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Original study

Effect of feed form, pellet diameter and enzymes supplementation on growth performance and nutrient digestibility of broiler during days 21-37 of age

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Abstract

A total of 420 21-day-old broilers were wing banded and randomly distributed among 60 cages of 7 birds per cage during days 21-37 of age. A factorial design (4×3) was used in which there were four feed forms (mash vs. pellet diet with diameter 2-2 mm, 2-3 mm and 3-3.5 mm, respectively) and three enzyme treatments (unsupplemented, phytase, phytase plus multi-enzyme). Each treatment was replicated 5 times with 7 broilers per replicate. Body weight gain of broilers fed 2-3 mm-diet was significantly greater than that of those fed mash diet and 2-2 mm or 3-3.5 mm pellet-diet. Feed conversion ratio was the best in broilers fed 2-3 mm and 3-3.5 mm pellet-diets. However, feed intake was significantly lower in broilers fed pellet-diets than that of those fed the mash diet. The production index and economic efficiency were significantly higher in groups fed 2-3 mm pellet diameter compared to those fed 2-2 mm and 3-3.5 mm pellet diets. Digestibility of crude protein, ether extract, crude fibre and crude ash were significantly and similarly greater in groups fed pellet diets in comparison with those fed mash diet. Enzyme supplementations significantly and similarly increased growth and production index whereas improved feed conversion ratio and economic efficiency than the control group and this concurred with greater digestibility of crude protein, ether extract and crude ash. However, multi-enzymes plus phytase induced greater effect on the production and economic traits than phytase

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alone showing synergetic effects. Pellet diet at 2-3 mm supplemented with multi-enzyme plus phytase resulted in the highest performance and nutrient digestibility of broilers during day 20-37 d of age.

Keywords: broilers, feed form, multi-enzymes, phytase, growth performance, digestibility

Abbreviations: BWG: body weight gain, CA: crude ash, CF: crude fibre, CP: crude protein, DM: dry matter, EE: ether extract, EPEI: European Production Efficiency Index, FCR: feed conversion ratio, FI: feed intake, NE: net energy

Introduction

The efficient use of feed is extremely important in broiler production. Investigations have to be continued to decrease cost of broiler production and improve broiler performance. Pellet feed has been shown to have the greatest potential to improve feed conversion ratio (FCR) and reduce cost compared to mash feed (Maiorka *et al.* 2005, Salari *et al.* 2006, Amerah *et al.* 2008). These improvements have been associated with changes in nutrients, digestibility and less feed wastage (Amerah *et al.* 2007).

Sundu *et al.* (2009) reported that birds tended to prefer larger pellet sizes, while the fine pellet sized diets (more than 50 % <2.0 mm) were not attractive to the birds at any age and they become less attractive as the birds got older; the larger pellet sizes of the mixed diet increased body weight and feed intake significantly. Tufarelli *et al.* (2011) reported that live body weight, feed intake and feed conversion ratio (FCR) were greater in guinea fowls and pheasants fed 2 mm pellet diet than those of them fed 4 mm pellet diet. The best FCR observed in birds fed processed feeds compared to birds given mash feed, may be accounted for an increased available net energy because less activity is used for eating.

Energy utilization in corn-soybean meal and sorghum-soybean meal diets could be improved by an enzyme cocktail contains amylase, xylanase and protease to promote the breakdown of starch, cell walls and endogenous proteins, respectively (Hong *et al.* 2002). Several studies have found that optimizing phosphorus intake and digestion with phytase reduce the release of phosphorus in manure by around 30 % (Attia *et al.* 2006). Also Wu *et al.* (2006) reported that phytase supplementation to diets containing 0.11 % nonphytate phosphorus significantly reduced excreta phosphorus with no adverse effect on performance. The use of phytase not only releases the bound phosphorus but also other essential nutrients (proteins, starch, calcium, magnesium, iron and zinc) which led to higher nutritional value of the diet (Ceylan *et al.* 2003, Panda *et al.* 2005, Jiang *et al.* 2013). Attia *et al.* (2008) observed that the addition of multi-enzyme to the diet improved the economic efficiency of chicken's diets. However, improved performance of poultry depends on dietary composition and type of enzyme (Attia 2003, Abudabos 2012, Nourmohammadi *et al.* 2012).

The use of an enzyme complex containing carbohydrases and phytase should allow the improvement of energy, protein, P and Ca utilization by broilers, laying hens, ducks and Japanese quails (Attia 2003, Attia *et al.* 2003a, 2003b, El-Ghamry *et al.* 2005, Attia *et al.* 2008, Yang *et al.* 2010) and thus it would be possible to add a low dose of these nutrients to the diet.

This study aimed to investigate the effect of phytase with or without multi-enzyme supplementation on performance, nutrient digestibility and economic traits of broilers fed mash or pellet diets with different diameter (2-2, 2-3 and 3-3.5 mm) during 21-37 days (d) of age.

Material and methods

Experimental design

A total of 420, 21-day-old unsexed Arbor Acres broiler chicks were distributed keeping equal initial body weight in 60 cages (7 birds per cage). The trial was listed from 21 to 37 d of age and along this period the birds fed two kinds of diet: grower (from 21 to 29 d) and finisher (from 30 to 37 d). The groups were submitted to the following dietary treatments: mash group (fed mash diets); 2-2 mm pellet group (fed pellet diets with 2 mm diameter in both 21-29 and 30-37 d periods); 2-3 mm pellet group (fed pellet diets with 2 and 3 mm diameter, respectively during grower and finisher periods); 3-3.5 mm group pellet (fed pellet diets with 3 and 3.5 mm of diameter, respectively during grower and finisher periods). Each group was divided into 3 subgroups (5 cages and 35 chicks/subgroup) whose diets were, respectively, unsupplemented (control subgroups), supplemented with phytase (phytase subgroups, Phyzyme XP at 0.07 g/kg diet) and supplemented with multi-enzyme plus phytase (multi+phytase subgroups, Avizyme 1505 at 0.2 g/kg diet plus Phyzyme XP at 0.07 g/kg diet). Pelleting temperature did not exceed 80 °C. Phyzyme and Avizyme are products of Danisco Animal Nutrition (Marlborough, Wiltshire, UK). Avizyme 1505 is a multi-enzyme containing 1 500 U/g endo-1, 4-β-xylanase, 2 000 U/g α-amylase and 20 000 U/g subtilisin. Phyzyme XP is an *Escherichia coli* phytase classified as a 6-phytase with hydrolysis of the phosphate moiety being initiated at the 6-position on the phytate molecule.

The feeding system and husbandry practice during 1-20 d of age are presented by Attia *et al.* (2012).

The available phosphorous (avP) and Ca contents were adjusted in the diets supplemented with phytase according to phytase equivalent values (Attia 2003, Attia *et al.* 2003a, Choct 2006). The experimental diets were formulated according to NRC (1994). Ingredients and chemical composition of the experimental basal diets fed during the grower and finisher stages are shown in Table 1.

Housing and husbandry

Broilers were housed in battery brooders in semi-opened house. They were fed *ad libitum* the experimental diets and given free access to water. A light schedule was 20 h light during 21st to 34th day of age followed by 24 h of light until slaughter. The average outdoor minimum and maximum temperature and relative humidity during the experimental period were 21.2 and 24.2 °C and 56.7 and 58.7 %, respectively. The housing temperature was 24 °C at 21 d of age, declined gradually to 21 °C at 28 d of age and then was around 21 °C until slaughter. Broilers were vaccinated against the most common diseases such as Newcastle disease, avian influenza, infectious bursa disease and infectious bronchitis.

Table 1
Ingredients and chemical composition of the experimental diets (as fed basis) fed during the grower and finisher stages

	Grower diets (21-29 d of age)			Finisher diets (30-37 d of age)		
	Without	Multi-Enzymes	Phytase	Without	Multi-Enzymes	Phytase
Ingredients, g/kg						
Maize	518.5	518.5	518.5	560.0	560.0	560.0
Soybean meal (44 %)	244.2	244.2	244.2	280.0	280.0	280.0
Full fat soybean meal	130.0	130.0	130.0	0.0	0.0	0.0
Rye	50.0	50.0	50.0	70.0	70.0	70.0
Vegetable oil blend	20.0	20.0	20.0	53.0	53.0	53.0
Dicalcium Phosphate	16.0	11.0	11.0	16.0	11.0	11.0
Limestone	10.0	10.0	10.0	10.0	10.0	10.0
NaCl	4.5	4.5	4.5	4.5	4.5	4.5
Vit+min premix[1]	3.0	3.0	3.0	3.0	3.0	3.0
DL-Methionine	2.0	2.0	2.0	2.0	2.0	2.0
L-Lysine	1.5	1.5	1.5	1.5	1.5	1.5
Washed building sand	0.3	5.03	5.23	0.0	4.73	4.93
Avizyme 1505	0.0	0.2	0.0	0.0	0.2	0.0
Phyzyme xp	0.0	0.07	0.07	0.0	0.07	0.07
Determined* and calculated** chemical-nutritional composition, g/kg						
Dry matter*	875.5	875.0	876.1	870.0	870.3	870.6
ME, MJ/kg**	12.98	12.98	12.98	13.38	13.38	13.38
CP*	211.2	211.0	211.4	185.3	185.5	185.0
Lysine**	12.3	12.3	12.3	10.4	10.4	10.4
Methionine**	5.2	5.2	5.2	4.8	4.8	4.8
Meth+cystine**	8.7	8.7	8.7	7.8	7.8	7.8
Calcium**	8.5	7.4	7.4	8.3	7.2	7.2
Total P**	5.8	4.9	4.9	5.3	5.3	5.3
Available P**	4.1	3.2	3.2	4.1	3.2	3.2
Crude fat*	64.5	64.3	64.7	68.0	68.3	67.8
Crude fibre*	35.1	35.3	34.9	38.0	38.2	38.3
Ash*	54.8	54.8	54.8	57.0	57.0	57.0
Nitrogen Free Extract**	634.4	634.6	634.2	651.7	651.0	651.9

[1]Vit+Min mix. provided per kilogram of the diet: Vit. A, 12 000 IU, vit. E (dl-a-tocopheryl acetate) 20 mg, menadione 2.3 mg, Vit. D3, 2 200 ICU, riboflavin 5.5 mg, calcium pantothenate 12 mg, nicotinic acid 50 mg, Choline 250 mg, vit. B12 10 mg, vit. B6 3 mg, thiamine 3 mg, folic acid 1 mg, d-biotin 0.05 mg. Trace mineral (mg/kg of diet): Mn 80 Zn 60, Fe 35, Cu 8, Selenium 0.1 mg.

Data collection

Birds were weighed individually at 21, 29 and 37 d of age and body weight gain (BWG) was calculated. Feed intake was recorded for each replicate and was used to calculate FCR (g feed/g gain) during 21-29, 30-37 and 21-37 d of age. The survival rate (100 – mortality rate) was also recorded along the trial.

Apparent digestibility of dry matter (DM), crude protein (CP), ether extract (EE), crude fibre (CF) and crude ash (CA) was measured on finisher diets on three replicates of three males per treatment using the total collection method as described by Attia *et al.* (2003a). Dry matter, CP, EE, CF and CA contents of the excreta as well as those of feed were determined according to AOAC (2004).

European Production Efficiency Index (EPEI) was calculated using Hubbard Broiler Management Guide (1999) equation as follows:

$$EPEI = \frac{BW\,(kg) \times SR}{PP \times FCR} \times 100 \qquad (1)$$

where BW is the body weight in kg, SR is the survival rate, PP is the production period in days and FCR is the feed conversion rate.

Economical evaluation for all experimental diets was made as described by Attia *et al.* (2014).

Statistical analyses

Statistical analysis was carried out using the GLM procedure of Statistical Analysis Software 2002 (SAS Institute Inc., Cary, NC, USA) using a two-way factorial design (4 types of feed with 3 different enzyme treatments); the experimental model also included the interaction between the main factors. All percentages were transformed to their corresponding arcsin value before run the analyses. Mean difference at $P \le 0.05$ was tested using Student-Newman-Keuls-test. Survival rate was analysed as percent using chi-square analyses.

Results

Body weight gain

The effects on growth of broilers because of diet and/or enzyme supplementation are shown in Table 2. Body weight gain in broilers fed pellet diets was higher ($P<0.01$) from 21-29 and 21-37 days than that of those fed mash diet. However, there were no significant differences in BWG during 21 to 29 d of age among groups fed different diameter of pellets. Broilers fed 2-3 mm pellet diameter had a significantly higher BWG during d 30 to 37 and 21 to 37 d of age than those fed mash or 2-2 mm and 3-3.5 mm pellet diets.

Table 2
Effects of feed form and phytase with or without multi-enzyme supplementation on body weight gain of broilers during 21-37 d of age

Treatment	Body weight gain, g		
	21-29 d	30-37 d	21-37 d
Feed form:			
Mash	592^{b}	535^{c}	$1\,120^{d}$
Pellet 2-2 mm	639^{a}	542^{c}	$1\,192^{c}$
Pellet 2-3 mm	642^{a}	629^{a}	$1\,279^{a}$
Pellet 3-3.5 mm	649^{a}	577^{b}	$1\,233^{b}$
Enzymes supplementation			
Control	612^{b}	507^{c}	$1\,127^{c}$
Phytase	638^{a}	582^{b}	$1\,221^{b}$
Multi-enzyme+phytase	642^{a}	620^{a}	$1\,270^{a}$
SEM	9.44	14.38	19.42
P-Value			
Feed form	0.0001	0.0001	0.0001
Enzymes supplementation	0.0001	0.0001	0.0001
Feed form × Enzymes suppl.	ns	0.003	ns

[a,b,c]Means in the same column followed by different letters are significantly different at ($P \le 0.05$), ns: not significant

Control group resulted in significantly lower BWG in the period 21-29, 30-37 and 21-37 d of age, while multi-enzyme+phytase supplementation resulted in a significantly higher BWG in the period 30-37 and 21-37 d of age than the phytase group.

A significant interaction between diet form and enzyme supplementation was shown only on BWG during 30-37 d of age. In broilers fed mash diets the BWG did not change when phytase or multi-enzyme+phytase were supplemented while with pellet diets BWG increased ($P<0.01$) when multi-enzyme+phytase (2-2 mm diets) or both phytase and multi-enzyme+phytase (2-3 and 3-3.5 mm diets) were added.

Feed intake and feed conversion ratio

Data concerning feed intake (FI) and FCR of broilers affected by form of diet and/or enzyme supplementations are shown in Table 3. Feed intake was significantly decreased in broilers fed the pellet-feeds compared with those fed the mash feed during the experimental period. There was neither a significant effect of enzyme supplementation on FI during the tested periods, nor a significant interaction between form of diet and enzyme supplementation on FI during the tested periods.

Table 3
Effects of feed form and phytase with or without multi-enzyme supplementation on feed intake and feed conversion ratio of broilers during days 21-37 of age

Treatment	Feed intake, g/bird			Feed conversion ratio, g feed/g gain		
	21-29 d	30-37 d	21-37 d	21-29 d	30-37 d	21-37 d
Feed form:						
Mash	1 258[a]	1 181[a]	2 439[a]	2.13[a]	2.29[a]	2.21[a]
Pellet 2-2 mm	1 179[b]	1 054[b]	2 232[b]	1.85[b]	1.95[b]	1.88[b]
Pellet 2-3 mm	1 166[b]	1 045[b]	2 211[b]	1.82[b]	1.68[d]	1.74[c]
Pellet 3-3.5 mm	1 175[b]	1 025[b]	2 199[b]	1.81[b]	1.81[c]	1.79[c]
Enzymes supplementation						
Control	1 199	1 093	2 292	1.96[a]	2.18[a]	2.04[a]
Phytase	1 197	1 081	2 278	1.88[b]	1.89[b]	1.89[b]
Multi-enzyme+phytase	1 187	1 053	2 240	1.86[b]	1.73[c]	1.78[c]
SEM	22.3	28.7	48.6	0.044	0.07	0.049
P-Value						
Feed form	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Enzymes supplementation	ns	ns	ns	0.004	0.0001	0.0001
Feed form × Enzymes suppl.	ns	ns	ns	ns	0.05	ns

[a,b,c]Means in the same column followed by different letters are significantly different at ($P\leq0.05$), ns: not significant

Feed conversion ratio was significantly lower in broilers fed pellet diets than that of those fed mash diet and in the period 30-37 d of age birds fed 2-3 mm diets had the lowest FCR. During days 21 to 37 broilers fed 2-3 mm and 3-3.5 mm pellet diets had significantly lower FCR than those fed mash or 2-2 mm diets.

Both phytase and multi-enzyme+phytase significantly improved FCR compared to the unsupplemented control from day 21 of age. However, FCR of broilers fed multi-enzyme plus phytase diet was significantly lower than that of those fed phytase alone during 30-37 and 21-37 d of age.

A significant interaction between form of diet and enzyme supplementations was shown for FCR during only 30-37 d of age with a different trend among the type of diets. In broilers fed mash diets FCR was similarly improved (*P*=0.05) due to the supplementation of phytase or multi-enzyme+phytase; with 2-2 mm pellet diets, only multi-enzyme+phytase was able to improve FCR in comparison to the control group; broilers fed 3-3.5 mm pellet diets had better FCR when both phytase and multi-enzyme+phytase were administered and no differences were observed between the FCR obtained with the two types of enzymes; just with 2-3 mm pellet diets there is a progressive improvement of FCR from control, phytase and multi-enzyme+phytase groups.

Apparent digestibility of nutrients

Data concerning the effects of the diet form and enzyme supplementation on apparent digestibility of nutrients of broilers are shown in Table 4.

Pellet diets resulted in a significantly higher CP, EE, CF and CA digestibility than mash diet, but did not affect DM digestibility. However, there were no significant differences on the apparent nutrient digestibility among groups fed different pellet diameters.

Groups fed diets supplemented with either phytase or multi-enzyme plus phytase showed significantly and similarly greater CP, EE and CA digestibility than the control group. There was no significant interaction between feed form and enzyme supplementation in the apparent digestibility of nutrients.

Table 4
Effects of feed form and phytase with or without multi-enzyme supplementation on apparent nutrient digestibility of nutrients of broilers during days 21-37 of age

Treatment	Apparent digestibility, %				Apparent Ash retention, %
	Dry matter	Crude protein	Ether extract	Crude fibre	
Feed form:					
Mash	75.0	61.3[b]	70.2[b]	12.1[b]	33.2[b]
Pellet 2-2 mm	75.7	70.7[a]	85.8[a]	16.3[a]	38.4[a]
Pellet 2-3 mm	74.6	71.9[a]	84.3[a]	16.0[a]	38.0[a]
Pellet 3-3.5 mm	74.4	72.1[a]	84.3[a]	16.2[a]	38.2[a]
Enzymes supplementation					
Control	75.7	65.9[b]	77.9[b]	13.4	33.3[b]
Phytase	74.8	69.7[a]	81.5[a]	15.8	38.5[a]
Multi-enzyme+phytase	74.3	71.4[a]	84.1[a]	16.3	39.1[a]
SEM	1.5	2.46	1.97	1.93	1.56
P-Value					
Feed form	ns	0.0001	0.0001	0.0259	0.0003
Enzymes supplementation	ns	0.0076	0.0002	ns	0.0001
Feed form × Enzymes suppl.	ns	ns	ns	ns	ns

[a,b,c]Means in the same column followed by different letters are significantly different at ($P \leq 0.05$), ns: not significant

Survival rate, production index and economic efficiency

During the trial, no deaths were observed. The data concerning production index and economic efficiency are presented in Table 5. The production index was the highest in broilers fed 2-3 mm pellet diets, followed by 3-3.5 mm, 2-2 mm pellet and mash diets. The economic efficiency was higher ($P<0.01$) in 2-3 than 2-2 mm and mash diets while no differences were observed between 2-3 and 3-3.5 mm diets; however mash diets had the lowest economic efficiency. Either phytase alone or multi-enzyme+phytase showed a significantly higher production index and economic efficiency than the control group. However, broilers fed multi-enzyme plus phytase had a significantly higher production index and an economic efficiency than those supplemented with phytase alone. There was no significant interaction between feed form and enzyme supplementation on production index and economic efficiency.

Table 5
Effects of feed form and phytase with or without multi-enzyme supplementation on production index and economic efficiency of broilers during 21-37 d of age

Treatment	Production index	Economic efficiency, %
Feed form		
Mash	235^{d}	45.9^{c}
Pellet 2-2 mm	303^{c}	65.7^{b}
Pellet 2-3 mm	343^{a}	74.7^{a}
Pellet 3-3.5 mm	323^{b}	70.2^{ab}
Enzymes supplementation		
Control	264^{c}	54.8^{c}
Phytase	306^{b}	65.5^{b}
Multi-enzyme+phytase	333^{a}	72.1^{a}
SEM	11.8	2.86
P-Value		
Feed form	0.0002	0.0001
Enzymes supplementation	0.0003	0.0001
Feed form × Enzymes suppl.	ns	ns

[a,b,c]Means in the same column followed by different letters are significantly different at ($P\leq0.05$), ns: not significant

Discussion

Feeding pellet diets with 2-2, 2-3 and 3-3.5 mm diameter increased BWG (6.4, 14.2 and 10.1 %, respectively), decreased feed intake (8.5, 9.3 and 9.8 %) and then improved FCR (14.9, 21.3 and 19.0 %) compared to broilers fed mash diets. This coincided with a higher digestibility of CP (15.3, 17.3 and 17.6 %), EE (22.2, 20.1 and 20.1 %), CF (34.7, 32.2 and 33.9 %) and CA (15.7, 14.4 and 15.1 %) and resulted in a greater production index (28.9, 46.0 and 37.4 %) and economic efficiency (43.1, 62.6 and 52.9 %). These results are similar to those reported by Cerrate *et al.* (2009), Sundu *et al.* (2009), Tufarelli *et al.* (2011) and Corzo *et al.* (2012). These improvements have variously attributed to the size of pellet, whose particles with a dimension suitable for the oral cavity of the bird, allowed a reduction in the energy for eating and consequently a greater net energy (NE) value (Tufarelli *et al.* 2007, Latshaw 2008, Cerrate *et al.* 2008, 2009, Dozier *et al.* 2010). In addition, in many studies it was observed that pellet diets improve FCR compared to mash feed. These improvements have been associated with greater digestibility of nutrients and less feed wastage and microbial load (Kilburn & Edwards 2001, Engberg *et al.* 2002, Maiorka *et al.* 2005, Salari *et al.* 2006, Amerah *et al.* 2007, Attia *et al.* 2012). The nutritive value of pellet diets may be improved as a result of increasing starch gelatinization in the pellet process (Heffner & Pfost 1973, Moritz *et al.* 2005).

Phytase and multi-enzyme plus phytase supplementation increased BWG (8.3 and 12.7 %), decreased feed intake (0.6 and 2.3 %) and improved FCR (7.4 and 12.7 %) compared to broilers fed diet without enzyme supplementation. The positive effect of enzymes on growth performance of broilers was observed along with increasing nutrient digestibility of CP (5.8 and 8.3 %), EE (4.6 and 8.0 %) and CA (15.6 and 17.4 %); production index (15.9 and 26.1 %) and economic efficiency (19.6 and 31.5 %). These results are in agreement with those reported by Douglas *et al.* (2000), Persia *et al.* (2002) and Attia *et al.* (2003a, b, 2008). Multi-enzyme containing amylase, xylanase and protease was found to improve energy utilization in corn-soybean meal and sorghum-soybean meal diets due to the breakdown of starch, cereal cell walls and endogenous proteins (Hong *et al.* 2002, Attia *et al.* 2003a, El-Ghamry *et al.* 2005, Attia *et al.* 2008).

The improvements due to phytase supplementation could have attributed to the capability of phytate to form complexes with proteins and inorganic mineral such as calcium, magnesium, iron and zinc. Thus phytase not only releases the bound phosphorus but also the other essential nutrients which led to higher nutritional value of the diet (Keshavarz 2003, Ceylan *et al.* 2003, Panda *et al.* 2005).

The greater effect of both enzymes when added together indicated a synergetic effect and this is in agreement with the results of Cowieson *et al.* (2006) and Yang *et al.* (2010). The use of an enzyme complex containing carbohydrases and phytase can improve the utilization of phytate P, energy, protein, and Ca concentrations. However, the results reported by Attia *et al.* (2003a and 2008) indicated that phytase or multi-enzyme alone may be adequate. The response to enzyme supplementations may be affected by type of diet, age of birds and enzyme profiles (Zanella *et al.* 1999, Attia 2003, Attia *et al.* 2003a, b, 2006, 2008).

The form of feed and/or two enzymes had no significant effect on survival rate; this is similar to reports by Deaton (1992) and Dozier *et al.* (2010). Also Cerrate *et al.* (2009) and Tufarelli *et al.* (2011) reported that the physical form of diet had no influence on the health status of poultry.

The beneficial effects of pellet feed and/or enzyme supplementation on production index and economic efficiency are in line with those reported by Jahan *et al.* (2006). Also Fairfield (2003) noticed that pelleting of feed provides opportunities to reduce feed formula costs.

However, the lack of significant interaction between feed form and enzyme supplementations on performance and nutrient digestibility for the whole period indicated that the effects of multi-enzyme plus phytase or phytase alone supplemented to mash or pellet diets are independent of feed type.

In conclusion, phytase and multi-enzyme plus phytase supplementation resulted in an improved performance of broilers fed mash or pellet diet. However, broilers fed 2-3 mm pellet diet supplemented with multi-enzyme plus phytase resulted in the greatest productive performance, production index and economic efficiency during days 21-37 of age.

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