Research Article

Natural and Biological Dietary Herbal Extracts Supplement on Productive and Physiological Parameters, Cecal Fermentation, and Meat Characteristics of Growing Rabbits

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Abstract | The objective of this study was to determine the influence of five herbal extracts in rabbit diets on productive performance, digestibility, cecal fermentation, antioxidant enzyme activities, immunity and meat quality. One hundred twenty six male growing New Zealand White rabbits aged eight weeks old with an average body weight of 675±47.95 g were divided into six equal groups 21 rabbits each, control diet group, C fed the basal diet and the other five groups (GE, ClE, ThE, TE, and CE) fed on basal diet supplemented with 200 ppm of garlic, clove, thyme, turmeric and cinnamon extracts respectively. These extracts revealed an increase in final body weight, daily weight gain, digestibility coefficient of crude protein, crude fiber, neutral detergent fiber and acid detergent fiber, nitrogen balance, acetic acid and propionic acid, the aerobic and facultative anaerobic bacteria (*Lactobacillus spp*.) in all treatment groups. Concurrently, they showed increase (P<0.05) in total protein, albumin, and globulin, total antioxidant capacity, superoxide dismutase, catalase, glutathione peroxidase, immunoglobulins G and A. Moreover, the extracts supplementation decreases ammonia-nitrogen, butyric acid, *Escherichia coli*, *Clostridium spp*., and *Enterococcus spp*., total cholesterol, high density lipoprotein, low-density lipoprotein, and triglyceride compared to the control group. Also, these extracts had positive effects (P<0.05) on the rabbit meat nutritional compounds, and decrease meat fat content, thiobarbituric acid and increased antioxidant activity. It was concluded that these extracts as a natural biologically active substance improved growth performance, feed digestibility, antioxidant activities and immunity, allowing growing rabbits to produce high quality meat of growing rabbits.

Keywords | Herbal Extracts, Digestibility and performance, Cecal fermentation, Meat quality, Rabbit.

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INTRODUCTION

Medicinal plants and their extracts are important natural sources of nutrients for both human beings and animals, and have long been applied in both conventional and modern nutritional recommendations to treat many disorders and promote good health (Kuralkara and Kuralkarb, 2021). The use of these natural compounds such

as, herbal and their extracts, as feed and food supplementation has received the attention of nutritional researchers worldwide. Researchers and breeders are searching for feed additives to improve animal performance, nutritional content, and eventually carcass qualities. Extracts from known herbs, as garlic, clove, thyme, turmeric, and cinnamon can be utilized as natural feed supplement in livestock feed (El-Naggar et al., 2017). The biological properties of herbal phytochemical compounds, or their extracts, are beneficial to the health and contributes to improve animal performance, intestinal microbiota, antioxidant capacity, antimicrobial, antibiotic, cholesterol reduction, immune modulatory, and eventually in enhancing carcass characteristics and quality of meat to the human as the end consumer, (Elsherif et al., 2021; Lamiaa et al., 2022).

Many researches have extracted sulfur-containing organic substances from garlic and reported on their antibacterial and antibiotic effects (Bhatwalkar et al., 2021). Adding 200 or 400 ppm garlic extract to growing rabbit rations enhanced performance, improved antioxidant capacity (El-Naggar and Ibrahim 2018), carcass characteristics, meat crude protein, and reduced meat fat percentage (Samy et al., 2022). This emphasizes the significance of the role that herb extracts play in the functional food sector. Researchers Liu et al. (2014) and Cortes-Rojas et al. (2014) have focused on the use of the phenolic compound (nearly 70-96% eugenols, acetate, α-humulene, 2-heptanone, and β-caryophyllene) isolated from clove as an antifungal, anti-inflammatory, anaesthetic, antioxidant, antidiabetic, and antiviral properties, which would encourage their potential application in the feed market as natural feed additives.

The addition of dietary thyme to rabbit diets has been shown to significantly improve feed conversion ratio (FCR) by promoting feed intake, boosting body weight, body weight growth, and intestinal health (Placha et al., 2013; Kucková et al., 2021). Additionally, thyme contains antibacterial and antioxidant characteristics. This is mostly because of its active ingredients such as thymol, phenols and carvacrol, which also increase appetite and have been shown to support growth performance (El-Naggar et al. 2017; Raskovic et al., 2015).

Curcumin is the main biologically active component in turmeric, according to Mehdipour and Gharachorloo (2020), and it has antiviral, antimicrobial and antioxidant properties, Curcumin can also boost the excretion of lipase, trypsin, chymotrypsin, and amylase enzymes and lower total cholesterol, probably by its ability to inhibit the hepatocellular enzyme 3-hydroxyl-3-methyglutaryl Co-A reductase, which is responsible for the cholesterol synthesis in the liver (Al-Kassie et al., 2011). Cinnamon contains bioactive substances such saponins, flavonoids and tannins that help in reducing triglycerides and cholesterol, while raising high density lipoprotein (HDL) (Azima et al., 2004; Ervina et al., 2019).

The antioxidant properties of cinnamaldehyde can support improving blood fatty acid and glucose metabolism (Gruenwald et al., 2010). As a result of cinnamonaldehyde's capability ability to stimulate the insulin-like growth factor (IGF-1), which improves the body's tissues' ability to synthesize protein and collagen, more proteins are deposited in the body can help to support body building muscle (Takasao et al., 2012). The functional activities and direct effects of herbal extracts in animal feed can enhance the nutritional, chemical efficiency and sensory of meat and other animal products. Animal nutrition may enhance animal's health as well as improve carcass characteristics, meat's quality and the ability to produce healthy meat as a functional property in human food chain.

Therefore, the aim of this study was to examine the effects of garlic, clove, thyme, turmeric and cinnamon herbal extracts in rabbit diets on productivity, digestibility, cecal fermentation, antioxidant enzyme activities, immunity, and meat quality.

MATERIALS AND METHODS

Materials

About 100 g leaves from each plant, garlic *(Allium sativum), Clove (Syzygium aromaticum), Thyme (Thymus vulgaris L.), Turmeric (Curcuma longa) and Cinnamon (Cinnamomum zeylanicum)* were purchased from an Alexandrian herbs market. These herbs were separately washed, dried in a Universal hot air oven for 48 hours at 40°C, ground so they could pass through a sieve (60 mesh), The dried herbs were cooled and kept in polyethylene bags at room temperature for later use.

Aqueous extract preparation

Fifty g leaves powder from each dry herb were separately extracted in 400 mL of hot distilled water H_2O with continual stirring for 12 hours before being homogenized in a household juicer (model name is Braun Combimax 700 Vital, Germany) for 3 minutes at average speed. The mixture was kept in a closed jar and was centrifuged at 3000 rpm for 10 minutes. Whatman no.1 was used to filter the supernatant. The extracted garlic (GE), clove (ClE), thyme (ThE), turmeric (TE), and cinnamon (CE) samples were lyophilized (Telstar, Cryodos-50, Spain) and kept in dry dark glass containers at 4 °C until used (Handa, 2005).

Identifying the composition of herbs aqueous extracts using gas chromatography-mass spectrometry (GC-MS)

The bioactive nature components from the lyophilized extract of medicinal plants were extracted with diethyl ether and analyzed using a GC-MS (HP 8644) at the following conditions: flame ionization detector (FID) on a fused silica 132 capillary column DB-5, (25 m, 0.32 mm i.d., and 0.5 mm film thickness), split/spitless injector, split at ratio of 15:1, an injection volume of 1µL, and helium as the carrier gas, flow rate of 1.6 ml/min. The injector temperature was 250 °C. The temperature of the oven was programmed to increase from 130 to 260 °C at a rate of 4 °C/min. The extract compounds were identified by comparing the obtained mass spectra to those in the National Institute of Standards and Technology (NIST) library with a quality above 80%, and the major constituent percentages were calculated as a percentage of the total area under the curve according to Heftman (1967) and Gunther and Joseph (1978).

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Animals, diets and experimental design

This study was carried out at the animal house of the Agricultural Research Center, Animal Production Research Institute, Giza, Egypt. Feeding experiments were carried out for 70 days on 126 eight-week-old male New Zealand White Rabbits with an average body weight of 675±48 g. Rabbits were housed in galvanized wire cages (50×50×45 cm) which provided with feeding hoppers and drinking nipples. Feeders were allowing record feed intake during the feeding trial that continued for 70 days. All the experimental rabbits were healthy and clinically free from parasites and were kept under the same managerial conditions, hygienic and environmental conditions in rooms with standard air conditioning where the ambient temperature ranged from 20 to 25 °C with 55-65 humidity and a photoperiod of 16L:8D, and rations were offered pelleted with diameter 4 mm. The experimental pelleted rations were formulated to cover the nutrient requirements for rabbits according to NRC (1994).

Animals were divided into six equal groups of 21 animals each (seven replicates of three rabbits each); the control diet group received the basal diet (Table 1) contained 9.4 yellow corn, 27.28 barley grain, 7.2 wheat bran, 18.85 Soybean meal, 30.6 berseem hay, 3 molasses, 0.7 limestone, 1.3 dicalcium phosphate, 0.3 DL-Methionine, 0.3 salt and 0.57 premix, while the other groups received basal diets supplemented with 200 ppm of GE, ClE, ThE, TE, and CE. Feed residual data was collected each day when experimental diets were offered. Every week, body weights were recorded. The rabbits were promptly treated if there were any health aspects, and were checked routinely on a continuous basis.

Digestibility trials

After the feeding trial (70 days), six digestibility experiments lasting eight days each were conducted, containing three days for adaptation, and five days for quantitative collection of feces and urine. Seven rabbits from each group were separated inside stainless steel metabolic cages with separate feces and urine collecting systems. During the collecting period, daily measurements of feed intake were conducted, and feces excretion and urine production were recorded. The daily urine weight of growing rabbits was collected every day in a single jar, acidified with 3 mL of concentrate H_2SO_4 to prevent N losses and urease activity. and dry feces were stored for the time of analysis.

Table 1: Ingredients of the basal diets and calculated nutrient content (fed basis, %)

Basal diet			
Composition		Calculated nutrient content	
Ingredient	(%)	Component	(g/kg)
Yellow corn	9.4	Organic matter	93.06
Barley grain	27.78	Crude protein	16.31
Wheat bran	7.2	Ether extract	2.84
Soybean meal	18.85	Crude fiber	13.94
Berseem hay	30.6	Neutral detergent fiber	33.15
Molasses	3	Acid detergent fiber	19.53
Limestone	0.7	Acid detergent lignin	4.84
Dicalcium phosphate	1.3	DE (kcal/ kg DM)	2796.42
DL-Methionine	0.3		
Salt	0.3		
Premix[1]	0.57		
Total	100		

[1] Premix provided per kg of diet: 10,000 IU vitamin A; 3,000 IU vitamin D3 ; 30 IU vitamin E; 1.3 mg menadione,; 2.2 mg thiamin; 8 mg riboflavin; 40 mg nicotinamide; 600 mg choline chloride; 10 mg calcium pantothenate; 4 mg pyidoxine HCl,; 0.04 mg biotin; 1 mg folic acid; 0.013 mg vitamin B12; 80 mg ferrous sulphate; 8 mg copper sulphate; 110 mg manganese sulphate); 1.1 mg calcium iodate; 0.3 mg sodium selenite. DE (kcal/ kg DM) calculated using equation: DE (kcal/ kg DM) = 4253 - 32.6 (CF %) -144.4 (ash). According to Fekete and Gippert (1986)

Cecal fermentation and microbial count

Seven rabbits from each group were mercifully sacrificed at the end of the experiment by quickly cuttings the jugular vein and the cecal contents were extracted and placed in beakers. Immediately after being filtered via two layers of sterile gauze, the cecal contents were used to measure the pH of strained liquors using an electrical digital pH meter. Then, the mixture was centrifuged for 12 minutes at 7000

rpm.

Two portions of the supernatant fluid were separated. One portion was treated with a 0.2M hydrochloric acid solution to determine the concentration of ammonia nitrogen (NH_3-N), while the other was treated with a mercuric chloride 1% (w/v) plus orthophosphoric acid 5% (v/v) solution to determine the concentration of total volatile fatty acids (TVFA's) and the proportions of the numerous VFA's. According to Chaney and Marbach, (1962). Spectrophotometry was used to measure the quantities of NH_3-N in the cecum. According to the method used by Eadie et al. (1967) total VFA concentrations were determined by steam distillation. High performance liquid chromatography (HPLC; Model Water 600; UV detector, Millipore Crop) was used to assess the molar ratios of VFA's in accordance with the Mathew et al. (1997). At the screw bottle, the cecal samples were combined with sterile saline peptone solution 1:10 (w/v) and homogenized for three minutes. Microorganisms were calculated using various mediums. A plate count agar was performed at 30 °C for two days, and total bacterial count (TBC) was determined. On violet red bile agar, the total number of coliforms was measured after 24 hours at 37°C (Harrigen and Mccance-Margart, 1976). *Lactobacillus* spp. and *Clostridium* spp. was isolated on De Man-Rogosa-Sharpe agar and PEA agar using methods according to Maturin and Peeler's (1998). An optical counter was used to count bacterial colonies in plates (Reichert darkfield Quebec, optical counter 3338). After incubating for 24 hours at 37 °C, *Escherichia coli* and *Enterobacteriaceae* were counted on eosin methylene blue agar media (Oxoid, 1982). Each culture medium's typical colony classes and morphological traits were looked for on every plate. The microbial counts in the rabbit caecum, however, were estimated using diet data. Cecal samples were homogenized in a screw bottle with sterile saline peptone solution (1:10, w/v) using five replicates. The preparation of decimal serial dilutions up to 10^7. On specific medium, the various microorganisms were counted (Abdelnour et al., 2020). According to Sheiha et al. (2020) and Reda et al. (2020), total bacteria were counted on Plate count agar (PCA). After 24 hours of incubation at 37 °C, the total number of coliforms was counted on violet red bile agar (Harrigen and Mccance-Margart, 1976). On eosin methylene blue agar plates, *Escherichia coli* were counted after being incubated for 24 hours at 37 °C (Oxoid, 1982). In Chromocultfi enterococci agar, *Enterococcus* spp. was counted (Miranda et al., 2005).

Serum biochemistry and antioxidant indices

Blood samples from sacrificed rabbits were taken at the end of the experimental study and placed in sterile, clean tubes. The samples were left to coagulate before being centrifuged at 3500 rpm for 15 min to separate the serum, which was then kept at -20 °C until analysis. Using commercial biodiagnostic kits from Biodiagnostic, Egypt, the following serum biochemical parameters were measured: Albumin (AL), total protein (TP), total cholesterol (TC), low-density lipoprotein (LDL), high density lipoprotein (HDL) and triglyceride (TG), also immunity parameters were measured: immunoglobulin M (IgM), G (IgG) and A (IgA) levels, total anti-oxidant capacity (TAC), superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GSH-Px) and malondialdehyde (MDA) levels.

Analytical methods

The moisture, crude protein (Kjedahl method), crude ether extract and ash content were determined according of the standard methods of the Association of Official Analytical Chemists (AOAC, 2019). Nitrogen free extract (NFE) was calculated by difference. Urinary nitrogen (UN) was determined by the micro-kjeldahl method. Caloric value was calculated as mentioned by Mohammed et al. (2019). The pH was measured in muscle homogenates using a digital pH meter (pH MVx100 Beckman, USA) by inserting the electrodes into the homogenates (Goulas and Kontominas, 2007). The antioxidant activity of rabbit meat were measured using the DPPH (2, 2-diphenyl-1-picrylhydrazyl) radical scavenging method according to Brand-Williams et al. (1995) using spectrophotometer (Model, 91102 Laxco, inc. USA) at 517 nm absorbance. The thiobarbituric acid (TBA) to measure lipid peroxidation level (mg malonaldehyde/Kg sample) value of rabbit meat was determined according to Park et al. (2007). The water holding capacity (WHC) of rabbit meat samples was determined using the filter paper press method as described by Aman (1983) using the following equation:

WHC (%) = (A M - 8.4 B) /M × 100. Where: A= Moisture content (%), M= Weight of sample (mg), B= Wetted filter paper area resulting from the pressing of sample (in cm^2) and 8.4= Quantity of juice produced by the pressing of sample (mg per cm^2 wetted area). The cooking loss was evaluated as described by Honikel (1998) method. The color values were evaluated of all fresh meat samples by a Hunter Lab Ultra Scan VIS model, colorimeter (USA), which includes lightness (L*), redness (a*) yellowness (b*), and chroma (C*) values according to Daszkiewicz and Gugołek (2020).

Sensory evaluation of cooked meat samples.

The cooked rabbit meat samples from different cuts were prepared by heating in 0.6% aqueous NaCl solution with onion and black pepper for one hour at 96°C. Sensory evaluation of all the meat samples was conducted by 12 trained panelists based on the appearance, color, taste, odor, texture (hardness, moistness) and overall acceptability using hedonic scale, as described by Meilgaard et al. (1999).

Statistical analysis

Data were analyzed using (SAS, 2005) (SAS Software, Inst. Inc., Cary, NC, USA) according to completely randomized design. Differences among groups were separated by Duncan's multiple range tests. The level of significance was pre-set at ($P<0.05$), following the model: $Yij = \mu+Ti+eijk$; where: Yij = individual observation, μ = the overall mean, Ti = effect of treatment (i = 1, 2, 3,…5), and eijk = random error.

RESULTS

GC-MS was used to evaluate the constituents of essential oils of Egyptian garlic, clove, thyme, turmeric, and cinnamon extracts, and the samples' identified were displayed in Table (2), and Figure 1 shows their chromatograms (a, b, c, d and e). There were 8 different chemicals detected in garlic volatile compounds (Fig 1-a) and (Table 1-a). The main substances were Di-2-propenyl trisulfide (54.47%) and diallyl disulfide (20.09%) , followed by 1,3-dioxane-2-yl (6.42%), allyl tetrasulfide (4.36%), and methyl 2-propenyl disulfide (2.05%), respectively.

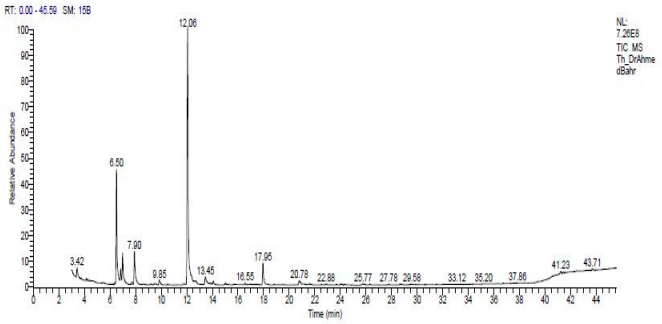

Figure (1-a): GC-MS chromatogram of volatile compounds of garlic extract.

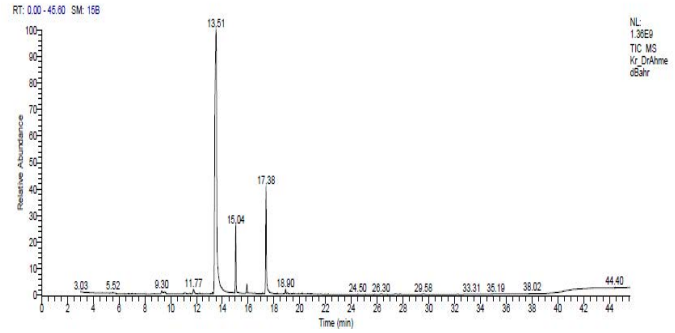

Figure (1-b): GC-MS chromatogram of volatile compounds of clove extract.

Eugenol (72.45%) is the main component of the clove extract's (Fig. 1-b) and (Table 2-b), followed by phenol, 2-methoxy-4-(2-propenyl)-acetate (15.37%), and caryophyllene (8.98%).

The thyme extract included eleven volatile chemicals (Fig, 1-c) and (Table, 2-c), but the predominant ones were phenol, 2-methyl-5-(1-methylethyl), camphene, o-cymene, thymol, and caryophyllene oxide, which constituted 44.86, 30.51, 19.55, 15.05, and 10.94%, respectively.

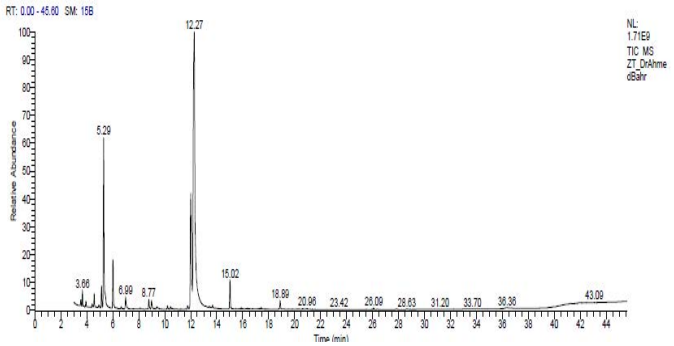

Figure (1-c): GC-MS chromatogram of volatile compounds of thyme extract.

Twenty-six volatile chemicals were found in turmeric extract (Fig, 1-d) and (Table 2-d). Benzene, á-sesquiphellandrene, 1-(1,5-dimethyl-4-hexenyl)-4-methyl, o-cymene, eucalyptol and 1-(2-Methoxy-1-methylethyl)-2-methylbenzene were the main substances. At quantities of 3%, the other detected volatile chemicals were present.

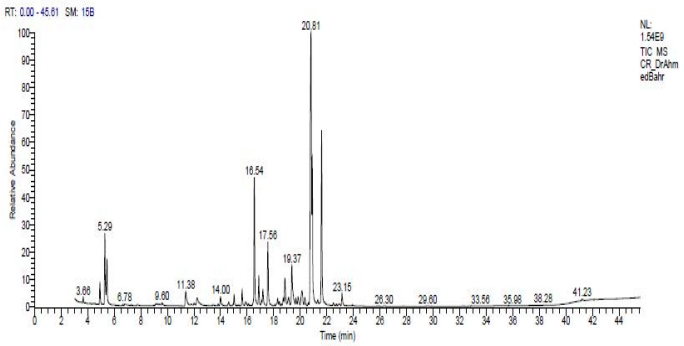

Figure (1-d): GC-MS chromatogram of volatile compounds of turmeric extract.

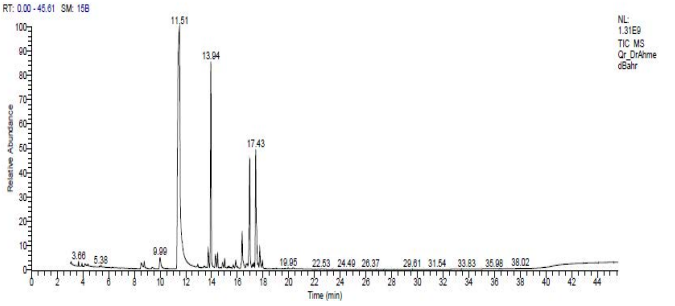

Figure (1-e): GC-MS chromatogram of volatile compounds of cinnamon extract.

Table (2-a): Retention time and concentration of essential oil components of garlic extract, identified by GC-MS.

Retention rate (RT)	Concentration (area %)	Compound name	Molecular formula	Molecular weight
3.41	2.05	Disulfide, methyl 2-propenyl	C4H8S2	120
3.51	0.41	9,10 Dideutero Octadecanal	C18H34D2O	270
6.50	20.09	Diallyl disulphide	C6H10S2	146
6.83	1.97	(Z)-1-Allyl-2-(prop-1-en-1-yl) disulfa ne	C6H10S2	146
6.97	5.10	Diallyl disulphide	C6H10S2	146
7.71	0.53	Propane, 1,1,2,3,3-pentachloro	C3H3Cl5	214
7.90	6.42	1,3-Dioxane, 2-(1,3-Dioxolan-2-YL)	C7H12O4	160
9.85	1.07	2-Vinyl-4H-1,3-dithiine	C6H8S2	144
12.06	54.47	Trisulfide, di-2-propenyl	C6H10S3	178
12.36	0.39	Trisulfide, di-2-propenyl	C6H10S3	178
13.44	1.70	Phenol, 2-methoxy-3-(2-propenyl)	C10H12O2	164
14.06	0.66	10-Heptadecen-8-ynoic acid, methyl ester, (E)	C18H30O2	278
17.95	4.36	Allyl Tetrasulfide	C6H10S4	210
20.77	0.78	1H-cyclohepta[B]Cyclopen TA[C]FURAN, 2,3,3A,4-Tetrahydro-3,6,9-Tri-methyl	C15H20O	216

Table (2-b): Retention time and concentration of essential oil components of clove extract, identified by GC-MS.

Retention rate (RT)	Concentration (area %)	Compound name	Molecular formula	Molecular weight
9.30	0.47	Benzoic Acid, 2-Hydroxy-, Methyl Ester	C8H8O3	152
11.77	0.83	Estragole	C10H12O	148
13.50	72.45	Eugenol	C10H12O2	164
15.04	8.98	Caryophyllene	C15H24	204
15.91	1.23	Humulene	C15H24	204
17.38	15.37	Phenol, 2-methoxy-4-(2-propenyl)-, acetate	C12H14O3	206
18.90	0.66	4,12,12-Trimethyl-9-Methyle NE-5-Oxatricyclo[8.2.0.0~4,6 ~] Dodecane	C15H24O	220

Table (2-c): Retention time and concentration of essential oil components of thyme extract, identified by GC-MS.

Retention rate (RT)	Concentration (area %)	Compound name	Molecular formula	Molecular weight
3.53	0.57	Bicyclo[3.1.0]hex-2-ene, 2-methyl-5-(1-methylethyl)	C10H16	136
3.66	1.38	Bicyclo[3.1.1]Hept-2-ENE, 2,6,6-Trimethyl	C10H16	136
3.93	30.51	Camphene	C10H16	136
4.40	0.34	1,6-Octadien-3-OL, 3,7-Dimethyl	C10H18O	154
4.56	1.26	7-Methyl-3-Methylene-1,6-OC Tadiene	C10H16	136
4.92	0.37	à-Phellandrene	C10H16	136
5.13	2.14	1,4,8-Cycloundecatriene, 2,6,6,9-Tetramethyl-, (E,E,E)	C15H24	204
5.29	19.55	o-Cymene	C10H14	134
6.01	4.91	ç-Terpinene	C10H16	136
6.98	1.38	1,6-Octadien-3-Ol, 3,7-Dimethyl	C10H18O	154
8.77	1.14	endo-Borneol	C10H18O	154
8.98	1.04	Terpinen-4-ol	C10H18O	154
10.20	0.41	Anisole, 2-Isopropyl-5-Methyl	C11H16O	164
10.45	0.33	Benzene, 2-methoxy-4-methyl-1-(1-methylethyl)	C11H16O	164

11.76	0.43	Phenol, 2-Methyl-5-(1-Methylethyl)	C10H14O	150
11.99	15.05	Thymol	C10H14O	150
12.27	44.86	Phenol, 2-methyl-5-(1-methylethyl)	C10H14O	150
13.68	0.29	Thymol	C10H14O	150
15.02	3.09	Caryophyllene	C15H24	204
18.89	10.94	Caryophyllene oxide	C15H24O	220

Table (2-d): Retention time and concentration of essential oil components of turmeric extract, identified by GC-MS.

Retention rate (RT)	Concentration (area %)	Compound name	Molecular formula	Molecular weight
3.66	0.35	trans-á-Ocimene	C10H16	136
4.92	1.57	à-Phellandrene	C10H16	136
5.29	5.09	o-Cymene	C10H14	134
5.45	3.34	Eucalyptol	C10H18O	154
11.37	1.38	p-Cymene	C10H14	134
12.23	0.68	Phenol, 2-Methyl-5-(1-Methylethyl)	C10H14O	150
14.00	0.73	Benzene, 2-Methyl-1,4-Bis(1-Methylethyl)	C13H20	176
14.62	0.39	Ylangene	C15H24	204
15.02	0.81	Caryophyllene	C15H24	204
15.63	1.15	7-Ethynyl-4a,5,6,7,8,8a-Hexahydro-1, 4a-Dimethyl-, (1à,4aá,7á,8aà)	C14H18O	202
15.88	0.44	á-Longipinene	C15H24	204
16.55	9.29	Benzene, 1-(1,5-Dimethyl-4-Hexenyl)-4-Methyl	C15H22	202
16.88	2.10	1,3-CYCLOHEXADIENE, 5-(1,5-Dimethyl-4-Hexenyl)-2 -Methyl-, [S-(R*,S*)]	C15H24	204
17.09	0.33	Tridecane, 2-Methyl-2-Phenyl	C20H34	274
17.19	1.37	á-Bisabolene	C15H24	204
17.56	5.16	á-Sesquiphellandrene	C15H24	204
18.30	0.61	Caryophyllene oxide	C15H24O	220
18.43	0.32	Caryophyllene oxide	C15H24O	220
18.72	0.57	Tumerone	C15H22O	218
18.84	2.43	p-Menthane, 2,3-Dibromo-8-Phenyl	C16H22Br2	372
19.13	0.85	6-Isopropenyl-4,8a-Dimethyl-3,5,6,7,8,8a-Hexahydro-1h-Na Phthalen-2-One	C15H22O	218
19.37	3.65	1-(2-Methoxy-1-methylethyl)-2-meth ylbenzene	C11H16O	164
19.68	0.46	trans-Sesquisabinene hydrate	C15H26O	222
19.84	0.75	Cyclopentanol, 3,3,4-Trimethyl-4-P-Tolyl-, (R,R)-(+)-	C15H22O	218
20.14	1.89	Santalol, cis,à-	C15H24O	220
20.35	0.64	1-Oxaspiro[2.5]Octane, 5,5-Dimethyl-4-(3-Methyl-1,3-Buta-dienyl)	C14H22O	206
20.82	29.73	aR-Turmerone	C15H20O	218
20.91	9.10	(E)-ç-Atlantone	C15H22O	218
21.32	0.34	10,12-Tricosadiynoic Acid, Methyl Ester	C24H40O2	360
21.61	13.45	Curlone	C15H22O	218
23.15	1.02	7-Oxabicyclo[4.1.0]Heptane, 2,2,6-Trimethyl-1-(3-Methyl-1,3-Butadienyl)-5-Methylene	C15H22O	218

Twenty seven volatile chemicals components were discovered in the cinnamon extract (Fig, 1-e) and (Table, 2-e), however only 15 of them were recognized, and the main ingredients were á-cadinene (11.96%), copaene (17.51%),

Table (2-e): Retention time and concentration of essential oil components of cinnamon extract, identified by GC-MS

Retention rate (RT)	Concentration (area %)	Compound name	Molecular formula	Molecular weight
3.08	0.19	9-Octadecenoic acid (Z)-, 2-hydroxy-1-(hydroxymethyl)ethylester	C21H40O4	356
3.65	0.32	trans-á-Ocimene	C10H16	136
3.92	0.22	Camphene	C10H16	136
4.39	0.12	BICYCLO[3.1.1]HEPTANE, 6,6-DIMETHYL-2-METHYLENE-, (1S)	C10H16	136
8.53	0.59	3-PHENYLPROPANAL	C9H10O	134
8.76	0.51	endo-Borneol	C10H18O	154
9.99	1.28	Cinnamaldehyde, (E)	C9H8O	132
11.46	43.99	Cinnamaldehyde, (E)	C9H8O	132
12.93	0.27	Copaene	C15H24	204
13.74	1.63	(+)-cycloisosativene	C15H24	204
13.94	17.51	Copaene	C15H24	204
14.30	1.25	Cyclohexane, 1-ethenyl-1-methyl-2,4-bis(1-methylethenyl)-, [1S-(1à,2á,4á)]	C15H24	204
14.47	1.17	Aromandendrene	C15H24	204
14.85	0.60	Isosativene	C15H24	204
15.02	0.77	Caryophyllene	C15H24	204
15.68	0.35	Epicubenol	C15H26O	222
15.88	0.75	Humulene	C15H24	204
16.38	3.45	ç-Muurolene	C15H24	204
16.70	0.26	Naphthalene, 1,2,3,4,4a,5,6,8a-octahydro-4a,8-dimethyl-2-(1-methylethenyl)-, [2R-(2à,4aà,8aá)]	C15H24	204
16.77	0.21	1H-CYCLOPROP[E]AZULENE, 1A,2,3,5,6,7,7A,7B-OCTAHYDRO-1,1,4,7-TETRAMETHYL-, (+)	C15H24	204
16.96	9.35	Naphthalene, 1,2,4a,5,6,8a-hexahydro-4,7-dimethy l-1-(1-methylethyl)-, [1S-(1à,4aá,8aà)]	C15H24	204
17.19	0.29	2,6,10-DODECATRIEN-1-OL, 3,7,11-TRIMETHYL	C15H26O	222
17.29	0.37	ç-Muurolene	C15H24	204
17.43	11.96	á-CADINENE	C15H24	204
17.63	0.21	Naphthalene, 1,2,3,5,6,7,8,8a-octahydro-1,8a-dimethyl-7-(1-methylethenyl)	C15H24	204
17.75	1.79	Cubenene	C15H24	204
17.95	0.61	à-Calacorene	C15H20	200

and cinnamaldehyde (43.99%).

Effect of plant extracts in feed on performance and digestibility coefficient of growing rabbits

Table (3) displays the effects of supplementing developing rabbits with garlic, clove, thyme, turmeric, and cinnamon extracts on live body weight, daily weight gain, daily feed consumption, and feed conversion ratio.

The outcomes demonstrated that the addition of 200 ppm of herbal plant extract during the study period had a significant (P<0.05) positive impact on final body weight. When compared to the control group, the plant extracts considerably (P< 0.05) increased both final body weight and daily weight growth values. The daily feed intake of the rabbits fed diets containing different herbal plant extracts was not noticeably impacted. During the trial period, the feed conversion ration (FCR) of developing rabbits was significantly (P<0.05) enhanced by the supplementation of these extracts.

According to the findings in Table 3, adding 200 ppm of supplements of garlic, clove, thyme, and turmeric significantly (p < 0.05) improved the digestibility coefficient of crude protein, crude fiber, neutral detergent fiber, and acid detergent fiber. By reducing the N excreted through urine and faeces, the supplementation of the studied plant extr-

Table 3: Effects of some plants extract supplementation on performance, digestibility coefficients and nitrogen balance of growing rabbits

Parameters	Treatments						SEM	*P*-value
	C	GE	ClE	ThE	TE	CE		
Performance								
Initial body weight, g	685.45	664.96	671.06	671.44	674.84	686.15	23.76	0.853
Final body weight, g	2425.65 ^{c}	2899.86^{a}	2900.56^{a}	2817.64^{a}	2954.04^{a}	2673.35 ^{b}	78.46	0.001
Daily weight gain, g/day	24.86 ^{c}	31.93 ^{a}	31.85 ^{a}	30.66 ^{a}	32.56 ^{a}	28.39 ^{b}	1.43	0.001
Daily feed intake, g/day	122.64	125.11	125.42	124.52	125.58	121.68	16.96	0.831
Feed conversion ratio	4.93 ^{a}	3.92 ^{c}	3.94 ^{c}	4.06 ^{c}	3.86 ^{c}	4.29 ^{b}	0.12	0.001
Digestibility coefficients (%)								
Dry matter	61.85 ^{c}	63.84 ^{ab}	64.36 ^{a}	64.44 ^{a}	64.85 ^{a}	62.94 ^{b}	0.53	0.001
Crude protein	63.14 ^{c}	65.93 ^{a}	66.06 ^{a}	66.16 ^{a}	66.74 ^{a}	64.89 ^{b}	0.68	0.001
Crude fiber	41.54 ^{c}	44.34 ^{a}	44.75 ^{a}	44.84 ^{a}	44.81 ^{a}	43.14 ^{b}	0.13	0.001
Neutral detergent fiber	49.25 ^{c}	50.93 ^{a}	51.33 ^{a}	51.64 ^{a}	51.57 ^{a}	50.14 ^{b}	0.21	0.001
Acid detergent fiber	44.06 ^{c}	45.53 ^{a}	45.86 ^{a}	45.06 ^{a}	45.11 ^{a}	44.41 ^{b}	0.19	0.001
Dietary nitrogen utilization								
Nitrogen intake, g	3.17	3.24	3.25	3.21	3.26	3.15	0.14	0.883
Urinary N, g	1.07^{a}	0.91 ^{b}	0.86 ^{b}	0.83 ^{b}	0.78 ^{b}	0.97 ^{ab}	0.08	0.011
Fecal N, g	1.21 ^{a}	1.03 ^{b}	0.98 ^{b}	0.99 ^{b}	0.91 ^{b}	1.14 ^{ab}	0.06	0.019
N balance. g	0.88 ^{c}	1.29 ^{ab}	1.41 ^{a}	1.39 ^{a}	1.55 ^{a}	1.04 ^{bc}	0.22	0.001

^{a,b,c}Means within rows followed by different superscripts are significantly different at ($P < 0.05$).

Table 4: Effects of Some Plants Extract Supplementation on Cecal fermentation and microbial count of Growing Rabbits

	Treatments						SEM	*P*-value
	C	GE	ClE	ThE	TE	CE		
Cecal fermentation								
pH	6.14	6.09	6.11	6.10	6.05	6.08	0.11	0.874
NH_3-N (mmol/L)	11.74^{a}	10.18 ^{b}	9.78 ^{b}	10.22^{b}	9.86 ^{b}	9.73 ^{b}	0.41	0.001
Total VFA (mmol/L)	58.31 ^{b}	61.07 ^{a}	62.66 ^{a}	61.42 ^{a}	62.49 ^{a}	62.58 ^{a}	1.54	0.001
Acetic acid (mol/100 mol VFA)	61.76 ^{b}	65.49 ^{a}	66.53 ^{a}	65.31 ^{a}	66.73 ^{a}	66.61 ^{a}	0.98	0.012
Propionic acid (mol/10 mol VFA)	19.76 ^{b}	21.33 ^{a}	22.69 ^{a}	21.14 ^{a}	22.15 ^{a}	22.44 ^{a}	1.68	0.017
Butyric acid (mol/100 mol VFA)	8.46 ^{a}	7.21 ^{b}	7.06 ^{b}	7.37 ^{b}	7.11 ^{b}	7.16 ^{b}	0.19	0.022
Microbial counts								
Aerobic and facultative anaerobic bacteria (log UFC/g)	5.76 ^{b}	7.07 ^{a}	7.66 ^{a}	7.12 ^{a}	7.45 ^{a}	7.34 ^{a}	0.58	0.001
Lactobacillus spp. (log UFC/g)	2.13 ^{b}	3.11 ^{a}	3.45 ^{a}	3.14 ^{a}	3.44 ^{a}	3.27 ^{a}	0.33	0.019
Escherichia coli (log UFC/g)	4.67 ^{a}	3.03 ^{b}	2.89 ^{b}	3.11 ^{b}	2.86 ^{b}	2.99 ^{b}	0.16	0.011
Clostridium spp. (log UFC/g)	4.43 ^{a}	2.87 ^{b}	2.63 ^{b}	2.93 ^{b}	2.62 ^{b}	2.77 ^{b}	0.27	0.001
Enterococcus spp. (log UFC/g)	5.86 ^{a}	4.55 ^{b}	4.25 ^{b}	4.46 ^{b}	4.21 ^{b}	4.33 ^{b}	0.24	0.001

^{a,b,c}Means within rows followed by different superscripts are significantly different at ($P < 0.05$)

-acts also improved (P< 0.05) the N balance. Except for faecal N, which tended to be greater in the control group, there were no statistically significant variations in nutritional digestibility or N balance between the supplementary sources.

Effect of plant extracts in feed on cecal fermentation and microbial counts of growing rabbits

The effects of supplemental garlic, clove, thyme, turmeric, and cinnamon extract on cecal fermentation and microbi

Table 5: Effects of Some Plants Extract Supplementation on Blood biochemical parameters, Antioxidant status and Immunological parameters of Growing Rabbits

	Treatments						SEM	*P*-value
	C	GE	ClE	ThE	TE	CE		
Blood biochemical parameters								
Total protein (g/dl)	6.43 [b]	7.26 [a]	7.56 [a]	7.13 [a]	7.48 [a]	7.32 [a]	0.39	0.001
Albumin (g/dl)	4.06 [b]	4.65 [a]	4.85 [a]	4.52 [a]	4.78 [a]	4.65 [a]	0.25	0.003
Globulin (g/dl)	2.37 [b]	2.61 [a]	2.71 [a]	2.61 [a]	2.70 [a]	2.67 [a]	0.08	0.006
Albumin/Globulin ratio	1.71	1.78	1.79	1.73	1.77	1.74	0.08	0.783
Total cholesterol (mg/dl)	196.54 [a]	165.67 [b]	156.53 [b]	169.55 [b]	158.46 [b]	166.23 [b]	9.67	0.001
Triglyceride (mg/dl)	122.06 [a]	106.74 [b]	99.62 [b]	103.15 [b]	98.46 [b]	108.42 [b]	7.44	0.004
HDL-cholesterol, mg/dl	78.46 [a]	70.45 [b]	68.55 [b]	71.45 [b]	68.24 [b]	71.63 [b]	1.97	0.002
VLDL, mg/dl	55.48 [a]	48.52 [b]	45.18 [b]	46.89 [b]	44.75 [b]	49.28 [b]	2.37	0.012
LDL-cholesterol, mg/dl	62.60 [a]	46.70 [c]	42.80 [c]	51.21 [b]	45.47 [c]	45.32 [c]	2.16	0.009
Antioxidant status								
TAOC (U/mL)	2.24 [b]	3.97 [a]	4.08 [a]	3.88 [a]	4.13 [a]	4.01 [a]	0.09	0.001
Catalase (U/L)	33.86 [b]	40.75 [a]	41.96 [a]	39.86 [a]	42.33 [a]	41.42 [a]	1.77	0.008
SOD (U/mL)	18.75 [b]	22.61 [a]	23.28 [a]	21.98 [a]	23.76 [a]	22.27 [a]	0.95	0.016
GSH-Px (U/mL)	25.65 [b]	30.07 [a]	31.74 [a]	29.78 [a]	31.88 [a]	30.44 [a]	1.67	0.022
MDA (mmol/l)	25.75 [a]	17.76 [b]	15.98 [b]	16.86 [b]	15.88 [b]	16.94 [b]	1.57	0.019
Immunological parameters								
IgG (mg/dl)	18.55 [b]	22.76 [a]	23.08 [a]	22.65 [a]	23.12 [a]	22.72 [a]	0.34	0.021
IgM (mg/dl)	9.86	9.77	9.96	9.85	9.99	9.63	0.18	0.009
IgA (mg/dl)	31.08 [b]	34.46 [a]	35.08 [a]	34.55 [a]	35.11 [a]	34.33 [a]	0.57	0.013

[a,b,c]Means within rows followed by different superscripts are significantly different at ($P < 0.05$)

Table 6: Effects of Some Plants Extract Supplementation on physicochemical properties of rabbit meat samples (means±SE).

	Treatments					
Component*	**C**	**GE**	**ClE**	**ThE**	**TE**	**CE**
Moisture (%)	75.35[a]±0.47	74.66[b]±0.42	75.20[ab]±0.31	71.82[d]±0.46	73.31[c]±0.40	74.81[ab]±0.32
Crude Protein (%)	69.13[a]±0.27	68.94[a]±0.55	68.97[a]±0.66	68.82[a]±0.63	67.57[b]±0.96	69.69[a]±0.68
Crude ether extract (%)	14.65[a]±0.31	13.93[ab]±0.83	13.53[b] ±0.55	13.55 [b]±0.54	14.29[ab]±0.52	13.64[ab]±0.45
Ash (%)	8.54 [a]±0.44	7.48 [bc]±0.39	7.93[abc] ±0.43	8.51[a]±0.50	8.33 [ab]±0.47	7.30[c]±0.54
Total carbohydrates (%)	7.68[b]±0.99	9.65[ab]±1.22	9.57[ab]±0.53	9.12[ab]±0.41	9.81[a]±0.97	9.37[ab]±0.47
Energy value (Kcal/100g)	439.09[a]±0.86	439.73[a]±0.99	435.91[ab]±0.92	433.83[b]±0.83	438.13[ab]±0.98	439.00[a]±1.12
pH value	5.89[a]±0.12	5.67[b]±0.04	5.71[b]±0.02	5.66[bc]±0.03	5.62[bc]±0.02	5.57[c]±0.05
TBA (mg malonaldehyde/ Kg sample)	0.16[a]±0.04	0.09[b]±003	0.06[b]±0.01	0.09[b]±0.01	0.09[b]±0.01	0.10[b]±0.03
WHC (%)	75.29[a]±0.86	74.61[ab]±0.99	75.04[a]±1.03	74.73[a]±0.36	73.26[b]±0.69	74.72[ab]±0.58
Cooking loss (%)	20.84[a]±0.57	17.92[b]±1.17	18.02[b]±0.84	17.13[b]±0.99	16.77[b]±1.05	17.45[b]±1.63
The antioxidant activity						
Radical scavenging activity (%Inhibition)	2.24[e]±0.31	10.77[bc]±0.60	13.62[a] ±0.81	10.15[c]±0.68	11.45[b]±0.48	8.84[d]±0.440
Color						
Lightness (L*)	44.90[c]±0.49	47.14[b]±1.08	46.79[b]±0.62	46.40[b]±0.76	50.20[a]±0.92	47.00[b]±0.32
Redness (a*)	0.42[bc]±0.03	0.68[b]±0.08	0.24[c]±0.01	1.73[a]±0.19	0.26[c]±0.06	2.06[a]±0.35
Yellowness (b*)	3.82[b]±0.52	4.68[b]±0.92	4.45[b]±0.93	6.18[a]±0.61	4.16[b]±0.27	6.94[a]±0.38

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Chroma (C*)	2.84[c]±0.63	4.73[b]±0.57	4.45[b]±0.43	6.42[a]±0.95	4.17[b]±0.36	7.24[a]±0.47
Sensory evaluation of cooked meat						
Odor	8.90±0.32	8.90±0.31	9.00±0.05	9.00±0.00	9.00±0.00	9.00±0.00
Color	8.80±0.42	9.00±0.20	8.90±0.32	8.80±0.42	8.80±0.42	9.00±0.00
Taste	9.00±0.32	8.90±0.27	8.80±0.42	8.90±0.06	8.90±0.30	9.00±0.37
Texture	8.90±0.17	8.90±0.41	8.80±0.48	8.90±0.95	8.90±0.49	0.90±0.23
Appearance	9.00±0.42	8.80±0.67	8.80±0.42	8.90±0.52	9.00±0.73	8.90±0.10
Overall Acceptability	9.00±0.32	9.00±0.00	8.90±0.32	8.90±0.26	9.00±0.00	9.00±0.00

Means in the same raw sharing the same letters are not significantly different at ($P \leq 0.05$) level

*Data as mean ± SD..

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al counts in growing rabbits were shown by data in Table (4). There was no. significant difference between groups in the pH of the cecal fermentation results. While the VFA, acetic acid, and propionic acid in supplement extract herbal plants increased significantly (P<0.05) compared to the control group, the NH_3-N and butyric acid groups were greatly reduced in comparison with the control group.

Microbial counts revealed a substantial variation across groups. Compared to the control group, the groups that received supplement extracts from herbal plants showed a considerable rise in the levels of aerobic and facultative anaerobic bacteria as well as *Lactobacillus spp*. As opposed to the control group, *Escherichia coli*, *Clostridium spp*., and *Enterococcus spp*. considerably decreased in the supplemented extract herbal plant groups.

According to data in Table 5, rabbits given diets supplemented with extracts of garlic, clove, thyme, turmeric, and cinnamon exhibited higher (P<0.05) levels of TP and Glb than those in the control group. Additionally, for all plant extracts supplemented rabbits showed lower levels of LDL and TC (P<0.05) than control rabbits. In contrast, HDL levels were higher (P< 0.05) in all treatment groups compared to the control group. In rabbits receiving feed additives, there were no significant differences in the levels of Alb, or triglycerides.

Table (5) shows boosting of antioxidant enzymes in rabbits given extracts of garlic, clove, thyme, turmeric, and cinnamon. In comparison to the control group, the herbal plant extract substantially (P<0.05) improved TAC , SOD, CAT, and GSH-Px. The addition of the herbal plant extract caused a definite (P<0.05) decrease in MDA. According to Table (5), adding extracts of garlic, clove, thyme, turmeric, and cinnamon to a rabbit's diet considerably boosted the animal's immunological parameters (IgG and IgA), but the IgM of rabbits fed diets containing diverse herbal plant extracts was unaffected.

Meat characteristics and quality of growing rabbits supplemented with plant extracts

Table (6) illustrates how plant extracts affect the physicochemical characterizations of fresh meat for developing rabbits. The addition of GE, ThE, and TE had a considerable impact on the moisture content. The amount of ether extract in the meat samples from the CLE and ThE supplemented groups was significantly lower than that of the control group's (P< 0.05), but there was no significant difference between those from the other treatment groups. Compared to the control, TE supplementation decreased the levels of protein, ash, and total carbohydrate (Table 6). Except for ash content, there was no difference between the meat samples from the control group and the CE-treated group that was significant (P<0.05). The meat samples from the ThE-treated group had the lowest energy content (433.83Kcal/100g).

In comparison to the control samples, the pH, TBA, and cooking loss values for the treated meat samples significantly decreased. However, there was no significant change in WHC% between meat samples from the control and treatment groups. On the other hand, the TE-treated sample showed a significant decrease in same parameter.

As plant extracts were fed to growing rabbits, the antioxidant activity in the meat increased; the ClE sample had the greatest value of radical scavenging activity (13.62%). Additionally, the addition of various extracts changed the color of the meat, with meat from the treated groups higher scores in (L*), (b*), and (C*). However, the study indicates no significant difference in sensory properties between both the treatments as shown in (Table 6).

DISCUSSION

Previous research indicated that the production efficiency, carcass characteristics, health status and immunity of growing rabbits were all positively impacted by the phytochemicals in medicinal plant extracts (Samy et al., 2022).GE, ClE, ThE, TE, and CE all contained bioactive chemicals, including phenolic compounds, eugenol, dial-

lyl disulfide, o-cymene, camphene, and cinnamaldehyde, according to phytochemical analyses of the plant extracts. Flavonoids have been demonstrated to improve prevention of carcinogenic diseases. Natural bioactive chemicals have been discovered as anti-tumor medicines via a free radicals reducing mechanism (Jirovetz et al., 2006, Dvorackova et al., 2015 and Lawson and Hunsaker, 2018).

With regard to performance of growing rabbit, the herbal plant extract had a big benefit. Effects of plant extracts showed improved growth caused on by feed being utilized more effectively. These results are in line with those of several studies, including Kafi et al. (2017), who showed that adding to broiler feeds of 0.75 percent turmeric significantly increased growth rate.

In broilers, adding garlic to the diet increased body weight gain and feed conversion ratio (Chimbaka and Walubita, 2020). The antiprotozoal, antiviral, antibacterial, antifungal, anticancer, antioxidant and anti-inflammatory properties of allicin, which is present in garlic and its extract, may be responsible for those positive effects. Increased pancreatic enzyme activity, which provides a better condition for nutrient digestion and absorption, may be one of the causes of improved performance with garlic extract as a natural feed additive (Ismail et al., 2021). There is considerable proof that different plant extracts, herbs, and spices have antibacterial and appetite and digestion stimulating characteristics (Kamel, 2001). Different compounds found in clove extract, mainly eugenol, have natural bioactivities on animal physiology and metabolic activity (Olszewskaet al., 2020). The advantages of herbal plants and their extracts in animal nutrition include enhancing the secretion of digestive enzymes, enhancing appetite, prompting the immune system, and besides having antibacterial, antiviral, and antioxidant effects that may affect the physiological and chemical function of the digestive tract (Rahimi and Ardekani, 2013). The same effects were also noted by El-Naggar and Ibrahim (2018), who used 2 % garlic powder as natural feed additives in the lamb's diet, and reached the conclusion that the bioactive compounds in garlic provides a better environment for digestion and nutrient absorption.

And which noted by Suriya et al. (2012), who used 0.5% garlic powder in the broiler diet, and reached the conclusion that the increased enzyme activity of the pancreas, which provides a better environment for digestion and nutrient absorption, may be the reason for the better effect of garlic as natural feed additives. Also Turmeric extract (Curcumin) seems to be an antioxidant that can assist the gallbladder release bile and increase pancreatic juice production, which includes enzymes such as amylase, protease, and lipase that aid in carbohydrates, lipid, and protein digestion (Utami et al., 2020). We may also add that clove extract enhanced the digestion of rabbit diets. The positive impacts of various additions on digestibility increased rabbit overall performance.

Essential oils (EOs) in poultry have been shown to increase saliva, enzyme activity and bile secretion which may explain some of the improvement in nutritional absorption and digestion, reduced pathogenic microorganisms in the gut and may increase epithelial cells' ability to repair villi, hence improve intestinal absorption capacity, due to their well-documented inhibitory effects against pathogens (Lee et al., 2003; Emami et al., 2012).

Mansoub (2011) reported that addition clove powder to bird feed significantly enhanced the amino acids' ability to be released and absorbed. Additionally, he stated that the herbal combination encourages the synthesis of digestive and pancreatic enzymes, which improves nutrient absorptiondue its antimicrobial properties, and enhanced intestinal absorption by lowering fermentation losses, promoting VFA production, and increasing the synthesis of microbial crude protein. According to the findings of our research, various fermentation parameters, including microbial protein and VFA, reveal that herbal plant extract is rich in secondary plant metabolites and may have potential as a feed addition for rabbit diets (Chimbaka and Walubita, 2020).

In the present research, the use of herbal plant extract affects cecal metabolites in rabbits. The rise in total VFAs and the modest (non-significant) reduction in pH imply that the cecum fermentation activity of the herbal plant extract supplemented groups has increased. This conclusion agrees with the findings of Sheng et al. (2017) who indicated that differences in NH_3-N and VFAs levels might be related to variations in the composition of the cecal and intestinal micro-flora, since most of the microorganisms in the cecum originate from the gastrointestinal tract. A role for phenolic acids, alkaloids and flavonoids in regulating intestinal microflora was also observed in the treatment of intestinal flora problem in streptozotocin induced diabetic rats.

Flavonoids appear to be useful in avoiding pH decrease through influencing bacterial activity. The cecal microbial activity in rabbits is essentially similar to role of the rumen in ruminants. As essential flavonoid supplements raised the rumen molar proportion of propionate while decreasing the acetate-to-propionate ratio, suggesting that the flavonoid additions affected the overall microbiota and boosted the formation of propionate-producing bacteria. Additionally, flavonoid supplementation decreased rumen NH_3-N concentrations while increasing urine PD excretion (a measure of the microbial N flow in the duodenum).

The decrease in rumen ammonia concentrations, along with a considerable rise in the duodenal flow of microbial N, shows that rumen N consumption has improved (Gladine et al., 2007). Similar effects in cecum of rabbits may help explain some of the noted positive effects in our study. Sun et al. (2018) observed a clear link between the antioxidant capacity of *Thymus zygis* extracts and the total phenols they contained. Thyme phenols have redox characteristics and can scavenge free radicals. Antimicrobial characteristics of essential oils high in phenolic compounds has been observed and reported (Chouhan et al., 2017; El-Naggar et al., 2017). Evans and Martin (2000) found that thyme had antibacterial property against *Staphylococcus, Pseudomonas, Salmonella, E. coli, Klebsiella and Enterococci.*

Blood biochemical characteristics are typically correlated to one's state of health. These parameters have the potential to be used to clarify the effects of dietary additives and nutritional factors since they are good indicators of the physiological, pathological, and nutritional status of animals. Our study confirmed that supplementing diets with garlic, clove, thyme, turmeric, and cinnamon extract reduced blood triglycerides, total cholesterol, HDL, and LDL while increasing total protein, albumin, and globulin. These results are similar with those of El-Naggar and Ibrahim (2018), who reported that when lambs were fed an enriched diet containing 2 % garlic powder decreased LDL and MDA while total protein and globulin concentrations increased. The potential impact of garlic extract may be caused by increased fatty acid synthase, malic enzyme, 3-hydroxy-3-methylglutaryl-CoA reductase, and glucose-6-phosphatase dehydrogenase which are known to having decreased lipogenic and cholesterogenic activity. That may explain the mechanism of hypocholesterolemic and hypo-lipid synthesis (Mahmoud et al., 2010).

According to Wientarsih et al. (2002), adding *Curcuma* to rabbit diets resulted in a statistically significant drop in plasma concentrations of LDL, TC, and TG. The amount of 3-hydroxy-3-methylglutaryl coenzyme A reductase inhibitor activity increased when *Curcuma* was added to the diets of the rabbits, because *curcuma* has curcumin which influences TC metabolism, reduces plasma LDL considerably, decreases hepatic TC content, and raises plasma -tocopherol levels in rats.

An essential parameter that takes into account all blood antioxidants is total antioxidant capacity (Ghiselli et al., 2000). In this study, dietary herbal plant extract supplementation enhanced total antioxidant capacity, CAT, SOD and GSH levels, showing that herbal plant extract may enhance the overall antioxidant status of rabbits. Following supplementation with diets rich of antioxidant, changes in blood plasma total antioxidant capacity provide information on the bioavailability and absorption of dietary antioxidants (Ghiselli et al., 2000).

The present study findings tie with prior research on the antioxidant properties of herbal plants extract, which were also well demonstrated in this study. Allicin, alliin, allyl disulfide, and allyl cysteine are antioxidant chemicals found in garlic (Elkelawy et al., 2017). Benzie and Wachtel-Galor (2011) reported that turmeric extracts can scavenge free radicals, increase antioxidant enzymes, and inhibit lipid peroxidation, whereas turmeric extract (1.66 mg/kg of body weight) in rabbits high-fat diet, oxidation of erythrocyte membranes was found to be significantly lower than that in membranes of control animals. SOD "metalloprotein enzyme" is the first enzyme contributed in the antioxidant defense system. Consequently, elevated levels of these enzymes may improve the steady state of antioxidant system of rabbits.

Improving immunity is crucial for preventing infectious diseases in the animals. Immune deficiency and infection with diseases that weaken the immune system can be brought on by a number of factors, including deficient vaccination and antibiotic overuse. Improving immunity and mitigating the risk to infectious diseases can be achieved by using immune stimulators. Garlic, clove, thyme, turmeric, and cinnamon extracts are examples of herbs with high flavonoid content. These compounds enhance the efficiency of vitamin C as antioxidant, which may help the immune system (Acamovic and Brooker, 2005). This may explain how herbs plants affect immune-related parameters shown in Table (5). In rabbits fed diets with phytogenic additives, serum IgG and IgA levels were enhanced (P<0.05). Due to a rise in immunoglobulin levels (IgG and IgA) in rabbits given herbal plant treatments vs. the control diet, the inclusion of garlic and turmeric may boost the immune system. Garlic and its components have been linked to increased immune function, including phagocytosis, cytokine release, lymphocyte proliferation and killer cell activity, according to Wang et al. (2011). Additionally, it was proposed that adding garlic or allicin as a natural antibiotic had beneficial benefits on young animals, which were mostly attributed to an increase in immunity (Wang et al., 2011). Garlic and turmeric may have these beneficial benefits because of their antioxidant, anti-inflammatory and antibacterial properties. Thus, it is suggested that the use of turmeric and garlic will prevent the colonization of many pathogenic and non-pathogenic bacterial species in the stomach of rabbits and promote balanced microbial ecosystems in the gut, resulting in better feed utilization (Nouzarian et al., 2011). Herbal plants and extracts have beneficial effects in animal nutrition, including increased appetite stimulation, digestive enzyme secretion, antioxidant, immune response, antiviral and antibacterial that may influence the physio-

logical and chemical function of the gastrointestinal tract and, as a direct consequence in meat quality. So To increase the immune response, a greater dosage of natural herbal feed additives may be required.

In the present study, rabbits given the studied plant extract diets had higher levels of meat protein and carbohydrate compared to the control group, although their meat's moisture, ether extract, and ash contents were lower. Lower serum cholesterol and improved fat digestion may be held responsible for this decrease in fat content. The broiler chickens fed either 0.5% turmeric powder or 2% garlic showed no significant variation in their protein levels (Kanani et al., 2017). Curcumin or garlic extract supplementation had a significant ($P< 0.05$) decrease on the moisture, protein, and ether extract content of the growing rabbits' meat (Samy et al., 2022). The lowering in pH in the experimental rabbit meat samples may be related to the fact that adding plant extracts to a diet boosted muscle glycolytic metabolism and was more efficient as an antioxidant than the control group (Abdel-wareth et al., 2018; Samy et al., 2022). These results, however, disagree with those of Imbabi et al. (2021), who reported that the pH levels for rabbits meat fed fennel oil were lower than for the control group Herbal phenolic compounds have the capacity to prevent the oxidation of fatty acids, which might prevent the production of malonaldehyde as shown by the TBA value (Nurwantoro et al., 2015). In the control group, the increase in TBA was most likely attributable to the breakdown of hydroperoxides into secondary oxidation products, particularly aldehydes, during the latter stages of lipid oxidation. When rabbits were fed diets containing plant extract, their meat was of higher quality, rich in ω3/ω6, and their organs' redox balance was increased (Zeng et al., 2015; Mattioli et al., 2017). It was found that rabbit meat samples supplemented with herbal extracts had a lower water holding capacity than control rabbit meat samples. Raw muscle WHC is affected by pre-slaughter stress post-slaughter conditions and animal genetics; moreover, postmortem glycolytic metabolism and pH reduction are the major factors of WHC (Rybarczyk, 2022). Dried garlic supplementation prevented lipid biosynthesis and reduced fat deposition, resulting in a significant increase in water holding capacity levels as compared to the control group (Omojola et al., 2009). Cooking loss of rabbit meat samples in treatment groups was much lower than that of samples in the control groups (20.84). On the other hand, these findings conflict with those of Kone et al. (2016), who reported that the dietary addition of onion, strawberry, and cranberry extracts as well as essential oils had no significant impact on the cooking loss (30.0 to 30.6%).

One of the important aspects that customers take into consideration is meat color characteristics, which are connected to pH and have an effect on the oxidation of hem pigments in meat. High pH levels cause oxy-myoglobin to rapidly change into a dark red, decreased myoglobin, and because of the less compact structure, the muscle structure is less reflecting (Ouhayoun and Dalle Zotte, 1993).All experimental treatments groups had significantly higher L*, b* and C* values than the control samples. The pH was found to be negatively correlated with C* and L* values and the same result found with Sampels and Skoglund (2021).

Contrary to what is written in the literature, the darkest meat (pH=6.07) had lower L* values of strawberry extract than the control group (pH=6.23) (Kone et al., 2016). Additionally, pre-slaughter stress, muscle activity, and environmental variables connected to the housing and management system may all have an indirect impact on the color of the rabbit meat (Daszkiewicz and Gugoek, 2020). The sensory characteristics of the meat samples, including taste, color, texture, odor, appearance, and general acceptability, were unaffected (P≥0.05) by the use of herb extracts as a dietary supplement. This might be as a result of the decreasing meat fat content, which is a critical component essential for the flavor and odor of meat. All the meat samples were accepted by the panel. The panelists rated the overall acceptability of the meat samples as «like it very much» along with good organoleptic traits, which refers to meat quality resulting from supplementation of herbal plants extracts also includes nutritional characteristics (Arshad et al., 2018).

The increase in taste of ginger treated chicken meat samples might be attributable to flavor producing processes that happen during cooking (Pawer et al., 2007). Ingweye et al. (2021) found that meat samples from rabbit bucks fed 1.0% aidan in their diets had higher odor and acceptability scores but lower juiciness scores.

CONCLUSION

Supplementation of garlic, clove, thyme, and turmeric extracts as a natural biologically active substance to the growing rabbits feed improved growth performance, feed digestibility, cecal fermentation, antioxidant status and immunity, without any negative effect, that they have essential oils and bioactive compounds benefits for animal performance.

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CONFLICT OF INTEREST

The authors declare that they have no competing interests.

NOVELTY STATEMENT

Study the effect of different herbal plants at the same time and under the same conditions to clarify the effect of their extracts on rabbits performance.

AUTHORS CONTRIBUTION

All authors contributed equally to the manuscript.

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