presence of bioactive components found in Artichoke. Artichoke is known for its rich mineral content, low lipid levels, dietary fiber, and high proportion of phenolics. Additionally, it has a crude protein content similar to alfalfa hay (15%) and a relatively low crude fiber content of up to 14.5% (Farhan et al., 2018). Moreover, Artichoke is a valuable source of natural antioxidants, including vitamin C, carotenoids, polyphenols, hydroxyl cinnamic acid, and flavones (Gotardoa et al., 2019). These bioactive components are responsible for the positive effects observed in the study regarding the hemato-biochemical attributes (Abdelnour et al., 2022).

Conclusion

Based on our results, it could be concluded that using AE as an additive in the diets of growing rabbits at a rate of 10mg could improve productive performance, carcass traits as well as blood parameters. This implies that 10mg of AE may be useful as a suitable untraditional feed ingredient in feeding growing rabbits.

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All authors are contributed in this research

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Data Availability Statement

Data presented in this study are available on fair request from the respective author.

Ethics Approval and Consent to Participate

Not applicable

Consent for Publication

Not applicable.

Conflicts of Interest

The authors disclosed no conflict of interest.

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