Caponization Effects on Growth Performance and Lipid Metabolism in Taiwan Country Chicken Cockerels

Kuo-Lung Chen, Tseng-Yueh Hsieh[1] and Peter Wen-Shyg Chiou[1,] *

Department of Animal Science, National Chiayi University, 300 Syuefu Road, Chiayi 600, Taiwan, ROC

ABSTRACT : This trial was designed to study the caponization effects on the appearance, carcass characteristics, blood constituents and lipid metabolism of Taiwan country chicken cockerels. Cockerels were caponized at 8 weeks of age. Sixteen-week-old chickens, including 10 capons, 5 slips (incomplete caponized male chickens) and 20 normal chickens of equal sexes were selected for a 10 week *ad libitum* feeding trial. Results showed that the testosterone concentrations in the capons and females were lower ($p<0.05$) than that of intact males. The comb length, height and weights were also lower ($p<0.05$). The weight of the slips was between that of the capons and intact males, but was heavier ($p<0.05$) than that of the capon. The live-weight, carcass weight and shank perimeter in the capons were higher than those of the other groups ($p<0.05$). Hepatic lipogenic enzyme activity analyses showed that NADP-malic dehydrogenase (MDH) activity in the capons and female chickens was higher than that in intact male chickens ($p<0.05$). The MDH activity in the slips was between that for the capon and intact male chickens ($p>0.05$). The abdominal fat weight and relative abdominal fat weight of the capons and females were heavier than that for intact males ($p<0.05$); the slips were between the capons and intact males. The blood lipid content results showed that the triacylglycerol and cholesterol in the capons were higher than that for intact males ($p<0.05$). However, the percentage of low-density lipoprotein (LDL) was lower than that in intact male chickens ($p<0.05$). It appears that the increase in lipid accumulation in caponized male chickens is attributed mainly to an increase in MDH activity and the changes in lipid transportation in the capons. ***(Asian-Aust. J. Anim. Sci. 2006. Vol 19, No. 3 : 438-443)***

Key Words : Taiwan Country Chickens, Caponization, Capon, Slip, Lipid Metabolism

INTRODUCTION

Capons are defined as having the testis artificially removed via a surgical operation on 6 to 12-week old male chickens. The secondary male sexual characteristics then degenerate (including comb, wattle, colour, fighting behavior and sound production etc.). Capons experience fat accumulation upon sexual maturity, have enhanced flavor, texture and juicy muscle meat compared with intact cockerels (Chen et al., 2000a, b; Chang, 2001). In Taiwan, 4.3 million capons were consumed each year (Hsieh, 2002).

Literatures showed the caponization effects on carcass characteristics in male chickens (Rath et al., 1996), but results were discrepant due to strains, age on caponization and feeding period. The caponization effect on muscle formation is still not well understood. Some researchers regard it as a promoter (Ono et al., 1979, 1982; Cason et al., 1988), while others regard it as a depressor on muscle growth (Fennell and Scanes, 1992; Morgan et al., 1993; Burke and Edwards, 1994). Although most researchers agree on the promotion effect of caponization on lipid accumulation and regard it as the testosterone inhibitory effect on lipid accumulation (Deyhim et al., 1992; Fennell and Scanes, 1992), the lipogenesis mechanism after caponization has not been described in the literature and is still unclear. Therefore, further research is required on the lipid lipogenesis and metabolism in capons.

In general, 5 to 20% of incompletely caponized chickens (slip) are detected even when the surgical operation is conducted by an experienced technician. These slips present more prominent secondary sexual characteristics, compared with the capon, but less prominent compared with intact birds, especially the comb and wattle. Occurrence of these slips probably due to regeneration from the residual testis cells that could not be detected from visual inspection. Slips are not favored or accepted as capons by consumers, resulting in a huge loss in revenue. Moreover, the shape and body fat accumulation trend toward feminization after caponization in male chickens require using female chickens as negative controls.

The aim of this trial was to study the capon and slip effect on the appearance, growth performance, carcass characteristics, blood constituents and lipid metabolism in Taiwan country chickens by the commercial production model.

MATERIALS AND METHODS

Experimental animal and management

Taiwan Country chickens line D×L2 bred by National Chung-Hsing University were housed in individual 40×30 cm, 38 cm high cages. Water was provided using a water

* Corresponding Author: Peter Wen-Shyg Chiou. Tel: +886-4-22870613, Fax: +886-4-22860265, E-mail: wschiou@dragon.nchu.edu.tw

[1] Department of Animal Science, National Chung-Hsing University, 250 Kuo-Kuang Road, Taichung 402, Taiwan, ROC.

Received July 5, 2005; Accepted November 4, 2005

Table 1. Caponization effects on the testosterone, performance and appearance of Taiwan country chickens[1]

Items	Male	Slip	Capon	Female
Feed intake (g/day/bird)	112±5.7	109±6.5	117±5.9	94±5.8
Initial body weight (g)	2,286±143[a]	2,255±153[a]	2,301±146[a]	1,880±211[b]
Body weight (g)	2,316±244[b]	2,463±215[b]	2,894±303[a]	1,990±254[c]
Comb height (mm)	70±6[a]	50±17[b]	28±3 [c]	27±10[c]
Comb length (mm)	132±11[a]	98± 24[b]	61±4.8[c]	59±13[c]
Comb weight (g)	54.3±8.8[a]	27.2±19.5[b]	4.5±0.8[c]	5.3±2.8[c]
Shank perimeter (mm)	53.3±3.3[b]	56.0±5.9[ab]	58.3±6.1[a]	46.6±3.7[c]
Testosterone (pg/mL serum)	708±308[a]	246±210[b]	32.9±25[b]	123±78[b]

[1] Means±SD. [a, b, c] Means of the same row with different superscripts were significantly different ($p<0.05$).

trough and commercial growing diet of 16% CP and 11.72 MJ/kg ME with water was provided *ad libitum* for the chickens. Cockerels were caponized at 8 weeks of age. Thirty-five sixteen-week-old chickens, including 10 capons, 5 slips (incomplete caponized male chickens) and 20 normal intact birds of equal sexes were selected for 10 weeks feeding.

Testectomy

The procedure of testectomy is according to Chen et al. (2005a). Restricted to feed and water for 12 h before surgical operation, intact male chickens were then restrained and the site of incision was sterilized with iodine-alcohol. A 1 cm lateral incision was made at the second to last rib, and the testes were removed. Iodine-alcohol again was applied to the site of incision.

Measurements and analyses

Growth performance and appearances : During the feeding period, feed intake and live-weight were measured weekly. The appearance, including length, height and weight of comb and perimeter of shank were measured at the end of the feeding trial.

Carcass characteristics : The abdominal fat was stripped off immediately after the livers, gizzard, and testicles were removed and weighed. The abdominal fat included the fat surrounding gizzard and fat pad in the abdominal cavity. Fat located in the intestinal mesenteries was included in the intestinal tract.

Hepatic lipogenic enzymes activity : Approximately 5 g of the liver was sampled and chopped into small pieces, placed into 15 ml tubes of 0.25 M sucrose and 1 mM EDTA buffer solution (pH 7.4), and homogenized at 4°C for 2 min (12,000 rpm). The supernatant was taken after centrifugation at 10,000×g for 10 min under 4°C. After repeating the centrifugation procedure, the supernatant was centrifuged again at 105,000×g 4°C for 60 min to precipitate cell microsomes. The cytoplasm in the supernatant was taken for hepatic enzyme and protein concentration analysis. The hepatic lipogenic enzyme activities including; ATP-citrate cleavage enzyme (CCE, EC 4. 1. 3. 8), NADP-malic dehydrogenase (MDH, EC 1. 1. 1. 40), glucose-6-phosphate dehydrogenase (G-6-PDH, EC 1. 1. 1. 49), were measured using the modified method of Takeda et al. (1963), Ochoa (1969) and Löhr and Wallex (1974), respectively. The hepatic tissue protein content was measured according to Lowry et al. (1951) using bovine serum albumin as the standard protein.

Blood constituents : Blood samples, 10 ml each, were taken from the ulner-vein after birds were withdrawn from feed and water for 12 h before sacrifice at the end of the trial. Blood sera were obtained as supernatants after centrifugation at 1,500×g for 15 min. and stored at -40°C for further analysis. Blood serum glucose, triacylglycerol and total cholesterol concentrations were analyzed using an automatic blood chemical analyzer with Roche testing kits (Roche COBAS MIRA PLUS). Non-esterified fatty acid (NEFA) was determined using a spectrophotometer according to the modified method of Chromy et al. (1977). Lipoproteins were analyzed according to Houstmuller (1969) and using Helena titian gel electrophoresis. Electrophoresis data center scanning densitometry (Helena Laboratories, USA) was used to estimate the area of each fraction (Lien et al., 2005). Testosterone concentration was measured according to Li et al. (1987).

Statistical analysis

Analyses of variance were calculated using the general linear model procedure of the SAS (1985). Duncan's new multiple-range test was used to compare the means according to Steel and Torrie (1960). The correlation between the blood constituents, carcass characteristics and performance was analyzed using the PROC CORR of the SAS (1985) and Pearson's correlation analysis.

RESULTS AND DISCUSSION

Growth performance and appearances

Table 1 presents the caponization effect on the testosterone, performance and appearance of Taiwan country chickens. Caponization increased the live-weight as the capons became heavier ($p<0.05$) than the slips and intact males. The smallest ($p<0.05$) comb length, height and weight were in capons and females, followed by the slips

Table 2. Caponization effects on carcass traits of Taiwan country chickens[1]

Items	Male	Slip	Capon	Female
Carcass weight (g)	1,947±217^{b}	2,069±319^{b}	2,386±278^{a}	1,408±186^{c}
Dressing percent (g/100 g BW)	84.0±0.74^{a}	84.1±2.0^{a}	82.3±1.6^{a}	71.0±6.4^{b}
Subcutaneous fat weight (g)	24±7.4^{b}	40±16.2^{a}	38±8.6^{a}	37±6.9^{a}
Relative subcutaneous fat weight (g/100 g BW)	1.07±0.36^{c}	1.61±0.49^{ab}	1.35±0.39 ^{bc}	1.86±0.35^{a}
Abdominal fat weight (g)	5.65±7.7^{c}	37.7±46^{b}	94.3±43^{a}	101±42^{a}
Relative abdominal fat weight (g/100 g BW)	0.23±0.31^{c}	1.37±1.62^{bc}	3.18±1.96^{b}	5.02±1.81^{a}
Liver weight (g)	29.6±2.0^{ab}	28.1±4.3^{b}	32.7±5.0^{ab}	33.8±4.5^{a}
Relative liver weight (g/100 g BW)	1.29±0.16^{b}	1.14±0.07^{b}	1.13±0.17^{b}	1.71±0.20^{a}
Gizzard weight (g)	39.8±1.0^{b}	40.5±9.6^{b}	52.7±6.0^{a}	37.8±7.3^{b}
Relative gizzard weight (g/100 g BW)	1.70±0.31	1.63±0.23	1.85±0.37	1.90±0.33
Intestine weight (g)	52.5±6^{b}	71.9±30^{b}	100±19^{a}	84.4±28^{ab}
Relative intestine weight (g/100 g BW)	2.73±0.12^{c}	2.85±0.78^{bc}	3.48±0.58^{ab}	3.90±1.33^{a}
Testicle (g)	23.3±7.7^{a}	5.04±6.8^{b}	-	-
Relative testicle weight (g/100 g BW)	0.99±0.27^{a}	0.22±0.33^{b}	-	-

[1] Means±SD. $^{a, b, c}$ Means of the same row with different superscripts were significantly different ($p<0.05$).

and males. This reflected that caponization decreased the secondary sexual characteristics as the slips were partially affected. The perimeter of the shank was longest in the capon ($p<0.05$) followed by the slips, intact males and females with the shortest ($p<0.05$). The testosterone concentration was highest in the intact males ($p<0.05$).

The heavier live-weight in the capons compared with intact males in this trial agreed with the results of Chen et al. (2000a, b). The capons gained weight faster in the late growing phase (Chen et al., 2000b; Kuo, 2002). Farmers use the shank perimeter as the fatness indicator for capons. However, in this trial that the longest shank perimeter was not significantly correlated with fat deposition in the capon.

Caponization decreased the serum testosterone concentration (Mashaly, 1984; Burke and Edwards, 1994), hence the secondary male sexual characteristics, comb weight, were significantly decreased (Fennell and Scanes, 1992; Wang, 2001). This agreed with significantly increased comb weight produced by exogenous testosterone implantation in chickens (Fennell and Scanes, 1992; Astiningsih and Rogers, 1996). The testosterone concentration of capons was only 5% (32.9 pg/ml) of the intact males. The slips, however, with some remaining testicle tissue, approximately 26% of the weight of the intact bird, showed a trend toward secreting more testosterone than the capon ($p<0.10$). Hence, slips showed significant secondary male sexual characteristics as compared with the capon. However, these characteristics were less prominent than those in intact males. From appearance observations, the comb and wattle in the capons degenerated to female size with a pale colour. The slips possessed large red combs, that were longer in length, taller in height and heavier in weight ($p<0.05$) compared with the capons. These male secondary sexual characteristics were significantly correlated with the serum testosterone concentration, as shown in Table 4. The serum testosterone concentration (pg/ml) can be predicted from the comb length regression equation (=-563.18+10.492X, in mm), height (=-358.95+16.256X, in mm) and the comb weight (= 32.649+14.195X, in g) ($p<0.001$). Therefore, success of surgical caponization can be evaluated from the chicken appearance.

Carcass characteristics

Table 2 presents the caponization effect on the carcass traits of Taiwan country chickens. The carcass weight was heaviest ($p<0.05$) in the capon, but not different in dressing percentage from the slip and male. Caponization increased the lipid deposition as the subcutaneous fat and relative subcutaneous fat weight were lightest ($p<0.05$) in intact males. The abdominal fat and relative abdominal fat weight were heaviest ($p<0.05$) in the capon and females compared with the intact males ($p<0.05$). Caponization also increased the weight of gizzard, intestine and relative intestine weight ($p<0.05$) compared with intact males. The females also showed a trend toward heavier intestine weight and relative intestine weight compared with the slips and intact males. The testicle weight and relative testicle weight were lighter ($p<0.05$) in the slip compared with intact males.

Maturity of Taiwan country chickens occurs at around 16 weeks of age. The male has fighting behavior, probably due to the androgen effect after maturity, and depressed growth afterward (Wang, 2001). In this trial, the capons consumed more feed and gain with less fighting behavior compared with the intact males. The dressing percentage did not differ ($p>0.05$) among capons, slips and intact males. Caponization resulted in the heavier abdominal fat and intestine weight, but showed no effects on relative weights of liver, gizzard and subcutaneous fat weight, which resulted in the unmarked difference on dressing percent.

In the lipid deposition, the weight of subcutaneous fat in the breast and relative weight of the abdominal fat in the

Table 3. Caponization effects on the blood traits and hepatic lipogenic enzymes of Taiwan country chickens[1]

Items	Male	Slip	Capon	Female
ATP-citrate cleavage enzyme (U^2/mg protein)	23.2±9.0[a]	22.9±7.0[a]	24.6±8.4[a]	16.1±4.9[b]
Glucose-6-phosphate dehydrogenase (U^2/mg protein)	3.51±1.9[ab]	4.66±1.4[ab]	2.89±1.6[b]	4.57±1.7[a]
NADP-malic dehydrogenase (U^2/mg protein)	23.9±9.6[b]	38.8±9.6[ab]	44.5±15.1[a]	46.9±11.3[a]
Glucose (mg/dl)	173±32	171±22	175±33	161±24
Triacylglycerol (mg/dl)	41±20[c]	106±44[bc]	157±37[b]	628±145[a]
Phospholipid (mg/dl)	221±72[b]	271±58[ab]	266±58[ab]	302±59[a]
Cholesterol (mg/dl)	76.7±24[b]	113±11[ab]	118±15[a]	119±65[a]
Nonesterified fatty acid (mg/dl)	31.9±1.3[b]	33.6±2.1[b]	33.7±1.8[b]	40.9±2.6[a]
Very low density lipoprotein (%)	16.6±9.5[b]	21.4±17.0[b]	24.3±6.0[b]	71.6±12.3[a]
Low density lipoprotein (%)	7.25±7.3[ab]	4.19±5.2[bc]	0.40±2.4[c]	11.0±5.8[a]
High density lipoprotein (%)	76.1±5.6[a]	74.4±16.2[a]	76.6±6.2[a]	17.2±12.3[b]

[1] Means±SD. [2] U = 1n mole/mg protein.
[a, b, c] Means of the same row with different superscripts were significantly different ($p<0.05$).

Table 4. Correlation coefficient for comb traits, fat accumulation, the hepatic lipogenic enzymes and testosterone in Taiwan country chickens

Item	Testosterone	Relative abdominal fat weight
Comb length	0.745***	-0.708***
Comb height	0.700***	-0.691***
Comb weight	0.691***	-0.646***
Relative abdominal fat weight	- 0.44*	-
Relative subcutaneous fat weight	- 0.22	0.446***
ATP-citrate cleavage enzyme	0.32	0.089
Glucose-6-phosphate dehydrogenase	0.20	0.352
NADP-malic dehydrogenase	- 0.43**	0.582**

* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

capon were similar to that in the females. However, both were greater ($p<0.05$) than that in intact males. The weight and relative weight of the subcutaneous fat in the breast of slips did not differ from that of females ($p>0.05$). However, the weight was heavier than that in intact males ($p<0.05$). Caponization influenced the testosterone concentration in intact males ($p<0.05$) (Deyhim et al., 1992; Fennell et al., 1996; Chen et al., 2000a). In this trial, the testosterone concentration was negatively correlated with the fat deposition ($r = 0.44$; $p<0.05$, Table 4) and reflected the influence of testosterone on the fat deposition. Lack of testosterone in capons caused fat deposits similar to that in females. The liver is the major site for lipogenesis in poultry (Leveille et al., 1975; Donaldson, 1990; Griffin et al., 1992). In this trial, caponization did not influence the weight and relative weight of the liver as there were no differences among the capon, slip and intact males without fatty liver syndrome. The female, on the other hand, possessed the heaviest liver ($p<0.05$) with fatty liver appearance. When females are in the egg laying period, extra amounts of energy are required. This triggers oestrogen secretion and induces hepatic lipogenesis (Polin and Wolford, 1977; Squires and Lesson, 1988; Hermier et al., 1996).

Lipogenesis and metabolism

Table 3 presents the caponization effect on the blood traits and lipogenic enzymes of Taiwan country chickens. Females and capons showed a higher ($p<0.05$) MDH (NADP-malic dehydrogenase) activity than intact males. The slip fell in the middle. The other hepatic lipogenic enzymes, CCE (ATP-citrate cleavage enzyme) and G-6-PDH (Glucose-6-phosphate dehydrogenase) were not different ($p>0.05$) among the capon, slip and intact male. Conversely, the capon showed a higher triacylglycerol and total cholesterol concentration with lower ($p<0.05$) LDL ratio than intact males, while the slip was in between the two ($p>0.05$).

The hepatic CCE and MDH activity are positively correlated to fatty acid synthesis (Yeh et al., 1970; Yeh and Leveille 1971). Higher hepatic MDH activity and abdominal fat in females reflected more active lipogenesis in the females (Grunder et al., 1987). The hepatic lipogenic enzyme activity can therefore be an indicator for lipid synthesis in chickens. MDH is the major source of hydrogen from NADPH (Legrand et al., 1987). In this trial, the capon was close to the female in MDH activity ($p>0.05$) and both were higher than that for intact males ($p<0.05$). Females, however, showed a lower CCE activity than the other groups ($p<0.05$). This result agreed with Jiang (1989) in his comparison of female and male Taiwan country chickens, indicating that females showed significantly higher MDH activity with no significant difference with slightly lower trend in CCE activity than intact males. As shown in Table 4, the MDH activity was positively correlated to the abdominal fat deposition ($r = 0.582$; $p<0.01$). The serum testosterone concentration influenced MDH synthesis and is negatively correlated with MDH activity ($r = -0.43$; $p<0.01$). Caponization decreased the

serum testosterone concentration and increased MDH activity. The MDH activity is positive correlated to lipogenesis in female chickens, because estrogen enhances the MDH activity. In this trial, caponization showed no effects on estrogen concentration of male chickens (Chen et al., 2005b). Hence, the elevated MDH activity was resulted from the lower androgen concentration, or which cooperated to other hormones need further study.

Capons showed a higher ($p<0.05$) triacylglycerol and total cholesterol concentration in their blood constituents over intact males, with the slip in between ($p>0.05$). The higher MDH activity in capons may be attributed to the increase in hepatic lipogenic activity, leading to higher blood lipid concentrations, i.e., triacylglycerol and total cholesterol, especially extremely high triacylglycerol concentration (as much as three times that in intact males). Because lipoproteins play a major role in lipid transportation and females depend on VLDL (very low density lipoprotein) to transport lipids to the ovary for egg production, hence females showed a higher VLDL concentration (Schneider, 1992, 1995; Walzem et al., 1994). There are species that show differences in the lipoprotein ratio, higher LDL ratios occur in human beings and higher HDL ratios occur in cockerels and immature female chickens (Chapman, 1980; Hermier et al., 1984; Hermier, 1997). Hermier et al. (1984) indicated that the VLDL and HDL concentrations increased as the body lipid deposition increased. This VLDL concentration is utilized as the fatness selection index in chicken breeding (Whitehead et al., 1984). In this trial, the LDL ratio was lower in capons than in intact males and female ($p<0.05$). Generally, LDL is derived from VLDL hydrolysation by lipoprotein lipase (LPL) accompanied with a large amount of triacylglycerol from the VLDL content, triacylglycerol is hydrolyzed into NEFA and glycerol is the end product for energy. The lower LDL ratio in capons meant less VLDL was hydrolyzed, and leading to abdominal fat accumulation.

ACKNOWLEDGEMENT

Authors wish to thank the National Science Council of Taiwan for financially supporting this project. This project number is NSC91-2313-B005-129.

REFERENCES

Astiningsih, K. and L. J. Rogers. 1996. Sensitivity to testosterone varies with strain, sex and site of action in chickens. Physiol. Behav. 59:1085-1091.

Burke, W. H. and H. M. Edwards. 1994. Effect of early castration on body weight, muscle growth, and bone characteristics of male Nicholas strain turkeys. Poult. Sci. 73:457-463.

Cason, J. A., D. L. Fletcher and W. H. Burke. 1988. Effects of caponization on broiler growth. Poult. Sci. 67:979-981.

Chang, C. H. 2001. Investigation of carcass and meat characteristics from different sizes commercial capon in Taiwan. Master thesis. National Chung-Hsing University, Taichung, Taiwan.

Chapman, M. T. 1980. Animal lipoproteins: Chemistry, Structure and Comparative Aspects. J. Lipid Res. 21:789-852.

Chen, K. L., C. P. Wu and R. G. R. Chou. 2000a. Effect of castration age on growth performance and postmortem change in muscles of Taiwan country chicken. J. Agric. Assoc. China. 1(1):54-63.

Chen, K. L., C. P. Wu and Y. M. Hong. 2000b. Meat quality and carcass traits of capon in comparison with intact male and female Taiwan country chickens. J. Chin. Soc. Anim. Sci. 29(1):77-88.

Chen, K. L., M. H. Chang, S. M. Tsay, H. Y. Hurng and P. W. S. Chiou. 2005a. Effects of caponization on bone characteristics and histological structure in male chickens. Asian-Aust. J. Anim. Sci. 19(2):245-251.

Chen, K. L., W. T. Chi and P. W. S. Chiou. 2005b. Caponization and testosterone implantation effects on blood lipid and lipoprotein profile in male chickens. Poult. Sci. 84:547-552.

Chromy, V., J. Gergel, J. Voznicek, L. Krombholzova and J. Musil. 1977. Assay of serum free fatty acids by extraction-photometric procedure. Clin. Chim. Acta. 80:327-332.

Deyhim, F., R. E. Moreng and E. W. Kienholz. 1992. The effect of testosterone propionate on growth of broiler chickens. Poult. Sci. 71:1921-1926.

Donaldson, W. E. 1990. Lipid metabolism in liver of chicks: response to feeding. Poult. Sci. 69:1183-1187.

Fennell, M. J. and C. G. Scanes. 1992. Inhibition of growth in chickens by testosterone, 5α-dihydrotestosterone and 19-nortestosterone. Poult. Sci. 71:357-366.

Fennell, M. J., S. V. Radecki, J. A. Proudman and C. G. Scanes. 1996. The suppressive effects of testosterone on growth in young chicken appears to be mediated via a peripheral androgen receptor; studies of the anti-androgen ICI 176,344. Poult. Sci. 75:763-766.

Griffin, H. D., K. Guo, D. Windsor and S. C. Butterwith. 1992. Adipose tissue lipogenesis and fat deposition in leaner broiler chickens. J. Nutr. 122:363-368.

Grunder, A. A., J. R. Chambers and A. Forti. 1987. Plasma very low density lipoproteins, abdominal fat lipase, and fatness during rearing in two strains of broiler chickens. Poult. Sci. 66(3):471-479.

Hermier, D., M. J. Chapman and B. Leclercq. 1984. Plasma lipoprotein profile in fasted and refed chickens of two strains selected for high or low adiposity. J. Nutr. 114:1112-1121.

Hermier, E., D. Catheline and P. Legrand. 1996. Relationship between hepatic fatty acid desaturation and lipid secretion in the estrogenized chicken. Comp. Biochem. Physiol. 115:259-264.

Hermier, D. 1997. Lipoprotein metabolism and fattening in poultry. J. Nutr. 127:805-808.

Houstmuller, A. J. 1969. Agarose-gel electrophoresis of lipoproteins: A clinical screening test. Koninklike Van Gorcum and Comp, the Netherlands, pp. 5.

Hsieh, T. Y. 2002. Effects of castration in Taiwan country chicken cockerels on growth performance and lipid metabolism.

Master thesis. National Chung-Hsing University, Taichung, Taiwan.

Jiang, W. K. 1989. Effect of protein level of diet and breed on hepatic lipogenic enzymes activities of chicken. Master thesis. National Chung-Hsing University, Taichung, Taiwan.

Kuo, T. W. 2002. Effect of different castrated ways and different castrated weeks on meat characteristics of Taiwan country chicken. Master thesis. National Chung-Hsing University, Taichung, Taiwan.

Legrand, P., J. Mallard, M. A. Bernard-Griffiths, M. Douaire and P. Lemarchal. 1987. Hepatic lipogenesis in genetically lean and fat chickens. *In vitro* studies. Comp. Biochem. Physiol. 87B:789-792.

Leveille, G. A., D. R. Romos, Y. Y. Yeh and E. K. O'Hea. 1975. Lipid biosynthesis in the chick. A consideration of site of synthesis, influence of diet and possible regulatory mechanisms. Poult. Sci. 54:1075-1093.

Li, P. H., H. M. Chiang and T. T. Hsu. 1987. Serum testosterone concentrations and semen quality in landrace and duroc boars housed in a tropical area. J. Chin. Soc. Anim. Sci. 16(1-2):31-39.

Lien, T. F., K. H. Yang and K. L. Lin. 2005. Effects of chromium propionate supplementation on growth performance, serum traits and immune response in weaned pigs. Asian-Aust. J. Anim. Sci. 18:403-408.

Löhr, G. W. and H. D. Wallex. 1974. Method of Enzymatic Analysis. Academic Press, New York, pp. 636-645.

Lowry, O. H., N. J. Rosebrough, A. L. Farr and R. J. Randall. 1951. Protein measurement with the folin phenol reagent. J. Biol. Chem. 193:265-270.

Mashaly, M. 1984. Effect of caponization on cell-mediated immunity of immature cockerels. Poult. Sci. 63:369-372.

Morgan, J. B., T. L. Wheeler, M. Koogmaraie, J. D. Grouse and J. W. Savell. 1993. Effect of castration on myofibrillar protein turnover, endogenous proteinase activities, and muscle growth in bovine skeletal muscle. J. Anim. Sci. 71:408-414.

Ochoa, S. 1969. Malic enzyme. In: Method in Enzymeology. (Ed. S. P. Colowick and N. O. Kaplan). Academic Press, New York, Vol. 1 pp. 739-753.

Ono, O., I. Hisao, T. Hitoshi and O. Masao. 1979. Studies on the growth skeletal muscle of capon. Effects of castration on the weights of skeletal muscle, abdominal fat, intermuscular fat, skin, bone and viscera. Sci. Bull. Fac. Agr. Kyushu Univ. 34:39-46.

Ono, Y., I. Hisao and T. Hitoshi. 1982. Studies on the growth skeletal muscle of capon II. Effects of castration on muscle weights in different body parts and individual muscle weight. Sci. Bull. Fac. Agr, Kyushu Univ. 37:23-30.

Polin, D. and J. H. Wolford. 1977. Role of estrogen as a cause of fatty liver-hemorrhage syndrome. J. Nutr. 197:873-886.

Rath, N. C., W. E. Huff, J. M. Balog and G. R. Bayyari. 1996. Effect of gonadal steroid on bone and other physiological parameters of male broiler chickens. Poult. Sci. 75:556-562.

SAS Institute Inc. 1985. SAS/STAT User's Guide: Version 6. 4th edn. SAS Institute Inc., Cary, North Carolina.

Schneider, W. J. 1992. Lipoprotein receptors in oocyte growth. Clin. Investig. 70:385-390.

Schneider, W. J. 1995. Yolk precursor transport in the laying hen. Curr. Opin. Lipidol. 6:92-96.

Squires, E. J. and S. Lesson. 1988. Aetiology of fatty liver syndrome in laying hens. Br. Vet. J. 144:602-609.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, New York, New York.

Takeda, Y., F. S. Zuki and H. Inoue. 1963. Citrate cleavage enzyme. In: Methods in Enzymology. Academic Press Inc. New York, Vol. 5:154.

Walzem, R. L., P. A. Davis and R. J. Hansen. 1994. Overfeeding increase very low density lipoprotein diameter and causes the appearance of a unique lipoprotein particle in association with failed yolk deposition. J. Lipid Res. 35:1354-1366.

Wang, H. T. 2001. Effects of Surgical caponization and administration of estradiol to chicken embryos on daily activity, agonistic behavior, growth performance, carcass traits and sensory evaluation of males Taiwan country chickens. Master thesis. National Chung-Hsing University, Taichung, Taiwan.

Whitehead, C. C., R. L. Hood, G. S. Heard and R. A. E. Pym. 1984. Comparison of plasma very low density lipoproteins and lipogenic enzymes as predictors of fat content and food conversion efficiency in selected lines of broiler chickens. Br. Poult. Sci. 72:1479-1491.

Yeh, Y. Y., G. A. Leveille and J. H. Wiley. 1970. Influence of dietary lipid on lipogenesis and on the activity of malic enzyme and citrate cleavage enzyme in liver of the growing chick. J. Nutr. 100:917-927.

Yeh, Y. Y. and G. A. Leveille. 1971. Studies on the relationship between lipogenesis and the level of coenzyme A derivatives, lactate and pyruvate in the chick liver. J. Nutr. 101:911-918.