Original Article

Optimum Levels of Crude Protein and Metabolizable Energy in Diet as well as Sexual Effect on Performance and Carcass of Thai Native Crossbred Chicken (Pradu Hang Dam × Hubbard JA 57 Ki) During 1–13 Weeks of Age

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Abstract

This study aimed to determine the optimum dietary levels of CP, ME and sexual effect on performance of Pradu Hang Dam x Hubbard JA 57 Ki. The experiment had 3 phases, i.e. 1–5, 6–10 and 11–13 weeks of birds' age, using 1,440 one-day old chicks with equal number of male and female in separate pens. Each sex was randomly allotted to 6 groups of 3 replicates, containing 40 birds/rep. The diets for the 3 phases contained 21, 19, 17 vs 19, 17, 15% CP, respectively. Each CP level contained 3 ME levels (3.2, 2.9 and 2.6 kcal/g) according to a 2×3 Factorial in Randomized Complete Block design, having sex as a block. The result showed that high CP diets gave higher BWG, lower FI, better FCR, FCG, with higher percentage of carcass and drumstick (P<0.05). Higher ME diets (3.2 and 2.9 kcal ME/g) gave significantly higher BWG, lower FI, better FCR, FCG, higher percentage of carcass, drumstick and abdominal fat than the 2.6 kcal ME/g diet ($P<0.05$). Male had significantly higher BWG and FI than female. The optimum rations for this crossbred during the 3 phases were 21, 19 and 17% CP respectively with 3.2 kcal ME/g.

Key words: crossbred native chicken, growth performance, metabolizable energy, protein, sex

1. Introduction

Chicken meat especially from Thai native breeds has increased in popularity due to its tight texture and better flavor than commercial breeds (Leotaragul *et al*., 2009), thus gains highly demand from consumers in Thailand as well as in Asian countries (Tang *et al*., 2009). In addition, it is one of the most important protein sources for villagers particularly those live in rural area due to its high tolerance in rather harsh environment.

According to Agricultural Statistics of Thailand (2020), native chicken production in Thailand in the year 2010 was 70.806 million heads. It has been increased to 74.968 million heads in 2019 and was forecasted to be 82.132 million heads in 2020. The price of live native and crossbred native chicken was twice higher than the commercial broilers i.e. 2.4 and 2.24 vs 1.12 $US/kg live weight (personal survey at Chiang Mai local fresh market). These increase in production number and higher price as compare to broilers are the good indicators for the popularity of native and crossbred native chicken.

Pradu Hang Dam chicken is one of the Thai native breeds, being considered as a fighting cock. Its meat, like most of the native chicken, is healthier than broiler meat due to the lower fat, cholesterol and triglyceride content (Phianmongkhol, Wirjantoro, Chailungka, Prathum, & Leotaragul, 2012). However, raising native chickens has a big disadvantage because it requires a longer raising time due to the slow growing rate. Therefore, the attempts have been made to improve their genetic potential by crossbreeding with exotic breeds, such as Hubbard, which is one of the high-performance broiler breeds. The strain JA 57 Ki of Hubbard is a recessive female which allows its offspring to possess the male's phenotype (Hubbard Premium, 2020). The female of this strain achieves a body weight of 1.8–2.0 kg, while the male can reach 2.5–2.8 kg within 100 days (Hubbard, 2019). In many Asian countries this crossbred strain gain popularity at present, due to the high growth performance and good quality meat (Niyamcom, 2019). Although the breed has been improved, it is very necessary to receive appropriated nutrition.

It is well recognized that protein and energy levels need to be concern in formulating the diet. Some information about the effect of crude protein (CP) and metabolizable energy (ME) on performance of native chicken and crossbred native chicken have been reported. Tangtaweewipat, Cheva-Isarakul, & Pingmuang (2000) studied the optimum levels of major nutrients in 3 crossbred line Thai native chickens (Pradu Hang Dam × Rhode Island red – Barred Plymouth Rock). They found that the use of higher CP diet (21–19–15% CP) during 1–5, 6–10 and 11–13 weeks of age (WOA) gave significantly higher body weight gain (BWG), feed intake (FI) and better feed conversion ratio (FCR) than the groups fed lower CP diets (19–17–13 and 17–15–11% CP) due to the higher CP intake. Feed cost/kg BWG (FCG) was the lowest in the male and female groups fed 17–15–11% CP with 2.6 kcal ME/g and 19–17–13% CP with 3.2 kcal ME/g diets, respectively. The optimum diets for this crossbred chicken during 1–5, 6–10 and 11–13 WOA should contain 21% CP, 2.9 kcal ME/g, 17% CP, 2.9 kcal ME/g and 15% CP, 2.6 kcal ME/g, respectively. Pingmuang, Tangtaweewipat, Cheva-Isarakul, & Tananchai (2001) reported that the proper CP and ME levels for Thai native crossbred chicks during 6–10 WOA for male were 17% CP with 2.9 kcal ME/g, while those for female were 17% CP, 2.6 kcal ME/g. Tananchai, Tangtaweewipat, & Cheva-Isarakul (2001) found that the proper CP and ME levels for Thai native crossbred chicks during 11–13 WOA for both sexes should be 15% CP, 2.6 kcal ME/g. However, the data on appropriate dietary CP and ME levels are not available for Pradu Hang Dam × Hubbard JA 57 Ki (PDHK), therefore it is necessary to investigate.

In addition the sex may also affect the growth performance of chicken in this breed as being reported by many researchers who have observed in other types or breeds of chicken. Benyi, Tshilate, Netshipale, & Mahlako (2015) reported that male broilers consumed more feed, utilized the feed more efficiently, gained more BW, and were heavier at all stages of growth (1–49 days of age) than females, but had a higher mortality rate. De Marchi, Cassandro, Lunardi, Baldan, & Siegel (2005) reported that males were consistently heavier than females for the whole live in the Padovana breed of chicken. Tangtaweewipat *et al.* (2000) and Thananchai et al. (2001) reported that male Thai native crossbred chicken gained higher BW, consumed more feed and had better FCR than female in all dietary groups. However no details of sexual effect on performance of PDHK, therefore it is interesting to observe.

The objectives of this study are to investigate the optimum dietary CP and ME levels as well as the sexual effect on production performances and carcass quality of PDHK Thai native crossbred chicken during growing period.

2. Materials and methods

2.1 Animals, housing and experimental design

All procedures used in this study were approved by the Animal and Aquatic Sciences' Graduate Committee of Chiang Mai University (CMU; Protocol No. CMU-Agri. 262/2563), Thailand and were performed in accordance with the guidelines for experimental animals of the CMU farm.

The experiment was conducted at CMU farm and laboratory, Thailand. PDHK crossbred native chicken of both sexes were used as experimental animals in a 2 × 3 Factorial in Randomized Complete Block Design (RCBD) with 2 major factors, i.e. 2 levels of CP and 3 levels of ME, while the sex of birds was considered as a block.

A total of 1,440 one-day old chicks with equal number of male and female were used. Each sex, which being kept in separated pens, was randomly allotted to 6 groups, each group had 3 replicates and each replicate contained 40 birds. The whole experimental period was divided into 3 phases: Starter (1 to 5 WOA), Grower (6 to 10 WOA) and Finisher (11 to 13 WOA). The chicks were fed with diets containing 21 vs 19% CP, 19 vs 17% CP and 17 vs 15% CP in these 3 periods, respectively. Each CP level of every period contained 3 different energy levels i.e. 3.2, 2.9 and 2.6 kcal ME/g. Least cost program, FeedLIVE 1.60, Live Informatics Co., Ltd., was used to formulate the diets in this experiment, in which suitable ingredients were selected. Feed ration and chemical composition of experimental diets are shown in Table 1.

All chicks were reared in an open house of 36 pens with 2 × 4 m area/pen for 40 birds, containing rice husk as a litter. Light, 60 watt- 2 bulbs as a brooder, was on continuously during the first 2 WOA. After that the light was provided only at night. The birds were raised and vaccinated for Marek's disease and other vaccines according to the guideline and vaccination program of the CMU farm. Feed and water were available *ad libitum* throughout the experiment.

2.2 Feed analysis, data record and statistical analysis

At day 1 of age and at the end of each period at day 35, 70 and 91 of age, all birds in each pen were weighed for the calculation of body weight gain (BWG). The left over feed were removed from all troughs and bins, while the new feed were weighed before offering. Feed of each period were sampled for Proximate Analysis (AOAC, 2005) in which DM, CP, EE, CF and ash were determined according to AOAC Official Method 934.01, 2001.11, 920.39, 962.09 and 942.05, respectively, while %NFE was calculated from %DM - %ash - %EE - %CP - %CF. The amount of feed offer through each period and feed left at the end of each period were recorded for the calculation of FI. Feed conversion ratio (FCR) was calculated from FI/BWG and feed cost per kg BWG (FCG) was calculated from feed intake × cost of feed (THB/kg)/BWG. Mortality and culling rates as well as abnormal symptoms were recorded immediately at the notice. The influences of sex on these parameters were also calculated.

2.3 Carcass composition and meat quality

At the end of the experiment, 2 birds from each sex in each replicate, i.e. 6 birds/group were randomly selected for slaughtering after 12 hours of starvation. The carcass quality (weight and percentage of carcass as well as percentage on hot carcass of breast, thigh, drumstick, wing, gizzard, and abdominal fat) were recorded. Meat quality (protein and fat percentage) in breast, thigh and drumstick was also investigated according to Proximate Analysis (AOAC, 2005).

2.4 Statistical analysis

All the data were subjected to statistical analysis according to the factorial arrangement in RCBD using a software program (SAS University Edition Software). Duncan's new multiple range test was performed when significant differences were found. Results are expressed as mean ± standard deviation (SD). Statistical significance was interpreted as values of $P<0.05$.

3. Results and discussion

3.1 Chemical composition of diets and growth performance

The analysis results of the diets are shown in Table 2. Crude protein (CP) and some other nutrient levels of all experimental diets are closed to the calculated values. Low ME diet contained higher crude fiber (CF) content, while high ME diets contained higher EE.

Growth performance of 1 day old PDHK up to 13 WOA is shown in Table 3. There was significant interaction between CP and ME levels on all parameters, with the exception of mortality and culling rate. Chicken fed higher CP diets (21–19–17% CP) throughout the experiment, averaged from 3 ME levels, had significantly higher BWG but lower FI (5.25 vs 5.75 kg/bird), thus gave better FCR (2.98 vs 3.38) and FCG (35.99 vs 39.98 THB/kg BWG, respectively) than the lower CP diets (19–17–15% CP). On the contrary, the effect of ME on BWG did not show a linear tend. The highest value was found in the group fed 2.9 kcal ME/g. Lower dietary ME, averaged from both CP level, caused significantly higher FI, FCR and FCG.

When the performance of each treatment was taken into consideration, it was found that BWG of the group fed high CP diet throughout the experiment with medium ME level (2.9 kcal/g) was the highest ($P<0.05$), while that fed low CP diet (19–17–15% CP) with the lowest energy level (2.6 kcal ME/g) was the lowest among the 6 groups. In addition, this low CP with the lowest ME group also had the highest FI ($P<0.05$) and the worst FCR.

Crude protein level had no significant influence on mortality rate but ME level seemed to have some influence on this parameter, i.e. significantly highest in the groups fed 3.2 kcal ME/g. However, when individual treatment was taken into consideration, there was no significant difference among groups. Neither CP nor ME level had significant difference on culling rate. In addition, no interaction between the 2 factors was found on this parameter.

Considering about feed cost per kg BWG (FCG), it was found that feeding high CP diet throughout the experiment, averaged from 3 ME levels, gave lower FCG than the lower CP diet. Feeding diets with 3.2 and 2.9 kcal ME/g, averaged from both CP levels, gave lower FCG than the diets containing 2.6 kcal ME/g. When individual treatment was taken into consideration, it was found that feeding the diet containing 21–19–17% CP with 3.2 kcal ME/g throughout the experiment gave the lowest FCG among the 6 groups. Therefore, the proper diet for PDHK during 1–13 WOA should contain 21–19–17% CP with 3.2 kcal ME/g (Table 3).

3.2 Crude protein and metabolizable energy intake

The CP and ME intake of all groups are shown in Table 4. There are significant interactions between the 2 dietary factors on both parameters. Decreasing dietary CP level caused significantly lower CP intake but higher ME intake (P<0.05). Decreasing ME caused higher CP intake (P<0.05). The highest ME intake was found in groups fed 2.9 kcal ME/g.

When each treatment was taken into consideration, it was found that the groups fed the lowest ME diet (2.6 kcal ME/g) with any CP level had significantly the highest CP intake but not significantly differed from the group fed 2.9 kcal ME/g with high CP. The groups fed 3.2 kcal ME/g with both CP levels had the lowest CP intake.

The better performance of the higher CP groups should be due to the higher CP intake as indicated in Table 4. The improvement should be due to the role of protein which is essential for life. Animals require protein for growth, reproduction and production such as egg and milk. In addition, protein has many functions, such as a component of cells, enzymes, immune antibodies and some hormones. It also provides energy even though lower and less efficiency than fat (Cheva-Isarakul, 2003). Therefore, the groups fed high CP had higher BWG even though their FI was lower, thus caused significantly better FCR than those fed low CP. The result agreed with Tangtaweewipat *et al.* (2000) who found that Thai native crossbred chicken (N × Redbro) fed higher CP diet during 1-13 WOA had significantly higher BWG, lower FI and better FCR than the groups fed lower CP diet. Similar result was found in Black-bone chicken by Phaitong (2017), even though no significant difference on FCR. The current result also agreed with Songsee, Tangtaweewipat, Cheva-Isarakul, & Tossapol (2020) who reported that Bresse capon fed high dietary CP (19%) promoted significantly better FBW, BWG, FCR, ADG, CP intake, than low CP diet (17%).

Dietary ME level also had significant effect on performances. Feeding lower ME diet (2.9 vs 3.2 kcal /g) caused significantly higher FI (P<0.05, Table 3). It corresponded to Mbajiorgu, Ng`ambi, & Norris (2011) who found that chicken consume feed to primarily meet their energy requirement. The result agreed with Phaitong (2017) and Tangtaweewipat *et al.* (2000). However in this experiment the further lowering ME to 2.6 kcal/g caused significant the lowest BWG even though they consumed significantly higher amount of feed, thus caused the worst FCR. In spite of the highest CP and medium ME intake of the chicks fed 2.6 kcal ME/g diets, these diets may not be efficiently digested due to the high CF content as indicated in Table 2 which was beyond the recommended level by many researchers. It is well recognized that CF level exceeding the maximum limit will reduce the digestibility. Hubbard Premium (2020) suggested that the optimum CF level for chicks during 1–8 WOA should be 2.5–3.5% and during 8–19 WOA should be 3.5-8.0%. Tangtaweewipat, Wongrueng, & Ya-thep (1996) reported that the optimum dietary CF level of replacement pullets should be 8% for grower, while 11% caused lower feed efficiency and BWG, although no adverse effect on performance of layers. Widjastuti, Abun, & Tanwiriah (2019) investigated the effect of dietary CF level in Sentul chicken during 2–12 WOA. They found that 6-8% CF gave optimum carcass weight, gizzard weight and the length of intestine. At 10–12% CF, carcass weight decreased while gizzard weight and the length of intestine increased. The maximum CF for this breed was 8%.

The result of growth performance in each feeding phase (1-5, 6-10 and 11-13 WOA) are shown in Table 5, 6 and 7, respectively. They are agreed with the whole experimental period.

3.3 Carcass composition

Carcass composition as a percentage of hot carcass is shown in Table 8. No significant interaction was found between CP and ME levels but these factors had significant effect on some parameters. Higher dietary CP significantly improved the percentage of carcass and drumstick. It might be due to the higher CP intake of the groups. The result agreed with Songsee *et al.* (2020) who reported that Bresse capon fed high dietary CP (19%) promoted significantly better percentage of carcass, breast, thighs, liver and drumsticks than the low CP diet (17%).

Decreasing dietary ME from 3.2 to 2.9 kcal ME/g did not show significant effect on carcass characteristics. The result is similar to Phaitong (2017) who found no significant difference on dressing percentage and carcass composition of Black Bone chicken at 16 weeks of age fed 3.2 vs 2.9 kcal ME/g diet. However, further decreasing to 2.6 kcal ME/g in the current study caused significant lower carcass percentage, drumstick and abdominal fat. In contrast, these groups gave significantly higher percentage of gizzard than the higher ME diets (Table 8). The heavier gizzard might be due to the increasing of necessary muscle for digesting more fiber in the low ME diet. Widjastuti *et al.* (2019) also found significant higher gizzard weight and intestinal length with lower carcass weight of native Indonesian chicken breed fed diets containing 10-12% compared to those fed 6-8% CF during 2–12 WOA. They stated that too high dietary rough fiber caused the gizzard to work harder, which in turns the gizzard thicken and enlarged. It also caused slow digestion rate, resulted in the longer intestine.

3.4 Breast, thigh and drumstick nutritive meat quality

Table 9 presents the effects of dietary CP and ME on meat quality. No significant interactions were found between the dietary CP and ME levels. Neither dietary CP nor ME levels had significant effect (*P*>0.05) on any parameters, except higher fat percentage (*P*<0.05) in the thigh of the high CP group and in drumstick meat of the highest ME group. It partially agreed with Songsee *et al.* (2020) who reported that increased dietary CP level in Bresse capon had no effect on breast, thigh and drumstick quality but significantly higher percentage of fat in thigh meat. Rosa *et al.* (2007) noticed the increased fat in carcass with the increased dietary energy level of commercial Ross 308 broiler.

3.5 Sexual effects

Sexual effects on performance of PDHK during 1–13 WOA fed different CP and ME levels are shown in table 3. The result indicated that male had significantly higher BWG and FI than female. This phenomenon can be noticed in the average value from all treatments as well as in an individual treatment. In addition, both sexes fed high CP with high ME had the lowest FCR, while both sexes fed lower CP with the lowest ME diet had the highest FCR. Sex had no significant influence on FCR, mortality rate, culling rate and FCG.

The better growth rate of male should be due to the effect of androgens, such as testosterone which promote protein synthesis and thus the growth of tissues (Da Costa, Zaragoza-Santacruz, Frost, Halley, & Pesti, 2017). Benyi *et al.* (2015) reported that male broilers consumed more feed, utilized the feed more efficiently, gained more BW, and were heavier at all stages of growth than females, but had a higher mortality rate. De Marchi *et al.* (2005) reported that males were consistently heavier than females for the whole live in the Padovana chicken breed. Tangtaweewipat *et al.* (2000) reported that male Thai native crossbred chicken in all experimental dietary groups gained higher BW, FI and had better FCR than female. According to Zerehdaran, Vereijken, van

Arendonk, & van der Waaijt (2004), the differences between males and females in a trait should attributed by many factors such as greater competition for feed, aggressive behavior of males, social dominance, difference in nutritional requirements, and impact of hormones for growth and fatness. No influence of sex on mortality and culling rate in the current experiment might be due to the separation of sex to different pens through the whole rearing period.

Concerning with carcass composition, male had significantly higher percentage of heart, but lower breast weight than female (Table 8). Phaitong (2017) found that male Black Bone chicken had higher percentage of heart and drumstick meat but lower percentage of visceral organ, abdominal fat, gizzard, breast meat and fillet than female. However, no significant difference in abdominal fat between sexes in the present experiment. The reason might be due to the Thai native crossbred in this study is a lean type of chicken, therefore fat deposition between sexes may be less differ than the significant level.

In the case of sexual effects on meat quality, male had significantly lower percentage of protein in the thigh meat and fat in drumstick meat than female (Table 9).

4. **Conclusion**

Feeding 21–19–17% CP during the 3 phases of growing period gave better BWG, FCR and FCG due to the lower FI as comparing to 19–17–15% CP diets. It also significantly increased the percentage of carcass and drumstick weight as well as fat in thigh meat but decreased the percentage of gizzard weight (P<0.05). Lowering dietary energy from 3.2 to 2.6 kcal ME/g caused significantly higher FI, thus poorer FCR and higher FCG. In addition, it significantly increased the percentage of liver and gizzard weight as well as fat in drumstick meat but decreased the percentage of carcass, drumstick and abdominal fat ($P<0.05$). Male chicken had higher BWG, FI and percentage of heart weight but lower protein in breast meat and fat in drumstick meat than female ($P<0.05$). However, sex had no significant influence on FCR, FCG, mortality, culling rate and carcass quality. The optimum diet for PDHK should contain 21–19–17% CP for 1–5, 6–10 and 11–13 WOA with 3.2 kcal ME/g throughout the experiment due to the best FCR and FCG.

Declaration Interest

The authors state no conflict of interest and are responsible for the content and writing of this article.

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Table 1 Feed ration and chemical composition of experimental diet of experimental diets for PDHK chick.

CP (%) in diet	21			19			17			15		
ME (kcal/g) in diet	3.2	2.9	2.6	3.2	2.9	2.6	3.2	2.9	2.6	3.2	2.9	2.6
Ingredients (%):												
Yellow corn	58.53	55.92	24.99	61.03	54.97	25.03	64.24	54.78	27.02	69.8	55.11	29.81
Fine rice bran	0.00	5.99	39.98	0.00	11.99	45.05	0.00	16.93	48.03	2.00	22.04	47.70
Soybean meal, 44% CP	1.20	24.96	28.99	0.00	19.99	25.03	0.00	17.43	20.01	0.00	14.02	15.90
Full fat soybean	25.01	2.50	0.00	30.02	5.00	0.00	29.88	4.98	0.00	22.50	2.50	0.00
Meat meal, 50% CP	13.01	7.99	3.00	6.00	5.00	1.00	2.49	2.50	1.00	2.00	2.50	0.99
MCP, 22% P	1.70	1.70	1.50	1.70	1.70	1.50	1.64	1.70	1.50	1.80	1.70	1.50
Limestone	0.00	0.40	1.00	0.70	0.80	1.80	1.03	1.10	1.80	1.20	1.50	3.30
DL-Methionine	0.10	0.10	0.10	0.10	0.10	0.15	0.19	0.14	0.17	0.20	0.15	0.20
Salt (NaCl)	0.20	0.20	0.20	0.20	0.20	0.20	0.24	0.20	0.20	0.25	0.25	0.20
Premix*	0.25	0.25	0.25	0.25	0.25	0.25	0.24	0.24	0.25	0.25	0.25	0.24
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Calculated chemical composition (% air dry basis)												
CP	21.03	21.15	21.11	19.05	19.04	19.01	17.56	17.26	17.33	15.27	15.49	15.70
ME (kcal/kg)	3,200	2,921	2,662	3,201	2,929	2,652	3,200	2,922	2,688	3,190	2,915	2,679
Ca	1.01	0.93	0.90	0.95	0.94	1.10	0.90	0.92	1.09	0.91	1.06	1.71
Total P	0.68	0.78	1.16	0.71	0.85	1.21	0.70	0.90	1.22	0.70	0.94	1.20
P, available	0.42	0.43	0.45	0.43	0.44	0.46	0.42	0.45	0.46	0.42	0.45	0.45
Lysine	1.05	1.10	1.10	0.94	0.97	0.97	0.85	0.85	0.85	0.70	0.73	0.74

Methionine	0.45	0.44	0.42	0.42	0.41	0.44	0.49	0.43	0.44	0.46	0.41	0.42
Met + Cys	0.74	0.73	0.69	0.71	0.67	0.69	0.77	0.68	0.66	0.71	0.62	0.62
Threonine	0.77	0.79	0.75	0.71	0.70	0.66	0.66	0.63	0.59	0.57	0.55	0.53
Tryptophan	0.22	0.24	0.24	0.21	0.22	0.21	0.20	0.20	0.19	0.17	0.17	0.16
Linoleic acid	3.20	1.63	2.05	3.60	1.99	2.20	3.63	2.13	2.33	3.21	2.11	2.35
Feed cost of diet (THB/kg)	13.02	12.86	12.44	12.6	12.32	11.9	12.31	11.88	11.49	11.75	11.39	11.04

*Premix: Each kg contained 15,000 IU vitamin A, 3,000 IU vitamin D_3, 25 IU vitamin E, 5 mg vitamin K_3, 2 mg vitamin B_1, 7 mg vitamin B_2, 4 mg vitamin B_6, 25 mg vitamin B_{12}, 11.4 mg pantothenic acid, 35 mg nicotinic acid, 1 mg folic acid, 15 µg biotin, 250 mg choline chloride, 16 mg Cu, 60 mg Mn, 45 mg Zn, 80 mg Fe, 0.4 mg I, 0.15 mg Se.

PDHK = Pradu Hang Dam × Hubbard JA 57 Ki; ME = metabolizable energy; CP = crude protein

Table 2 Chemical composition of the diets fed to PDHK chicken during 1–13 weeks of age.

Level of CP (%)	Level of ME (kcal/g)	Chemical composition (% of air dry)						
		DM	CP	EE	CF	Ash	NFE	GE[1]
21	3.2	90.81	21.45	7.70	3.42	9.19	49.05	4.084
	2.9	90.77	21.93	6.07	4.18	7.81	50.78	3.915
	2.6	90.85	21.36	5.14	9.14	10.94	44.27	3.625
19	3.2	90.36	19.89	7.98	2.94	7.11	52.44	4.062
	2.9	90.04	19.42	5.64	4.41	8.78	51.79	3.839
	2.6	90.95	19.52	4.65	9.28	9.60	47.90	3.628
17	3.2	90.61	17.10	7.66	2.51	7.00	56.34	4.046
	2.9	90.74	17.05	5.51	4.88	7.60	55.70	3.821
	2.6	90.82	17.07	4.78	8.85	10.54	49.58	3.502
15	3.2	90.82	15.00	7.62	2.77	4.90	60.53	3.960
	2.9	90.52	15.06	5.47	4.89	4.78	60.32	3.799
	2.6	90.11	15.98	5.35	8.76	8.81	51.21	3.539

Analyzed at the Feed Lab., Dept. of Animal and Aquatic Sciences, Fac. of Agriculture, Chiang Mai University, Thailand.

[1] kcal/g

PDHK = Pradu Hang Dam × Hubbard JA 57 Ki

Table 3 Production performance of PDHK chicken fed diets containing various levels of CP and ME during 1–13 weeks of age.

Variables		BWG (kg/bird)	FI (kg/bird)	FCR	Mortality rate (%)	Culling (%)	FCG (THB/kg BWG)
Mean of main effect:							
Level of CP in diets (%)							
21–19–17		1.76±0.17^{m}	5.25±0.74^{n}	2. 98±0.37^{n}	2.94±1.69	1.22±0.88	35.99±3.48^{n}
19–17–15		1.72±0.16^{n}	5.75±0.72^{m}	3.38±0.55^{m}	2.94±1.32	1.38±0.89	39.98±5.50^{m}
Level of ME in diets (kcal/g)							
3.2		1.69±0.14^{y}	4.85±0.44^{z}	2.88±0.20^{y}	4.16±1.19^{x}	1.50±0.66	34.80±2.02^{y}
2.9		1.91±0.16^{x}	5.34±0.57^{y}	2.91±0.15^{y}	1.75±0.87^{y}	1.17±1.18	35.19 ± 1.82^{y}
2.6		1.63±0.12^{z}	6.12±0.66^{x}	3.77±0.37^{x}	2.92±1.27^{xy}	1.25±0.67	43.81±3.61^{x}
CP × ME							
21–19–17	3.2	1.69±0.15^{b}	4.59±0.38^{d}	2.72±0.02^{d}	5.00±2.83	2.00±3.16	33.26±0.22^{e}
	2.9	1.93±0.18^{a}	5.39±0.56^{bc}	2.79±0.04^{d}	2.00±1.55	0.16±0.41	34.02±0.40^{d}
	2.6	1.67±0.13^{b}	5.78±0.54^{b}	3.45±0.06^{b}	1.83±2.23	1.50±1.76	40.70±0.61^{b}
19-17-15	3.2	1.69±0.12^{b}	5.12±0.19 ^{cd}	3.03±0.11^{c}	3.33 ± 3.93	1.00 ± 0.89	36.70±1.60^{c}
	2.9	1.88±0.12^{a}	5.69±0.47^{b}	3.03±0.05^{c}	1.50 ± 1.76	2.17 ± 2.40	36.37±1.59^{c}
	2.6	1.58±0.10^{b}	6.45±0.45^{a}	4.09±0.03^{a}	4.00 ± 1.41	1.00 ± 1.67	46.91±0.20^{a}
Sex:							
Male		1.86±0.15^{A}	5.90±0.70^{A}	3.20±0.53	2.63±1.39	1.38±0.69	38.15±5.20
Female		1.62±0.12^{B}	5.11±0.59^{B}	3.18±0.50	3.75±1.56	1.94±1.05	37.84±4.85
P-value:							
CP		0.0001	0.0001	0.0001	0.1001	0.8019	0.0001
ME		0.0001	0.0001	0.0001	0.0415	0.9119	0.0001
CP × ME		0.0005	0.0053	0.0001	0.1659	0.1559	0.0002
Sex		0.0001	0.0001	0.3835	0.4231	0.9933	0.3577
SEM		0.03	0.12	0.08	0.43	0.31	0.80

$^{A-B,\ a-e,\ m-n,\ x-z}$ Values with no common superscript differ significantly (*P*<0.05) when tested with Duncan's new multiple range test following Analysis of Variance.

PDHK = Pradu Hang Dam × Hubbard JA 57 Ki; CP = crude protein; ME = metabolizable energy; SEM = standard error of the mean

Table 4 Effects of dietary CP and ME levels on CP and ME intake of PDHK chicken during 1–13 weeks of age.

Variables		CP intake (g/bird)	ME intake (kcal/bird)
Mean of main effect:			
Level of CP in diets (%)			
21–19–17		981±105^{m}	15,114±1,210^{n}
19–17–15		951±108^{n}	16,552±1,107^{m}
Level of ME in diets (kcal/g)			
3.2		853±54^{z}	15,533±1,320^{y}
2.9		979±80^{y}	16,063±1,496^{x}
2.6		1,077±78^{x}	15,903±1,541^{x}
CP × ME			
21–19–17	3.2	855±71^{c}	14,692±1,231^{c}
	2.9	1,007±102^{ab}	15,618±1,622^{abc}
	2.6	1,080±95^{a}	15,031±1,409^{bc}
19–17–15	3.2	852±32^{c}	16,374±616^{ab}
	2.9	950±73^{b}	16,507±1,352^{ab}
	2.6	1,074±73^{a}	16,775±1,179^{a}
Sex:			
Male		1,038±118^{A}	16,957±794^{A}
Female		902±88^{B}	14,709±1,009^{B}
P-value:			
CP		0.0051	0.0001
ME		0.0001	0.0017
CP × ME		0.0129	0.0059
Sex		0.0001	0.0001
SEM		0.02	236.4

A-B, a-b-c, m-n, x-y-z Values with no common superscript differ significantly ($P<0.05$) when tested with Duncan's new multiple range test following analysis of variance.

PDHK = Pradu Hang Dam × Hubbard JA 57 Ki; CP = crude protein; ME = metabolizable energy; SEM = standard error of the mean.

Table 5 Production performance of PDHK chicken during 1-5 weeks of age.

Variables		BWG (kg/bird)	ADG (g/bird/day)	FI (kg/bird)	FCR	Mortality rate (%)	FCG (THB/kg BWG)
Mean of main effect:							
Level of CP in diets (%)							
21		0.51±0.17^{n}	14.64±0.05^{n}	1.07±0.74^{n}	2.07±0.37	1.17±0.75	26.38±3.48^{m}
19		0.55±0.16^{m}	15.46±0.01^{m}	1.12±0.72^{m}	2.10±0.55	1.17±0.64	25.62±5.50^{n}
Level of ME in diets (kcal/g)							
3.2		0.50±0.14^{y}	14.20±1.52^{y}	0.90±0.44^{z}	1.80±0.20^{z}	1.66±0.81	23.00±2.02^{z}
2.9		0.55±0.16^{x}	15.84±0.96^{x}	1.18±0.57^{y}	2.13±0.15^{y}	1.10±0.17	26.88±1.82^{y}
2.6		0.54±0.12^{x}	15.10±0.18^{x}	1.25±0.66^{x}	2.32±0.37^{x}	1.66±0.54	28.20±3.61^{x}
CP × ME							
21	3.2	0.46±0.04^{b}	12.88±1.22^{b}	0.80±0.06^{e}	1.75±0.04^{d}	2.80±1.82	22.74±0.44^{d}
	2.9	0.54±0.03^{a}	15.80±1.12^{a}	1.17±0.07^{c}	2.15±0.01^{b}	0.86±0.53	27.70±0.14^{b}
	2.6	0.54±0.02^{a}	15.23±0.77^{a}	1.23±0.03^{ab}	2.31±0.06^{a}	1.33±1.28	28.69±0.80^{a}
19	3.2	0.54±0.02^{a}	14.98±0.67^{a}	1.01±0.04^{d}	1.86±0.04^{c}	1.73±1.30	23.26±0.26^{d}
	2.9	0.56±0.01^{a}	15.87±0.47^{a}	1.19±0.04^{cb}	2.12±0.02^{b}	1.33±0.70	26.06±0.86^{c}
	2.6	0.55±0.02^{a}	14.98±0.67^{a}	1.27±0.03^{a}	2.33±0.07^{a}	2.00±0.50	27.71±0.45^{b}
Sex:							
Male		0.55±0.15^{A}	15.49±0.08^{A}	1.15±0.70^{A}	2.08±0.53	1.31±0.46	26.01±5.20
Female		0.51±0.12^{B}	14.60±1.27^{B}	1.07±0.59^{B}	2.08±0.50	1.04±0.84	26.04±4.85
P-*value:*							
CP		0.001	0.001	0.001	0.080	1.000	0.001
ME		0.001	0.001	0.003	0.010	0.071	0.001
CP × ME		0.001	0.001	0.001	0.040	0.165	0.005
Sex		0.001	0.001	0.005	0.866	0.423	0.879
SEM		0.01	0.21	0.03	0.04	0.17	0.39

$^{A-B,\ a-e,\ m-n,\ x-z}$ Values with no common superscript differ significantly (P<0.05) when tested with Duncan's new multiple range test following Analysis of Variance.

CP = crude protein; ME = metabolizable energy; SEM = standard error of the mean.

Table 6 Production performance of PPDHK chicken during 6-10 weeks of age.

Variables		BWG (kg/bird)	ADG (g/bird/day)	FI (kg/bird)	FCR	Mortality rate (%)	FCG (THB/kg BWG)
Mean of main effect:							
Level of CP in diets (%)							
19		0.64±0.06	18.15±1.83	2.25±0.20^{n}	3.58±0.48^{n}	0.94±0.99	43.75±4.85^{n}
17		0.65±0.14	18.66±3.93	2.48±0.26^{m}	3.95±0.87^{m}	0.83±0.57	46.72±9.36^{m}
Level of ME in diets (kcal/g)							
3.2		0.66±0.07^{y}	18.85±0.07^{y}	2.16±0.14^{z}	3.31±0.32^{y}	1.25±0.07	41.13±3.59^{y}
2.9		0.72±0.13^{x}	20.36±0.13^{x}	2.33±0.18^{y}	3.34±0.34^{y}	0.50±0.55	40.41±4.67^{y}
2.6		0.58±0.05^{z}	15.98±0.05^{z}	2.59±0.23^{x}	4.64±0.45^{x}	0.92±0.92	54.18±4.29^{x}
CP × ME							
19	3.2	0.69±0.06^{ab}	19.80±1.69^{ab}	2.11±0.16^{d}	3.04±0.04^{d}	1.83±2.78	38.29±0.44^{d}
	2.9	0.64±0.05^{bc}	18.30±1.53^{bc}	2.24±0.21^{cd}	3.49±0.05^{c}	0.00±0.00	43.00±0.57^{c}
	2.6	0.57±0.02^{c}	16.33±0.50^{c}	2.40±0.13^{bc}	4.20±0.11^{b}	1.00±1.67	49.99±1.33^{b}
17	3.2	0.63±0.08^{bc}	17.89±2.21^{bc}	2.22±0.10^{cd}	3.57±0.28^{c}	0.66±0.81	43.97±3.41^{c}
	2.9	0.79±0.16^{a}	22.43±4.63^{a}	2.43±0.12^{b}	3.18±0.51^{d}	1.00±1.67	37.81±5.99^{d}
	2.6	0.55±0.03^{c}	15.64±0.83^{c}	2.78±0.16^{a}	5.08±0.04^{a}	0.83±1.60	58.39±0.45^{a}
Sex:							
Male		0.72±0.11^{A}	20.13±3.40^{A}	2.50±0.22^{A}	3.66±0.81^{B}	0.94±0.89	44.06±8.62^{B}
Female		0.59±0.06^{B}	16.68±1.25^{B}	2.22±0.22^{B}	3.86±0.63^{A}	0.83±0.71	46.40±6.21^{A}
P-*value:*							
CP		0.275	0.275	0.001	0.001	0.845	0.002
ME		0.001	0.001	0.001	0.001	0.559	0.001
CP × ME		0.001	0.001	0.001	0.001	0.306	0.001
Sex		0.001	0.001	0.001	0.012	0.845	0.012
SEM		0.02	0.52	0.04	0.04	0.27	1.33

$^{A-B,\ a-d,\ m-n,\ x-z}$ Values with no common superscript differ significantly ($P<0.05$) when tested with Duncan's new multiple range test following Analysis of Variance.

CP = crude protein; ME = metabolizable energy; SEM = standard error of the mean.

Table 7 Production performance of PDHK chicken during 11-13 weeks of age

Variables		BWG (kg/bird)	ADG (g/bird/day)	FI (kg/bird)	FCR	Mortality rate (%)	FCG (THB/kg BWG)
Mean of main effect:							
Level of CP in diets (%)							
17		0.62±0.13^{m}	29.37±6.20^{m}	1.94±0.36^{n}	3.19±0.52^{n}	0.28±0.39	37.85±5.52^{n}
15		0.51±0.04^{n}	24.30±2.09^{n}	2.12±0.33^{m}	4.19±0.79^{m}	0.22±0.27	47.56±7.98^{m}
Level of ME in diets (kcal/g)							
3.2		0.53±0.06^{y}	25.09±2.14^{y}	1.79±0.17^{z}	3.40±0.30^{y}	0.25±0.32	40.82±2.62^{y}
2.9		0.64±0.15^{x}	30.41±7.02^{x}	2.03±0.32^{y}	3.31±1.01^{y}	0.17±0.19	38.30±10.88^{y}
2.6		0.53±0.09^{y}	25.01±4.19^{y}	2.27±0.38^{x}	4.36±0.68^{x}	0.33±0.47	49.04±6.52^{x}
CP × ME							
17	3.2	0.53±0.05^{b}	25.46±2.46^{b}	1.68±0.16	3.15±0.02^{c}	0.16±0.40	38.75±0.26^{c}
	2.9	0.75±0.09^{a}	35.70±4.37^{a}	1.98±0.28	2.64±0.06^{d}	0.16±0.40	31.35±0.76^{d}
	2.6	0.57±0.09^{b}	26.94±4.21^{b}	2.15±0.39	3.78±0.12^{b}	0.50±1.22	43.46±1.40^{bc}
15	3.2	0.52±0.03^{b}	24.72±1.47^{b}	1.89±0.05	3.65±0.15^{b}	0.33±0.81	42.89±1.80^{bc}
	2.9	0.53±0.04^{b}	25.12±1.76^{b}	2.01±0.31	3.97±0.87^{b}	0.16±0.40	45.25±9.85^{b}
	2.6	0.48±0.05^{b}	23.07±2.34^{b}	2.40±0.27	4.95±0.05^{a}	0.16±0.40	54.62±0.50^{a}
Sex:							
Male		0.60±0.12^{A}	28.80±5.84^{A}	2.25±0.32^{A}	3.84±0.90^{A}	0.39±0.33	44.36±9.01^{A}
Female		0.52±0.08^{B}	24.86±3.84^{B}	1.81±0.20^{B}	3.54±0.79^{B}	0.11±0.27	41.07±7.97^{B}
P-*value:*							
CP		0.001	0.001	0.001	0.001	0.808	0.001
ME		0.001	0.001	0.001	0.001	0.836	0.001
CP × ME		0.001	0.001	0.211	0.011	0.661	0.011
Sex		0.001	0.001	0.001	0.014	0.231	0.014
SEM		0.02	0.83	0.06	0.13	0.27	1.34

$^{A-B,\ a-d,\ m-n,\ x-z}$ Values with no common superscript differ significantly (P<0.05) when tested with Duncan's new multiple range test following Analysis of Variance.

CP = crude protein; ME = metabolizable energy; SEM = standard error of the mean.

Table 8 Effects of dietary CP and ME levels on carcass composition of PDHK chicken during 1-13 weeks of age.

Variables		Carcass (%)	Carcass composition (% on hot carcass)					
			Breast	Thigh[1]	Drumstick[2]	Wing	Gizzard	Abdominal fat
Mean of main effect:								
Level of CP in diets (%)								
21–19–17		75.71±0.66^{m}	35.90±2.72	18.01±0.64	16.08±0.60^{m}	14.95±0.79	3.30±0.39^{n}	1.40±0.68
19–17–15		74.46±0.65^{n}	34.91±1.66	17.89±0.69	15.24±0.60^{n}	15.51±0.91	3.83±0.51^{m}	1.67±0.69
Level of ME in diets (kcal/g)								
3.2		75.67±0.73^{x}	36.46±1.40	17.69±0.63	15.72±0.45^{xy}	15.19±0.51	3.30±0.16^{y}	2.09±0.12^{x}
2.9		75.26±0.91^{x}	35.31±3.19	17.87±0.57	16.25±0.93^{x}	15.00±0.57	3.37±0.17^{y}	2.03±0.79^{x}
2.6		74.34±0.63^{y}	34.45±1.75	18.29±0.72	15.01±0.32^{y}	15.50±0.53	4.02±0.09^{x}	0.48±0.44^{y}
CP × ME								
21–19–17	3.2	76.23±1.20	37.10±4.71	17.49±3.63	16.14±1.23	15.09±1.74	3.17±0.61	1.86±1.32
	2.9	76.02±0.73	33.59±2.81	17.77±1.71	16.69±0.89	14.30±0.79	3.17±0.59	2.02±1.07
	2.6	74.88±1.51	34.05±4.77	18.42±1.28	15.42±2.80	15.45±1.04	3.57±0.86	0.32±0.18
19–17–15	3.2	75.10±1.25	35.81±3.84	17.90±1.55	15.31±0.76	15.29±1.81	3.44±0.58	2.32±0.84
	2.9	74.49±1.77	37.04±4.45	17.98±1.53	15.82±0.75	15.69±1.39	3.58±0.58	2.04±1.54
	2.6	73.80±1.42	34.85±3.85	18.17±2.26	14.59±1.46	15.55±2.92	4.48±0.72	0.64±0.36
Sex:								
Male		75.06±0.98	34.05±1.93^{B}	18.02±0.48	15.76±0.57	15.55±0.72	3.44±0.63	1.61±0.78
Female		75.11±0.92	36.75±1.63^{A}	17.89±0.28	15.56±0.75	14.91±0.78	3.69±0.39	1.46±0.74
P-value:								
CP		0.0002	0.2889	0.8149	0.0203	0.1707	0.0011	0.2607
ME		0.0041	0.2124	0.6146	0.0200	0.5968	0.0005	0.0001
CP × ME		0.8208	0.1174	0.8613	0.9979	0.3608	0.2190	0.7523
Sex		0.8869	0.0048	0.7995	0.5787	0.1191	0.1121	0.5363
SEM		0.18	0.50	0.25	0.19	0.21	0.09	0.15

[A-B, m-n, x-y-z] Values with no common superscript differ significantly (P<0.05) when tested with Duncan's new multiple range test following analysis of variance.

[1, 2] Meat including skin and bone from both legs.

PDHK = Pradu Hang Dam × Hubbard JA 57 Ki; ME = metabolizable energy; CP = crude protein; SEM = standard error of the mean.

Table 9 Effects of dietary CP and ME levels on meat quality of PDHK chicken during 1-13 weeks of age

Variables		Protein (%)			Fat (%)		
		Breast	Thigh	Drumstick	Breast	Thigh	Drumstick
Mean of main effect:							
Level of CP in diets (%)							
21–19–17		27.44±2.48	23.83±4.16	25.17±2.25	1.36±0.52	11.73±1.84^{m}	6.69±2.00
19–17–15		28.00±3.35	24.82±2.94	25.20±1.88	2.37±1.81	9.12±3.42^{n}	6.21±2.12
Level of ME in diets (kcal/g)							
3.2		29.12±3.14	24.62±4.14	24.83±1.92	1.60±0.75	10.20±4.02	7.69±2.92^{x}
2.9		27.29±2.80	23.14±3.43	25.52±2.11	1.87±0.38	10.66±1.56	6.36±0.85^{xy}
2.6		26.76±2.73	25.21±3.50	25.2±2.42	2.13±2.45	10.42±3.63	5.30±2.15^{y}
CP × ME							
21–19–17	3.2	27.71±1.05	26.97±2.94	24.83±1.12	1.22±0.49	10.97±1.46	7.14±2.31
	2.9	28.26±2.50	20.83±3.72	26.40±2.25	1.88±0.32	11.76±1.07	6.69±1.00
	2.6	26.35±4.11	23.68±4.29	24.28±2.79	0.98±0.19	12.44±2.82	6.23±2.60
19–17–15	3.2	30.52±4.26	22.28±4.69	24.83±2.85	1.98±0.75	9.43±5.39	8.24±2.12
	2.9	26.31±3.42	25.44±1.02	24.64±1.81	1.87±0.50	9.55±1.20	6.04±0.46
	2.6	27.18±1.34	26.75±1.05	26.12±2.66	3.28±2.91	8.39±2.79	4.36±0.65
Sex:							
Male		25.70±1.85^{B}	25.19±3.71	25.38±1.36	1.46±0.52	9.69±3.78	5.27±1.15^{B}
Female		29.74±2.08^{A}	23.46±3.31	24.98±2.58	2.27±1.87	11.16±1.89	7.63±2.00^{A}
P-value:							
CP		0.5032	0.4605	0.9752	0.0573	0.0379	0.3208
ME		0.0788	0.4333	0.8469	0.6931	0.9495	0.0022
CP × ME		0.0897	0.2028	0.3450	0.1850	0.6630	0.0536
Sex		0.0001	0.2052	0.6872	0.1204	0.2209	0.0001
SEM		0.62	0.76	0.45	0.27	0.59	0.39

$^{A-B, a-b, m-n, x-y-z}$ Values with no common superscript differ significantly (*P* <0.05) when tested with Duncan's new multiple range test following analysis of variance.

PDHK = Pradu Hang Dam × Hubbard JA 57 Ki; ME = metabolizable energy; CP = crude protein; SEM = standard error of the mean.