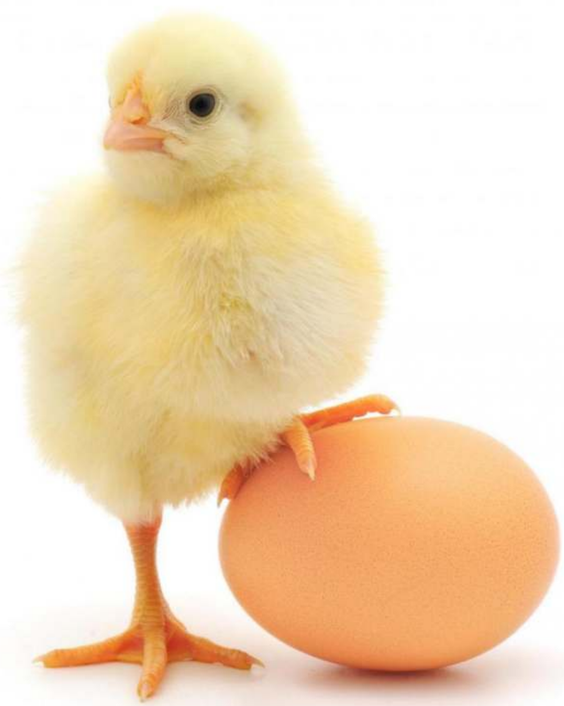
ISSN 1682-8356
ansinet.org/ijps



INTERNATIONAL JOURNAL OF POULTRY SCIENCE

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E-mail: editorijps@gmail.com

OPEN ACCESS International Journal of Poultry Science

ISSN 1682-8356
DOI: 10.3923/ijps.2019.181.186

Research Article
Effects of Different Phase-Feeding Programs with Different Feed Forms on Broiler Growth Performance, Carcass Traits and Intestinal Morphology

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Abstract
Background and Objective: Modern commercial broiler strains were developed to exhibit rapid growth. Therefore, phase-feeding programs with appropriate feed forms must be developed for these strains. This study aimed to investigate the effects of different phase-feeding programs with different feed forms on broiler performance. **Materials and Methods:** The experiment was conducted using a completely randomized block design. Eight hundred eighty male and female broilers (Ross308) were fed crumble or pellet diets in different phase-feeding programs: starter, grower, or finisher. The four dietary treatments (10 replicates per treatment) were as follows: Treatment 1 (control): crumble starter (CS), pellet grower (PG), or pellet finisher (PF) at 1-17, 18-33 and 34-37 days of age; Treatment 2: CS, PG and PF at 1-14, 15-33 and 34-37 days of age; Treatment 3: CS, PG and PF at 1-10, 11-33 and 34-37 days of age; and Treatment 4: CS, PG and PF at 1-7, 8-33 and 34-37 days of age, respectively. **Results:** No significant differences in body weight gain, feed consumption, feed conversion ratio, or mortality were observed ($p>0.05$) among the dietary treatments during the starter and overall periods. In addition, the different phase-feeding programs with different feed forms did not affect ($p>0.05$) carcass traits at 37 days of age. Similar results were observed for intestinal morphologies among the treatments at 33 days of age. **Conclusion:** Under the study conditions, changing the feed form from crumble to pellets at 8 days of age did not detrimentally affect broiler performance, carcass traits or intestinal morphology.

Key words: Broiler, carcass traits, feed forms, growth performance, phase-feeding programs,

Received: December 04, 2018 Accepted: February 11, 2019 Published: March 15, 2019

Citation: N. Saveewonlop, S. Rattanatabtimtong, Y. Ruangpanit, O. Songserm and S. Attamangkune, 2019. Effects of different phase-feeding programs with different feed forms on broiler growth performance, carcass traits and intestinal morphology. Int. J. Poult. Sci., 18: 181-186.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Feed constitutes approximately 60-70% of total broiler production costs[1]. Therefore, efficient feed use is extremely important in broiler production. Commercial feed producers are currently producing different forms of broiler feed for different aged broilers. The various physical forms of the feed (mash, pellets or crumbles) are important factors that directly influence feed costs and broiler production performance[2]. Each form has advantages and disadvantages and the effectiveness, digestibility and conversion efficiency of these forms vary.

Mash is a form of complete feed that is finely ground and mixed so that birds cannot easily separate out the ingredients. Pellets are a modification of the mash system and consist of mechanically pressing the mash into hard, dry pellets or artificial grains. Pellets are a form of complete feed that is compacted and extruded to approximately a 1/8-inch diameter and a 1/4-inch length[1]. Pelleted diets can affect animal performance in various ways. A previous study indicated that pellets have benefits that may contribute to improved performance, including decreased feed wastage, reduced selective feeding, decreased ingredient segregation, less time and energy expended for prehension, destruction of pathogenic organisms, thermal modification of starch and protein and improved palatability[3]. Crumbles are another feed type prepared by pelleting the mixed ingredients, then crushing the pellets to a consistency coarser than mash[2]. Choi *et al.*[4] reported that chicks fed a crumble starter diet consumed more feed. Similarly, Bolton and Blair[5] reported that the feed intake of broilers fed crumbles or pellets could increase by 10 percent compared with those fed mash.

Diets fed to broilers for the first few weeks after hatching are typically either mash or, more frequently, crumbled large pellets (crumbles)[4]. Few studies have focused on crumble quality and size and their effects on post-hatch chicken performance. One study investigated diets with different crumble sizes as coarse crumbles (4.0 mm), medium crumbles (-4.0 to +1.5 mm), or fine crumbles (-1.5 mm) on growth performance in broiler chickens at 0-3 weeks[6]. The results showed no significant differences in body weight gain between the coarse and medium-sized crumbles, although both the coarse and medium crumbles outperformed the fine crumbles on body weight and feed efficiency. Thus, crumble size can dramatically influence performance. Furthermore, the study suggested that feeding small intact pellets during the initial feeding period enhanced early growth rates and subsequent performance[7]. However, under the conditions of broiler farming, studies have revealed wide differences in phase-feeding programs using different feed forms during the starter period.

In recent years, commercial broiler producers have changed the recommended times for ending the starter diet from 21-23 to 10-17 days[8-13]. This change arose from the development of faster-growing strains. Modern broiler commercial strains grow more rapidly now than in the past because of ongoing broiler strain development. Genetic improvements are placing constant pressure on feed manufacturers to produce quality feeds that meet the requirements of these improved breeds and this pressure has also impacted the physical form of the feed, which is important to the broilers' productive performance and feed costs[8-13]. Consequently, feeding pellets to broilers as early as possible might be an appropriate means of enhancing growth performance and minimizing feed production costs. Therefore, the present study investigated the effects of different phase-feeding programs using different feed forms on growth performance, carcass traits and intestinal morphology in broiler chickens.

MATERIALS AND METHODS

Animals and management: The experimental protocol complied with Kasetsart University Kamphaeng Saen Campus's guidelines for animal care and use. Eight hundred eighty 1-day old broilers (Ross308) were obtained from a commercial hatchery. At the hatchery, the broilers were vaccinated for Gumboro's disease, New Castle disease and infectious bronchitis. The experimental house was properly washed and cleaned using tap water. The ceiling, walls and floor were also thoroughly cleaned and disinfected. The birds were raised in an evaporative cooling system house. Throughout the experiment, lighting was available 24 h day^{-1} and the room temperature was kept similar to that used in commercial broiler production. The birds were offered feed and drinking water *ad libitum* during the experimental period.

Experimental design and diet: The birds were allocated to a completely randomized block design with four treatments. Each treatment consisted of 10 replicates (5 replicates with males and 5 with females) with 22 birds each. The broilers were fed using 3 phase-feeding programs during the 37-day raising period. The starter and grower diets were formulated with the same nutrient specifications to measure the effect of the different phase-feeding programs with different feed

Table 1: Ingredients and chemical compositions of the experimental diets

Ingredients (%)	Starter and grower diets (1-17 and 18-33 days of age)	Finisher diet (35-37 days of age)
Corn	35.68	37.75
Soybean meal 50%	22.68	8.87
Tapioca chip	7.00	10.00
Meat and bone meal 50%	7.00	8.00
Distillers dried grains and solubles	8.00	8.00
Rape seed meal	2.00	4.00
Rice bran	10.00	10.00
Extracted rice bran	2.32	8.00
Rice bran oil	1.40	2.25
Lysine byproduct	1.50	1.50
L-lysine	0.14	0.30
DL-methionine	0.11	0.11
Threonine		0.05
Monodical P21	0.39	
$CaCO_3$	0.57	0.27
Salt	0.21	0.22
Premix and feed additives	1.00	0.68
Chemical composition (analyzed)		
Metabolizable energy (kcal kg^{-1})	3,100.00	3,204.94
Crude protein (%)	22.00	18.00
Calcium (%)	1.00	0.90
Phosphorus (%)	0.50	0.47

forms. Table 1 lists the feed ingredients and chemical compositions of the experimental diets. The diets were manufactured at a local feed mill.

The chicks were fed either crumbled or pelleted diets in the different feeding program phases (starter diameter before crumble: 3 mm, grower diameter: 3.5 mm and finisher diameter: 4 mm). The four experimental treatments were Treatment 1 (control): crumble starter (CS), pellet grower (PG) and pellet finisher (PF) at 1-17, 18-33 and 34-37 days of age; Treatment 2: CS, PG and PF at 1-14, 15-33 and 34-37 days of age; Treatment 3: CS, PG and PF at 1-10, 11-33 and 34-37 days of age and Treatment 4: CS, PG and PF at 1-7, 8-33 and 34-37 days of age, respectively. The control group's feeding phase was conducted based on commercial feeding program recommendations. All diets were analyzed for gross energy (GE), crude protein, calcium and phosphorus per the Association of Official Agricultural Chemists (AOAC[14]) methods.

Growth performance and carcass traits: Each replicate's body weight and feed consumption were measured at 1, 7, 10, 14, 17 and 37 days of age. Body weight gain, feed consumption and feed conversion ratio (FCR) were calculated periodically for each treatment. The number of dead birds was recorded daily for mortality rate calculations. At 37 days of age, all birds were fasted overnight (8 h) and three birds from each replicate were randomly selected and euthanized with CO_2. Each bird was slaughtered, chilled and cut into retail parts. The carcass traits were defined based on the chilled carcass and expressed as a percentage of the live weight.

Intestinal morphology: At 33 days of age, three birds per replicate were randomly selected, fasted overnight (8 h) and euthanized with CO_2. Intestinal samples were taken from the middle of each of the small intestinal segments (duodenum and jejunum) for histological measurements. The intestinal segment samples were excised (approximately 0.5 cm long), opened longitudinally at the antimesenteric attachment and gently flushed with NaCl (9 g L^{-1}). The samples were then fixed in buffered formalin (90 mL L^{-1}) at 4°C for 12-24 h until analysis per the methods of De Verdal *et al*.[15] Microscopic observation of the histological sections was randomized and the heights and widths of 10 villi and the depths of 10 crypts were assessed for each sample.

Statistical analysis: Analysis of variance was conducted on all data using a general linear model (GLM). Variables determined to be significant via the F-test were compared using Duncan's new multiple range test. The treatment effect was assessed using a t-test at 5% probability.

RESULTS

Growth performance: Table 2 shows the effects of the different phase-feeding programs with different feed forms on broiler performance for the entire period (1-37 days of age). The results revealed no significant differences in body weight gain, feed consumption, FCR, or mortality among birds fed the different phase-feeding programs with different feed forms ($p>0.05$). Table 3 shows the effects of the different phases on broiler growth performance for the starter period (1-17 days

Table 2: Growth performance of broilers fed different phase-feeding programs and feed forms until 37 days of age

	Treatment group				
Parameter**	CS 1-17, PG 18-33, PF 34-37*	CS 1-14, PG 15-33, PF 34-37*	CS 1-10, PG 11-33, PF 34-37*	CS 1-7, PG 8-33, PF 34-37*	p-value
FC (g bird^{-1})	3979.89	4046.23	4021.05	3888.26	0.1175
BWG (g bird^{-1})	2377.17	2440.49	2405.91	2389.41	0.4300
FCR	1.68	1.66	1.67	1.63	0.4409
Mortality (%)	1.82	1.36	1.82	0.45	0.4522

p<0.05. *CS: Crumble starter, PG: Pellet grower and PF: Pellet finisher (Feed forms were crumble or pellet diets. Phase-feeding programs were starter, grower and finisher). **FC: Feed consumption, BWG: Body weight gain, FCR: Feed conversion ratio

Table 3: Growth performance of broilers fed starter diets at 1-17 days of age (broiler commercial industry period) in each treatment

	Treatment group				
Parameter**	CS 1-17, PG 18-33, PF 34-37*	CS 1-14, PG 15-33, PF 34-37*	CS 1-10, PG 11-33, PF 34-37*	CS 1-7, PG 8-33, PF 34-37*	p-value
FC (g bird^{-1})	954.26	974.48	986.33	963.43	0.3733
BWG (g bird^{-1})	567.53	571.87	566.86	572.44	0.7041
FCR	1.68	1.7	1.74	1.69	0.3629

p<0.05, *CS: Crumble starter, PG: Pellet grower and PF: Pellet finisher (Feed forms were crumble or pellet diets. Phase-feeding programs were starter, grower and finisher). **FC: Feed consumption, BWG: Body weight gain, FCR: Feed conversion ratio

Table 4: Growth performance of broilers fed starter diets at 1-7 days of age in each treatment

	Treatment group				
Parameter**	CS 1-17, PG 18-33, PF 34-37*	CS 1-14, PG 15-33, PF 34-37*	CS 1-10, PG 11-33, PF 34-37*	CS 1-7, PG 8-33, PF 34-37*	p-value
FC (g bird^{-1})	126.22	126.39	124.93	124.07	0.4919
BWG (g bird^{-1})	105.40	107.20	108.66	106.44	0.3512
FCR	1.20	1.18	1.15	1.17	0.1528

p<0.05. *CS: Crumble starter, PG: Pellet grower and PF: Pellet finisher (Feed forms were crumble or pellet diets. Phase-feeding programs were starter, grower and finisher). **FC: Feed consumption, BWG: Body weight gain, FCR: Feed conversion ratio

Table 5: Growth performance of broilers fed starter diets at 1-10 days of age in each treatment

	Treatment group				
Parameter**	CS 1-17, PG 18-33, PF 34-37*	CS 1-14, PG 15-33, PF 34-37*	CS 1-10, PG 11-33, PF 34-37*	CS 1-7, PG 8-33, PF 34-37*	p-value
FC (g bird^{-1})	253.56	253.86	250.96	249.02	0.2029
BWG (g bird^{-1})	201.20	205.60	202.30	202.68	0.3732
FCR	1.26	1.24	1.24	1.23	0.3344

p<0.05. *CS: Crumble starter, PG: Pellet grower and PF: Pellet finisher (Feed forms were crumble or pellet diets. Phase-feeding programs were starter, grower and finisher). **FC: Feed consumption, BWG: Body weight gain, FCR: Feed conversion ratio

of age). No significant effects on body weight gain, feed consumption, or feed conversion ratio were observed among treatments (p>0.05). Table 3-6 show the effects of the different phase-feeding programs with different feed forms on broiler performance for the treatment periods (1-14, 1-10 and 1-7 days of age). The results revealed no significant differences in body weight gain, feed consumption or FCR for any treatment period (p>0.05).

Carcass traits: Table 7 shows the effects of the different phase-feeding programs with different feed forms on carcass traits. No significant differences were found in the carcass percentage, percentage of edible internal organs (liver, gizzard and heart) or percentage of cut parts (neck and head, breast, thigh, drum, wing, shank and leg, abdominal fat and skeleton) among treatments (p>0.05).

Intestinal morphology: The epithelial morphology parameters (villus height, crypt depth and villus width) at 37 days of age did not significantly differ between dietary treatments (p>0.05, Table 8).

Table 6: Growth performance of broilers fed starter diets at 1-14 days of age in each treatment

	Treatment group				
Parameter**	CS 1-17, PG 18-33, PF 34-37*	CS 1-14, PG 15-33, PF 34-37*	CS 1-10, PG 11-33, PF 34-37*	CS 1-7, PG 8-33, PF 34-37*	p-value
FC (g bird^{-1})	500.56	500.28	500.583	503.36	0.9300
BWG (g bird^{-1})	384.25	385.86	378.12	381.94	0.2936
FCR	1.30	1.30	1.32	1.32	0.2738

p<0.05. *CS: Crumble starter, PG: Pellet grower and PF: Pellet finisher (Feed forms were crumble or pellet diets. Phase-feeding programs were starter, grower and finisher). **FC: Feed consumption, BWG: Body weight gain, FCR: Feed conversion ratio

Table 7: Broiler carcass value index for each treatment (37 days of age)

	Treatment group				
Carcass values index**	CS 1-17, PG 18-33, PF 34-37*	CS 1-14, PG 15-33, PF 34-37*	CS 1-10, PG 11-33, PF 34-37*	CS 1-7, PG 8-33, PF 34-37*	p-value
CCW**	83.67	83.72	83.86	83.93	0.9610
LGH**	4.43	4.55	4.34	4.43	0.5034
NHW**	5.90	5.57	6.00	6.14	0.3416
BRW**	23.56	22.63	24.31	24.36	0.4433
TW**	13.32	12.90	13.33	13.31	0.9341
DSW**	9.86	9.58	10.09	9.94	0.8588
WW**	7.12	6.88	7.30	7.30	0.7034
SLW**	3.30	3.06	3.39	3.23	0.6832
ABFW**	1.28	1.02	1.19	1.17	0.1941
SLW**	17.00	16.14	16.95	17.33	0.7026

p<0.05. *CS: Crumble starter, PG: Pellet grower and PF: Pellet finisher (Feed forms were crumble or pellet diets. Phase-feeding programs were starter, grower and finisher). **CCW: Carcass weight, LGH: Liver gizzard heart, NHW: Neck and head weight, BRW: Breast weight, TW: Thigh weight, DSW: Drum stick weight, WW: Wing weight, SLW: Shank and leg weight, ABFW: Abdominal fat weight and SLW: Skeleton weight

Table 8: Effects of different phase-feeding programs and feed forms on broilers' gut morphology at 37 days of age (overall period) in each treatment

	Treatment group				
Parameters	CS 1-17, PG 18-33, PF 34-37*	CS 1-14, PG 15-33, PF 34-37*	CS 1-10, PG 11-33, PF 34-37*	CS 1-7, PG 8-33, PF 34-37*	p-value
Proximal villi (Duodenum)					
Villus height (μm)	1398.94	1447.56	1400.37	1422.67	0.1406
Crypt depth (μm)	190.25	193.07	194.08	190.64	0.0691
Villus width (μm)	189.10	196.58	195.99	189.10	0.1000
Middle villi (Jejunum)					
Villus height (μm)	1265.37	1253.04	1245.8	1265.05	0.2028
Crypt depth (μm)	229.43	232.85	233.64	240.60	0.1503
Villus width (μm)	190.59	194.30	191.5	191.50	0.7761

p<0.05. *CS: Crumble starter, PG: Pellet grower and PF: Pellet finisher (Feed forms were crumble or pellet diets. Phase-feeding programs were starter, grower and finisher)

DISCUSSION

The results of this study showed that broilers fed the pellet diet at 7, 10, 14 and 17 days of age did not significantly differ in growth performance, carcass traits, or intestinal morphology, suggesting that modern broiler strains can be fed crumble diets until 7 days of age and then changed to pelleted feed without adverse effects. These results were consistent with those of Serrano *et al.*[16], who reported that birds fed crumbles and pellets from 1-21 days of age had similar weight gains (p>0.05), while birds fed pellets had better FCR (p<0.001) than those fed crumbles and both weight gain and FCR were better than in birds fed mash. Similarly, Chehraghi *et al.*[17] compared the effect of feed forms (mash, crumble and pellet) on broiler growth performance. The results showed that weight gain, feed intake and FCR differed significantly between birds fed mash, crumble, or pellets (p<0.05), while crumble and pellets yielded similar results.

Feed in the form that is most appropriate to the broiler's age and breed could provide the best growth performance and minimize both the feed costs and total costs of broiler production. Jahan *et al.*[2] showed that statistically similar high profits were obtained from broilers fed pellets and crumble. Furthermore, Pestana[18] reported that a pelleted feed decreased meat production costs. These results confirmed the advantage of using appropriate phase-feeding programs and feed forms in broiler strains to optimize broiler production.

CONCLUSION

Modern broilers respond quickly to changes in feed-form patterns. In addition, broilers can receive pelleted feed at 8 days of age without negative effects on growth performance, carcass traits, or intestinal morphology.

SIGNIFICANCE STATEMENT

This study demonstrated that phase-feeding programs with different feed forms have changed for modern broilers. The broilers respond to pelleted feed faster during the starter period and they exhibit good performance that is consistent with other strains. The results of this study can help researchers and producers establish phase-feeding programs with feed-form management practices for modern broiler production farms that allow convenient, appropriate handling and that optimize feed costs.

ACKNOWLEDGMENTS

This research was supported by the Kasetsart University Scholarship for Doctoral Students, Kasetsart University.

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