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Research Article

Individual or Combination Impacts of *Alpinia galangal* and Zinc Sulfate on Growth Performance, Digestibility, and Carcass Traits of Weaning Male Rabbits

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Abstract | This study aims to evaluate the impact of individual or combination of *alpinia galangal* (AG) and zinc sulfate ($ZnSO_4$) on growth performance and carcass characteristics of growing rabbits. 48 male Baldi red rabbits aged 5 weeks were assigned to 6 treatments. Treatments were (1) control diet, (2) 50 mg (AG)/kg DM (AG_1), (3) 100 mg (AG)/kg DM (AG_2), (4) 100mg $ZnSO_4$/kg DM (Zn), (5) 50 mg (AG) + 100 mg $ZnSO_4$/ kg DM (AG_1Zn) and (6) 100 mg (AG) + 100 mg $ZnSO_4$/ kg DM (AG_2Zn). Feeding AG_2, AG_1Zn, and AG_2Zn recorded higher growth performance traits than control. The Zn, AG_1Zn, and AG_2Zn enhanced all apparent digestibility coefficient parameters compared to other treatments. In addition, carcass traits were improved by AG_2, Zn, AG_1Zn, and AG_2Zn treatments. Regarding economic efficiency, each AG_2 or AG_1Zn and AG_2Zn represented the most promising treatments. Results referred that an individual dose of (AG_2) or its combination (AG_1Zn and AG_2Zn) maximizes the growth performance and economic efficiency of growing rabbits.

Keywords | Bioactive components, Carcass traits, Growing rabbits, Medicinal plants, Synergistic effect

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INTRODUCTION

Medicinal plants and medicines derived from plant sources are devilishly used in traditional cultures worldwide and becoming increasingly popular as natural alternatives to synthetic chemicals in modern society. Herbal medicine has gained a vital target exponentially (Ben-Erik and Micheal, 2009), especially in animal feed (Khalifah et al., 2021; Elazab et al., 2022).

Alpinia galangal (AG) belongs to the Zingiberaceae family. The root contains a volatile oil resin, rich in β-Sitostero, 1-Diarabinoside (Fuloria and Fuloria, 2012), β-sitosteroldiglucosylcaprate, (Jaju et al., 2010), Galangoflavonoside, and 1-Acetoxychavicol acetate (Jaju et al., 2009). AG also contains flavonoids, some identified as kaemperol, kaempferide, galangin, and alpinin. Hence, it is thought to be a better supply of anti-oxidative ingredients than other herbal plants (Chudiwal et al., 2010). These components are considered powerful free radical scavengers (Kambar et al., 2014). Furthermore, AG extract may be an attractive and significant antioxidant (Valenzuela-Grijalva et al., 2017). The plant represents many pharmacological effects such as antibacterial (Zhang et al., 2010), anti-fungal, and antiviral (Lee et al., 2009). Galangal has antioxidant properties and antimicrobial activities, making it more beneficial as a natural animal feed additive (Hosoda et al., 2006) and stimulating the digestive effect (Khattab et al., 2017). Galangal extracts had significant effects on *Staphylococcus aureus, Klebsiellapneumonia* (Thomas et al., 1996) also, *Bacillus subtilis*, *Streptococcus faecalis*, Enterococcus faecalis, *Escherichia coli, Proteus vulgaris, Salmonella enteritidis, Saccharomyces cerevisiae,* in addition to anti-fungal activity for *Aspergillus niger*, through the competition for incorporation of unsaturated fatty acids in cell growth (Taechowisan and Lumyong, 2003).

Minerals play an important role in nutritional and physiological efficiency (Khalifah et al., 2022) Zn is an essential element in the alimentation of humans and an animal, besides being required in the genetic structure of every cell and are a critical requirement in all biological reproduction traits, also, in all DNA, RNA syntheses and its needed for every step of the cell cycle (Chrastinova et al., 2015). Attia et al. (2016) reported that supplementing rabbits with Zn significantly increased live weight gains and affected feed utilization during the metabolism of carbohydrates, lipids, and proteins. Also, (Attia et al., 2019; Selim et al., 2012) Reported that supplementing Zn improved live weight gain and feed conversion ratio. Zn plays a vital role in the antioxidant defense system (Hassan et al., 2021; Powell, 2000).

So a novel approach in the present study is applying medicinal plants with minerals such as Zn, which could serve as a platform to incorporate these elements into the body. This approach may enable direct transportation of active compounds to target organs, avoiding their fast degradability and encouraging several health benefits.

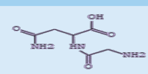
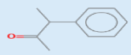
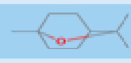
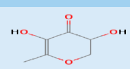
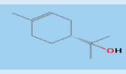
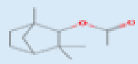
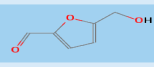
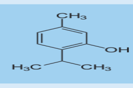
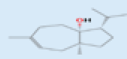
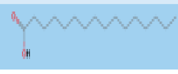
Therefore, the hypothesis of our study is the combination of AG and Zn could have a synergistic effect on each other, other than each one alone. The objective of the present study was to evaluate the impact of AG extract and $ZnSO_4$ supplementation on productive performance, nutrient digestibility, and carcass traits of weaning male growing rabbits.

MATERIALS AND METHODS

Study location

This experiment was conducted at El-Sabhia Research Station (31.21 N, 29.97 E) Animal Production Research Institute, Agricultural Research Center, Dokki, Egypt. While the analysis was performed at the livestock Research Department, Arid lands Cultivation Research Institute, the City of Scientific Research and Technological Applications, New Borg El-Arab city, Alexandria, Egypt. The rabbits were managed according to the Agricultural Research and Teaching of Federation of Animal Science Societies; Champaign, IL, USA.

Table 1: Chemical constituents identified by gas chromatography and mass spectrometry analysis in *Alpinia galangal* (AG) extracts.

Peaks	Compounds	tR (min)[a]	Peak area (%)	Molecular formula	Structure
1	Glycyl-D-asparagine	4.138	50.21	C6H11N3O4	
2	Benzenepropanal	9.051	37.35	C9H10O	
3	3-phenyl-2-butanone	11.880	20.49	C10H12O	
4	Eucalyptol	5.470	13.89	C10H18O	
5	Pyranone	9.174	7.743	C6H8O4	
6	α-Terpineol	10.519	9.09	C10H18O	
7	Fenchyl acetate	11.508	5.44	C12H20O2	
8	5-Hydroxymethylfurfural	12.840	11.28	C6H6O3	
9	Cinnamic acid	17.957	3.82	C9H8O2	
10	Thymol	21.19	25.25	C10H14O	
11	Carotol	25.894	17.44	C15H26O	
12	Palmitic acid	39.062	4.26	C16H32O2	

Preparation of extracts and GC-MS analysis

Sufficient amounts of AG fresh leaves and rhizomes were planted about 70 km south of Alexandria, Egypt, and were collected from mature trees during the summer season. Samples of leaves and rhizomes were separately pooled, washed, and cut into small pieces followed by oven-dried at40 °C for 72.0 h, and milled through a 0.25 mm screen to obtain a fine powder. The powder of the AG has extracted in a70% hydro-ethanolic solution (100 g/L) at 40°C for 72.0 h (El-Desoky et al., 2017). The extract was filtered with Whatman no. 1 filter paper (Camlab, Cambridge, UK). The obtained supernatant was evaporated at 45 °C to complete dryness and stored at −20 °C. The chemical constitutes in the extract were identified as shown in (Table 1) using a gas chromatography (GC)/ mass-spectrometry (MS) system, a 6890 series instrument (Agilent Technologies, Palo Alto, CA, USA) equipped with a mass selective detector with quadrupole analyzer, MSD 5973. The electron ionization energy was 70 ev, ion source temperature 230°C, and the interface temperature 280°C. A fused silica column HP-5 was used as the stationary phase. The oven was programmed as 50°C to 240°C at 4°C/ min; then 240°C to 270°C at 15°C/min; held isothermal at 50°C for 1 min and 270°C for 15 min. A sample of 1µl was injected through the mobile phase as helium with a flow rate of 1.0ml/min. The identification of compounds was performed by comparing their mass spectra with data from the US National Institutes of Standards and Technology (NIST08, LIB. USA).

Total bioactive constituents in AG

AG was subjected to analyze total bioactive components, as shown in (Table 2). Folin-Ciocalteu reagent was used to determine total phenols (as gallic acid) in dry AG according to the method described by (Kaur and Kapoor, 2002). Carotenoids as β-carotene were determined according to Nagata and Yamashita (1992). At the same time, total flavonoids as (quercetin equivalent) content were determined by Miliauskas et al. (2004). Total tannins (as tannic acid) were determined according to AOAC (2000) method. Saponins were determined by the method of Hiai et al. (1976).

Table 2: The total concentration of bioactive components identified in *Alpiniagalanga* (AG) on dry matter bases.

Components	mg/g DM
Total phenols	12.34
Carotenoids	0.57
Total flavonoids	6.22
Tannins	2.16
Saponins	0.27

Animal husbandry and experimental design

The experiment was carried out for eight weeks with 48 male Baldi red rabbits aged 5 weeks with an average body weight (BW) of 628 ± 5.92 g. The basal experimental diet was formulated to cover the nutrient requirements of rabbits according to (De Blas and Mateos, 2020), as shown in (Table 3). The rabbits were assigned to six treatments according to their initial BW. The first treatment was the basal diet control (C) with no additives in the diet. The second (AG_1) and third treatments (AG_2) were a basal diet supplemented with 50 and 100 mg AG/kg DM, respectively. And the fourth treatment was 100 mg $ZnSO_4$(Zn)/ kg DM, while the fifth treatment was 50 mg (AG) + 100 mg $ZnSO_4$/ kg DM (AG_1Zn) and the sixth treatment was 100 mg (AG) + 100 mg $ZnSO_4$/ kg DM (AG_2Zn). $ZnSO_4$ was manufactured by Sigma-Aldrich, United States Pharmacopeia (USP) Reference Standard, External ID,1724769-USP. The base of choosing Zn dose was as mentioned by (Selim et al., 2012), who stated that growing rabbits respond positively to 100 mg zinc/kg diets to improve body weight gain and feed conversion ratio (FCR).

Table 3: Ingredients and chemical composition (g/kg dry matter) of the experimental diet.

Ingredients	Basal diet (g/kg DM)
Clover hay	395
Soybean meal	175
Wheat bran	150
Barley	130
Yellow corn	100
Molasses	30
Di-calcium phosphate	8
Limestone	5
Sodium chloride	3
Vitamin andmineralpremix[a]	2
DL-methionine	2
Chemical composition	
Organic matter	801.4
Crud protein	169.8
Ether extract	23.7
Crude fiber	138.5
Ash	96.9
Digestible energy(kcal/kg)	2680
Zn in feed ingredients (mg/kg)	45
Total Zn intake	80

Vitamin and mineral premixa = provides per kg of diet: Vit. A 6000 IU; Vit. D 450 IU; Vit.E 40 mg; Vit. K 1mg; Vit. B1 1mg; Vit. B2 3 mg; Vit. B3 180 mg; Vit. B6 39 mg; Folic acid 2.5 mg; Vit. B12 5 µg; Pantothenic acid 10 mg; Biotin 10 µg; Choline Chloride 1200 mg; Zn 35 mg; Fe 38 mg; Cu 5 mg; I 0.2 mg; Se 0.05 mg and Mn 15 mg.

The rabbits were housed individually in galvanized wire battery cages with standard dimensions of 50 × 45 × 35 cm3 in a well-ventilated rabbitry. The cages were fitted with manual feeders and an automatic system of nipple drinkers to provide clean fresh water. Rabbits of all groups were kept under the same managerial conditions. They were individually weighed, maintained under standard laboratory conditions, and kept the managerial condition, healthy, hygienic, and clinically free of external and internal parasites. The ambient temperature ranged from 18 to 25°C while relative humidity ranged from 45 to 58%, and the light photoperiod was 16 hr light: 8 hr dark.

Growth performance traits

The average daily gain (ADG) was calculated on a group basis: ADG = (final live BW - initial live BW during a specific period)/ number of days. Feed intake (FI) was calculated as the difference between the weight of the feed offered and the remaining weight on the same day of weighing the animals. Feed conversion ratio (FCR) was computed as the ratio between FI and weight gain per period.

Digestibility experiment

Digestibility experiments were carried out at the end of the growth experiment (week 7). Six rabbits per treatment were randomly chosen and individually housed in metabolic cages equipped with a stainless- steel screen and 4 mm mesh to retain feces but allow free passage of urine. The digestion experiment and the collection period lasted for 7d. The assigned rabbits were subjected individually to a complete daily collection of feed, orts, and fecal samples. The obtained samples were stored at −20 °C and later pooled for each animal. The samples were collected separately in the morning before the ration was offered during the collection period. Representative samples were dried in a forced-air oven at 50 °C for 48.0 h, ground to pass through a 1-mm screen, and stored at−20 °C until further chemical analyses. Samples were analyzed chemically according to the AOAC (2000) for organic matter (OM), dry matter (DM), crude protein (CP; as 6.25 × N), ether extract (EE), and crude fiber (CF).

Carcass traits

At the end of the digestibility trial, the rabbits were slaughtered by cutting the jugular vein with a sharp knife based on the "Halal" method. Every effort was made to prevent unnecessary pain in the animals (Lopez et al., 2008). The rabbits fasted with a free water supply for 12 h before slaughter. The rabbits were weighed pre-slaughter, slaughtered for complete depletion, skinned, and eviscerated. The dressed carcass, free from any internal organs, was weighed (carcass weight without the head). The eviscerated carcass was weighed, including the liver, heart, and kidney. The carcass yields were calculated as a percentage of the rabbits' pre-slaughter live initial body weight. Additionally the percentages of the total edible parts and giblets were calculated as follows: Giblets % = kidney % + heart % + liver %, Total edible parts % = carcass % + kidney % + heart % + liver %.

Statistical analysis

All results were analyzed using the GLM procedure of SAS (SAS, 2002). For the growth performance variables, including BW, BW gain, average daily gain, feed intake, and feed conversion ratio, the statistical repetitions were 8 cages per treatment, including one rabbit each, as the rabbits were housed individually (8 cages/treatment, 6 treatment, one rabbit/cage). For the digestibility trial and carcass characteristics, statistical repetitions included individual rabbits (6 cages/ treatment, 6 treatments, and one rabbit/ cage) as rabbits were housed individually. Comparisons between treatment means were tested using the Tukey method. Statistical significance was accepted at ($P \leq 0.05$).

RESULTS AND DISCUSSION

Main active components identified in AG

The GC-MS identified twelve chemical compounds in the AG extracts, as shown in (Table 1). The most abundant constituents of the AG extract were glycol-D-asparagine, benzenepropanal, thymol, 3-phenyl-2-butanone, and carotol. All identified bioactive components belong to phenols and flavonoids compounds; hence AG is rich in such phenolics, as presented in (Table 2).

Growth performance

The growth performance of rabbits who received AG or Zn and a combination of both treatments compared to control is presented in (Table 4). Rabbits supplemented with AG_2, AG_1Zn, and AG_2Zn recorded higher (P <.0001) final BW, BWG, ADG, FI, and the best (P <.0001) improvement of FCR was recorded for AG_2, Zn, AG_1Zn, and AG_2Zn treatments compared to other treatments.

Digestibility coefficients

Each of Zn or AG_1Zn and AG_2Zn enhanced (P<.001) the all apparent digestibility coefficients parameters when compared to all other treatments, as shown in (Table 5). Furthermore, Both (AG_1 and AG_2) treatments recorded (P<.001) an increase in the digestibility coefficients parameters when compared to the control group.

Carcass traits

Pre-slaughter weight was increased (P<.001) by Zn or AG_1Zn and AG_2Zn treatments when compared to other

Table 4: Effect of *Alpinia galangal*(AG) or $ZnSO_4$(Zn) and their combination on growth performance of mal Baladi red rabbits.

Item	C	AG_1	AG_2	Zn	AG_1Zn	AG_2Zn	SEM	P Value
Initial BW g	622.00	629.20	631.20	637.50	628.40	633.10	4.88	0.2500
Final BW g	1981.00^{c}	2026.50^{b}	2395.8^{a}	2174.60^{b}	2321.30^{a}	2345.20^{a}	34.20	<.0001
BWG g	1359.00^{c}	1397.30^{cb}	1758.30^{a}	1634.40^{b}	1692.90^{a}	1712.10^{a}	28.60	<.0001
ADG g/ rabbit/ day	27.73^{c}	28.52^{cb}	35.88^{a}	33.37^{b}	34.54^{a}	34.94^{a}	3.50	<.0001
FI g/ rabbit/day	84.83^{c}	83.20^{c}	94.36^{a}	86.06^{cb}	93.63^{a}	93.29^{a}	13.60	<.0001
FCR	3.06^{a}	3.02^{a}	2.51^{b}	2.63^{b}	2.71^{b}	2.67^{b}	0.034	<.0001

^{a,b,c} means with different superscripts in the same row are significantly different (P<0.05). C: control, AG: Alpinia galangal, AG_1= 50mgAG/kg DM, AG_2= 100mg AG/kg DM, Zn= 100mg $ZnSO_4$/kg DM, AG_1+Zn= 50mg AG/kg DM+ 100mg Zn /kg DM, AG_2Zn = 100mgAG/kg DM+ 100mg Zn /kg DM, SEM= Stander error for means, BW= body weight, BWG= Body weight gain ADG= average daily gain, FI= feed intake and FCR= feed conversion ratio.

Table 5: Effect of *Alpinia galangal* (AG) or $ZnSO_4$ (Zn) and their combination on mal Baladi red rabbits apparent digestibility coefficients.

Items	C	AG_1	AG_2	Zn	AG_1Zn	AG_2Zn	SEM	P Value
Organic matter	56.37 ^{d}	59.06 ^{c}	64.64 ^{b}	68.79^{a}	70.21^{a}	70.31^{a}	0.079	<.0001
Dry matter	47.92^{d}	63.26^{c}	66.70^{b}	70.28 ^{a}	72.41^{a}	72.48^{a}	0.069	<.0001
Crude protein	85.27 ^{d}	87.21 ^{c}	89.84 ^{b}	91.57^{a}	90.83^{a}	90.67^{a}	0.087	<.0001
Ether extract	80.21 ^{c}	86.92 ^{b}	85.26 ^{b}	90.10 ^{a}	90.22^{a}	90.45^{a}	0.088	<.0001
Crude fiber	78.92 ^{c}	84.27 ^{b}	84.87 ^{b}	88.66 ^{a}	88.82^{a}	87.69^{a}	0.087	<.0001

^{a,b,c} means with different superscripts in the same row are significantly different (P<0.05). C=control, AG= Alpinia galangal, AG_1= 50mg AG/kg DM, AG_2= 100mg AG/kg DM , Zn=100mg $ZnSO_4$/kg DM, AG_1+Zn = 50mg AG/kg DM+ 100mg Zn /kg DM, AG_2Zn = 100mgAG/kg DM+ 100mg Zn /kg DM, SEM= Stander error for means.

Table 6: Effect of *Alpinia galangal* (AG) or $ZnSO_4$ (Zn) and their combination on mal Baladi red rabbits carcass traits.

Items	C	AG_1	AG_2	Zn	AG_1Zn	AG_2Zn	SEM	P Value
Pre-slaughter weight, g	1985^{c}	2019^{cb}	2189^{b}	2356^{a}	2325^{a}	2350^{a}	23.42	<.0001
Hot carcass, %	51.23^{c}	53.45^{b}	55.20^{a}	54.89^{ab}	55.61^{a}	55.62^{a}	0.92	<.0001
Liver, %	3.45	3.42	3.39	3.44	3.66	3.42	0.08	0.137
Heart, %	0.33 ^{b}	0.31 ^{b}	0.43^{a}	0.46^{a}	0.45 ^{a}	0.39 ^{a}	0.31	<.0001
Kidneys, %	0.52 ^{b}	0.55^{b}	0.57^{a}	0.61^{a}	0.59 ^{a}	0.56 ^{a}	0.33	<.0001
Total giblets[1], %	4.30	4.28	4.35	4.30	4.37	4.43	0.16	0.235
Total edible parts[2], %	55.53^{c}	57.73^{b}	59.55^{a}	59.19^{a}	59.98^{a}	60.05^{a}	2.76	<.0001

^{a,b,c} means with different superscripts in the same row are significantly different (P<0.05). C= control, AG= Alpinia galangal, AG_1=50mg AG/kg DM, AG_2= 100mg AG/kg DM , Zn= 100mg $ZnSO_4$/kg DM, AG_1+Zn= 50mg AG/kg DM+ 100mg Zn /kg DM, AG_2Zn= 100mgAG/kg DM+100mg Zn /kg DM, SEM= Stander error for means,Total giblets[1] % = kidney % + Heart % + liver % + lung %, Total edible parts[2] % = hot carcass % + kidney % + heart % + liver %.

treatments as presented in (Table 6), in addition, hot carcass, heart, kidneys, and total edible parts percentage improved (P<.001) by AG_2, Zn, AG_1Zn and AG_2Zn treatments when compared to other treatments.

Economic efficiency

As shown in (Table 7), there was a clear improvement in net revenue and relative economic efficiency of AG_2 or AG_1Zn and AG_2Zn treatment groups. The highest income from gain and the highest final margin were recorded in rabbit groups fed a diet supplemented with AG_2 or AG_1Zn and AG_2Zn compared to control.

Major quantified bioactive components (mg/g DM) presented in AG belong to phenols and flavonoids .our finding agrees with (Pahwa et al., 2016); in addition for qualified these compounds, GC-MS analysis obtained and confirming twelve chemical constituents and the most abundant constituents were glycyl-D-asparagine, benzenepropanal, thymol, 3-phenyl-2-butanone, and carotol. Such compounds could be responsible for AG action; hence it exhibits several pharmacological activities, including antioxidant (Boyle et al., 2000), and anti-inflammatory and antibacterial activity (Ouyang et al., 2018). It is also related to the intestinal tract's functions,

Table 7: Economic efficiency of mal Baladi red rabbits supplemented with *Alpinia galangal* (AG) or $ZnSO_4$ (Zn) and their combination.

Item	C	AG1	AG2	Zn	AG1Zn	AG2Zn
Body weight at marketing (kg)	1988.0	2029.6	2350.2	2179.6	2328.3	2350.2
Price of weaning litter (L.E)	30	30	30	30	30	30
Total fed intake at marketing (kg)	4.17	4.08	4.62	4.22	4.58	4.57
Total cost fed intake (L.E)	29.19	28.56	32.34	29.54	32.02	31.99
Total cost of supplementation (L.E)	3	3	3	3	3	3
Total cost of managements (L.E)	3.5	3.5	3.5	3.5	3.5	3.5
Total cost (L.E.)	65.69	65.06	68.84	66.04	68.52	68.49
Price of body weight at marketing (L.E)	103.8	105.54	122.21	113.34	121.07	122.21
Net revenue (L.E)	38.11	40.48	53.37	47.30	52.55	53.72
Economic efficiency	0.58	0.62	0.77	0.71	0.76	0.78
Relative economic efficiency (%)	100	106.9	132.8	122.4	131.03	134.5

C= control, AG= Alpinia galangal, AG_1= 50mg AG/kg DM, AG_2= 100mg AG/kg DM , Zn =100mg $ZnSO_4$/kg DM, AG_1+Zn = 50mg AG/kg DM+ 100mg Zn /kg DM, AG_2Zn = 100mgAG/kg DM+ 100mg Zn /kg DM,The total cost of feed = (Total feed intake × Kg feed cost). The total cost of management (L.E.)/litter = cost of housing + cost of medication +cost of care. The total cost of herbs and chemicals (Zn) (LE)= cost of Price herbs and chemicals. Total cost = (Total feed intake × Kg feed cost) + Price of weaning litter +Total of managements+ total cost of chemical and herbs. The Net revenue = Price body weight -Total cost price. Economic efficiency =Net revenue / Total cost. Relative Economical efficiency (%) = (Net revenue/ Total cost) x 100. Ingredients and selling of male growing rabbits in the local market at the experiment time (2021). The price of a one kg pellets diet was 7.00 L.E. and kg of marketing live weight 52 L.E.

such as digestive secretions and nutrient absorption (Dhama et al., 2014). Furthermore, these phytochemicals represent mucus protective and antiulcer effects by inhibiting the gastric proton pump (Dubey et al., 2013). These biological activities are primarily attributed to increased digestive secretions (digestive enzymes, bile, saliva, and mucus) (Costa et al., 2013), declining bacterial counts, and pathogen infection loads via an antibacterial effect in the intestinal lumen (Ahmed et al., 2012).

Rabbits supplemented with the combuination of low dose AG_1 and Zn, showed significantly higher performance. This enhancement could be related to the synergistic effect of AG (AG_1 and AG_2) combined with Zn with its active ingredients (total phenols and flavonoids). Our results are in agreement with previous researchers (Awad et al., 2009) who documented that flavonoides are capable of improving the BW, BWG gain, and FCR of broiler chickens, probable because of the adequate effect of flavonoids on gut morphology and the efficacious architecture of the small intestine additionally the potential of that flavones regulate the combination between the growth hormone and the hepatic growth hormone receptor, which raise insulin-like growth factor 1 concentration, thereby promoting animal growth (Ouyang et al., 2018). Interestingly, a consumed diet containing flavonoid supplementation has been shown to improve the growth performance of broiler chickens (Starˇcevi´c et al., 2015).

Regarding the role of zinc on productive performance, our results agree with Helal et al. (2018), who showed that rabbit's utilized a diet supplemented with Zn improved final BW, BWG, FI, and FCR. Also, Adham et al. (2020) documented that growth performance and FCR in rabbits were significantly enhanced due to Zn supplementation and significantly improved the digestibility of crude protein. Furthermore, Selim et al. (2012) showed improved BWG and FCR in growing rabbits utilizing a diet supplemented with 100 or 200 $ZnSO_4$ mg/kg diet compared to the control group.

The obtained results showed that whether Zn singly or combined with both (AG_1 and AG_2) positively affected the apparent digestion coefficient of feed, which could be attributed to several reasons. Zn supplementation affects protein and carbohydrate metabolism, which is found in increased purified enzymes functioning in protein and carbohydrate digestion (Underwood and Suttle, 1999). Increasing the digestive power of rabbits by Zn supplementation may be attributed to increasing the activity of some digestive enzymes related to the digestion of carbohydrates, fats, and protein such as amylase, lipase, trypsinogen, chemo trypsinogen enzymes, and some peptidases since these enzymes are known to be Zn-dependent enzymes (Banerjee, 1988). Our results agree with Gihan et al. (2017), who found that weaning rabbits supplemented with ZnSO4 augmented significant digestibility coefficients of organic matter, dray matter, and crude protein. Another theory of the Zn role was suggested by Carlson et al. (1998), who found that weaning pigs had an enteric effect of producing deeper crypts in the duodenum and a trend for longer villi caused the improved digestibility and nutrient after utilization of Zn supplementation, which could be directly related to the improving absorptive capacity of the mucous membrane. Another scenario for improving digestion coefficient could be described as enhancing intestinal epithelial health and improving absorption regarding the antibacterial effect of AG, which is illustrated by Eumkeb et al. (2010). Our results are in harmony with the observation of Ibrahim et al. (2011), who reported that the AG significantly increased dry matter, crude protein, ether extract, crude fiber, and organic matter digestibility when supplemented for rabbit diets due to the antimicrobial activity of AG against different kinds of bacteria.

Through what was discussed previously, the effect of each of Zn alone or AG_1Zn and AG_2Zn on growth rates, as well as the positive effect on feed digestion coefficient.So all these positive effects reflected the enhancement of the various carcass measures, which improved significantly compared to the control group. Our findings are harmonious with Lovita (2013), who recorded that carcass parameter and carcass weight augmented among each evaluated carcass characteristics of rabbits supplemented with 0.5 and 1.0 DM/AG. The same result was obtained by Ibrahim et al. (2011); hence, different levels significantly increased the carcass weight, dressing percentages, and carcass cuts. In addition, Helal et al. (2018) reported rabbits supplemented with Zn inorganic or organic source significantly increased pre-slaughter weight compared to control.

In contrast, Selim et al. (2012) mentioned that rabbit dressing percentages were insignificantly affected with Zn supplementation at several levels (50, 100, or 200 mg kg-1 diet). At the same time, liver and kidney weights were increased significantly. Regarding economic efficiency, each of AG_2 or AG_1Zn and AG_2Zn represented the most promising treatments, reflecting the value of net revenue and relative economic efficiency. Our results agree with (Ibrahim et al., 2011; Helal et al., 2018), who found that the administration of Zn enhances the economic efficiency of growing rabbits.

It was concluded that using an individual high dose of (AG_2) or its combination with zinc sulfate (AG_1Zn and AG_2Zn) in growing rabbit diets could be a good tool for improving the growth performance, carcass traits, digestibility, and increasing the net revenue and relative economic efficiency.

NOVELTY STATEMENT

The authors have developed the composition of Baladi growing rabbit diets by individual or combination of *alpinia galangal* (AG) and zinc sulfate as natural feed additive. The results of this study are published for the first time.

AUTHOR'S CONTRIBUTION

MEE, AMK & ASM Experiment idea and design. TAS, MAA & AMK performed the experiment. MEE, TAS, MAA, ASM analyzed the data. MEE, AMK & ASM wrote the draft with approval of all authors.

Conflict of interest

The authors have declared no conflict of interest.

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