Pertanika J. Trop. Agric. Sci. 38 (4): 455 - 464 (2015)

TROPICAL AGRICULTURAL SCIENCE

Journal homepage: http://www.pertanika.upm.edu.my/

Meat Characteristics of Red Jungle Fowl *(Gallus gallus Spadiceus)*, Malaysian Domestic Chickens *(Gallus gallus Domesticus)* and Commercial Broiler

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ABSTRACT

The meat characteristics of Red jungle fowl (*Gallus gallus Spadiceus*) and Malaysian Domestic chicken (*Gallus gallus Domesticus*), which are known as slow growing birds, were studied. Results were compared with those of the commercial broilers (ROSS) which are fast growing birds. The objective of the study is to determine the meat characteristics (pH, muscle fibre diameter and collagen content) of the breeds and the correlation to their meat quality. For this purpose, a total of 90 chickens (30 chickens for each breed) were used in this study. The chickens in each group were sacrificed at 20, 56 and 120 days post-hatching. Findings indicated that collagen content, pH, cooking loss and shear force values in Red jungle fowl and Malaysian Domestic chicken were significantly higher ($P<0.05$) than the commercial broilers. The smaller muscle fibre diameters and lower glycogen reserved contributed to higher pH. Meanwhile, the collagen content showed significantly ($P<0.05$) positive correlation to shear force and more prominent factors than the size of muscle fibre that determines tenderness of the meat. The commercial broilers' meat is much tender than that of the Malaysia Domestic chicken and Red jungle fowl.

Keywords: Red jungle fowl, Malaysian Domestic chicken, Commercial broilers, meat characteristic, correlation, meat quality.

ARTICLE INFO

Article history:
Received: 6 June 2013
Accepted: 11 March 2015

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ISSN: 1511-3701

INTRODUCTION

The quality of meat can be described as the attractiveness of the meat to the consumers

(Wood *et al.*, 2003), encompassing diverse issues such as nutritional, hygienic, technological and sensory quality (Hofman, 1994). The sensory and physical quality of poultry product varies with growth rate and body composition (Duclos *et al*., 2007). Although it remains inconclusive, the correlation between pH, size of muscle fibre and collagen content attribute to the meat quality has been discussed by most researchers (Liu *et al.,* 1996). Skeletal muscles rich in collagen are less tender (Dransfield, 1977; Light *et al.,* 1985); however, other research has shown a weak relationship between collagen content and meat tenderness (Hunsley *et al.*, 1971).

In relation to meat quality, there are differing opinions regarding the diameter of muscle fibre that influences meat tenderness. In commercial broilers, Smith and Fletcher (1988) reported that an increase in myofiber diameter potentially leads to less tender meat. Furthermore, Rehfeidt *et al.* (2000) suggested that animal with greater fibre number and moderate size produce higher quality and quantity of meat.

The Red jungle fowl (Wall & Anthony, 1995) and the present Malaysian domestic chicken (Azahan & Zahari, 1983; Peterson *et al.,* 1991) are known as slow growth birds. The Red jungle fowl breeds are protected by the Malaysian government and there are potential niche market in the future and Malaysian domestic chickens are among the growing industries (Engku Elini Engku Arif, 2010). Nevertheless, scientifically based information on those breeds is extremely limited. On the other hand, commercial broiler chickens have gone tremendous progress in the selection to increased growth, feed conversion and carcass quality (Steven, 1991; Schreiweis *et al*., 2005).

However, there is no correlation study conducted on the meat characteristic and meat quality of Red jungle fowl and Malaysia domestic chickens in the literature. Thus, the objective of the study is to determine the meat characteristics (pH, muscle fibre diameter and collagen content) of the Red jungle fowl (RJ) and domestic chickens (DC) and their correlation with meat quality, as well as to determine which factors that significantly determine the tenderness of meat.

MATERIALS AND METHODS

Animals and Experimental Design

Red jungle fowls (RJ), Malaysian domestic chickens (DC) and commercial broilers (CB), comprising of 30 birds for each breed with mixed sexes, were used in this study. The eggs of RJ were supplied by a farmer who has RJ in his farm at Jenderam Hulu, Sepang in Selangor, Malaysia. The RJ was identified and confirmed through phenotypic characteristics which include colour, head, comb and lappet, ear lobes, tail, body size, leg and vocal (Amin Babjee, 2009). The eggs of DC were also supplied by the same farmer and reared in different cages. The DC was also identified and confirmed through their phenotypic characteristics which include colour, head, comb and lappet, ear lobes, tail, body size, leg and vocal which differ from those of the RJ (Aini, 1990;

Roberts, 2008; Amin Babjee, 2009). The eggs of both the RJ and DC were incubated and hatched in a laboratory in Universiti Putra Malaysia (UPM).

Day-old chicks (DOC) of commercial line (Ross) were supplied by a private hatchery (Linggi Poultry farm Sdn. Bhd., CP lot 1354, Mukim LubukTebrau, 33010 Kuala Kangsar, Perak, Malaysia). All the three breeds of chickens were reared in an experimental house (located at N 03. 00551º, E 101. 70501º in UPM) in different cages according to their age and breed. Feed and water were provided *ad libitum* consisting of standard commercial starter (201-P, Malayan Federal Flour Mill Sdn. Bhd) given from Day 1 to Day 21 post hatch, while finisher (203-P, Malayan Federal Flour Mill Sdn. Bhd) was given from Day 22 to Day 120 post hatch. All the birds were euthanized serially at Days 20, 56 and 120 post hatch through intravenous (cutaneous ulnar vein) administration of 80mg/kg of pentobarbitone sodium (Mitchell & Smith, 1991). As a standard for comparison, the comparisons were based on chronological time to examine differences in growth rather than physiological time (Chambers, 1990).

Sampling and Measurement

Ten birds were selected randomly from each breed and the *pectoralis major* muscle was selected for the analysis. The measurement of cross sectioning muscle fiber diameter was performed using a computerised image analyser (Leica DM LB2, Germany) after staining it with Haematoxylin and Eosin and six muscle bundles were selected randomly from each section and the diameter of muscle fibres was consistently evaluated. An attempt was made not to include the longitudinal and oblique muscle fibres so as to avoid the tendency of wrong measurement interpretation, and thus obtaining the most accurate results. The results were expressed as mean fibre diameter in a muscle bundle.

Meanwhile, pH measurements were carried out by using combined glass electrode pH meter (Mettler Toledo, USA) as described by Wattanachant *et al.* (2004). The samples were subjected to moist cooking at 80°C in a pre-heated water bath as described by Sazili (2003) for cooking loss determination. Measurement of meat tenderness was carried out by using Volodkovich shear force method. The total collagen analyses were determined by direct measurement of hydroxyproline after acid hydrolysis, as described by Reddy and Chukuka (1996). Hydroxyproline was converted to total collagen by using the factor of 8.0 (Kolar, 1990; Salakova *et al*., 2009).

Statistical Analysis

One-way ANOVA and Duncan's multiple range tests were used to elucidate differing means by using SPSS (17.0) programme.

RESULTS AND DISCUSSION

Fibers Diameter, pH and Collagen Content

The diameter of muscle fibres, pH and collagen content (mg/g) of the breast muscles in RJ, DC and CB at different ages are shown in Table 1. Within all the breeds, the diameter of the muscle fibres significantly increased (P<0.05) as the age increased. Both RJ and DC showed significantly (P<0.05) smaller fibre diameters as compared to the CB, whereas the diameter of RJ muscle fibre was the smallest (P<0.05) among the three breeds. Meanwhile, the diameter of the RJ muscle fibres was approximately 3 times smaller than CB at days 56 and 120 post hatch. As compared to DC, the diameter of RJ muscle fibres was significantly smaller (P<0.05) at days 56 and 120 post hatch. Small increase in the myofibres diameter (hypertrophy) in RF and DC were the results of slow growth of RJ and DC as compared to CB.

The muscle pH of RJ and DC was significantly higher (P<0.05) than the CB, as shown Table 1. High accumulations of lactic acids (Aberle *et al*., 2001; Duclos *et al*., 2007) due to anaerobic glycolytic pathway caused pH to decline. In this study, RJ and DC were found to have much smaller muscle fibres and less glycolytic muscle fibres than CB, and thus, the muscle pH of RJ and DC was higher than that of CB.

The significant reduction of the muscle pH in RJ and DC as the age increased (days 20 to 56 post hatch) in Table 1 might be due to the increased glycogen storage resulting from the increase in the muscle fibre diameters (Klosowska *et al*., 1993; Remignon *et al*., 1993). Meanwhile, higher glycolytic process might produce higher lactic acids accumulation after bleeding and this led to lower pH (Aberle *et al*., 2001; Duclos *et al*., 2007). Total collagen contents of the breast muscles in RJ and DC were significantly higher (P<0.05) than CB (Table 1). The total collagen of breast muscle for all the three breeds increased as the age increased and this finding agrees well with most previous studies (Dawson *et al*., 1991; Lee & Lin, 1993; Nakamura *et al*., 2004; Watanachant *et al*., 2004). Up to date, there have been no reported data on the collagen composition in RJ muscle. Smaller fibre diameters in RJ and DC might be the reason for the higher composition of collagen in the slow growing birds (Nakamura *et al*., 2004).

Shear Force Value and Cooking Loss

The shear force values in RJ and DC were significantly (P<0.05) higher than the CB at days 56 and 120 post hatch (Table 2). Among all the three breeds, the shear force values were found to increase with age of the chicken. Significantly higher compositions of collagen content in the breast muscles of RJ, followed by DC and the least in the CB (Table 1), were the reasons for the different values of the shear force between the breeds. High collagen contents associated with high shear force value and high toughness of the meat reduce the tenderness of meat (Sims & Bailey, 1981; Liu *et al.,* 1996; Fletcher, 2002; Lawrie, 2006). In this study, the CB meat was found to have better quality in term of meat tenderness than the meat of DC and RJ due to the lower collagen contents which result in lower shear force value.

In general, the mean percentages of cooking loss of breast muscles in RJ and DC were significantly higher (P<0.05) than CB (Table 2). The percentage of cooking loss of the breast muscle showed a similar

TABLE 1
Mean diameter (µm) of muscle fiber, pH and collagen content (mg/g) of breast muscle in RJ, DC and CB at different ages (mean ± SE)

	RJ			DC			CB		
	Diameter (µm)	pH	Collagen (mg/g)	Diameter (µm)	pH	Collagen (mg/g)	Diameter (µm)	pH	Collagen (mg/g)
Day20	21.71 ±0.20 $^{a, x}$	6.18 ± 0.05 $^{a, y}$	2.27± 0.26 $^{a, x}$	22.52 ± 0.47 $^{a, x}$	6.09 ± 0.06 $^{a, y}$	2.48 ± 0.21 ^{a,x}	31.76 ± 1.18 $^{b, x}$	5.89 ± 0.06 $^{b, x}$	0.72 ±0.16 ^{b,y}
Day56	27.54 ±0.79 $^{a, y}$	5.89 ± 0.05 $^{a, z}$	2.94 ± 0.25 $^{a, y}$	31.27 ± 0.55 $^{b, y}$	5.85 ± 0.04 $^{a, z}$	3.58± 0.10 $^{b, y}$	61.29 ± 1.39 $^{c, y}$	5.76 ± 0.06 $^{a, x}$	1.07 ±0.14 ^{c,y}
Day120	36.68 ±1.60 $^{a, z}$	5.91 ± 0.04 $^{a, z}$	5.21± 0.32 ^{a,z}	59.40 ±0.7 $^{b, z}$	5.70 ± 0.04 $^{b, z}$	4.52± 0.21 $^{a, z}$	84.51 ± 2.55 $^{c, z}$	5.74 ± 0.07 $^{b, x}$	2.54 ±0.43 ^{b,z}

^{abc} Mean values within a row with different superscript were significantly different (P<0.05).
^{xyz} Mean values within a column with different superscript were significantly different (P<0.05).

TABLE 2
Mean shear force value (kg) and percentage of cooking loss of breast muscles in RJ, DC and CB at different ages (mean ± SE)

	RJ		DC		CB	
	Shear Force (kg)	Cook loss(%)	Shear Force(kg)	Cook loss(%)	S.Force(kg)	Cook loss(%)
Day20	0.91 ±0.07 $^{a, x}$	14.59 ±0.50 $^{a, x}$	0.89 ±0.05 $^{a, x}$	16.35 ±0.78 $^{b, y}$	0.76 ±0.03 ^{b,x}	12.65 ±0.34 $^{c, y}$
Day56	1.49 ±0.11 $^{a, y}$	18.02 ±0.53 $^{a, y}$	1.42 ±0.04 $^{a, y}$	17.09 ±0.29 $^{a, y}$	1.20 ±0.06 $^{b, y}$	16.03 ±0.98 $^{b, z}$
Day120	1.71 ±0.07 $^{a, z}$	19.98 ±0.34 $^{a, z}$	1.74 ±0.11 $^{a, z}$	19.16 ±0.56 $^{a, z}$	1.41 ±0.09 ^{b,z}	17.05 ±0.63 $^{b, z}$

^{abc} Mean values within a row with different superscripts were significantly different (P<0.05).
^{xyz} Mean values within a column with different superscripts were significantly different (P<0.05).

pattern at days 56 and 120 post hatch, where it was the highest in RJ, followed by DC and the least in CB. The percentage of cooking loss of the breast muscle showed an increasing pattern as the age increased in all the breeds evaluated. The low pH of the breast muscle in CB (as shown in Table 1) causes higher protein denaturation (Van Laack *et al*., 2000; Barbut, 1997) and thus loss of water binding ability and functionality of many proteins (Fujii *et al*., 1991), which break the attraction of water to the protein. The denaturation of myosin head at low pH is also responsible for higher shrinkage within the myofiber that causes water to be squeezed out from the muscle (Offer, 1991); the current results however showed that percentage of cooking loss of breast muscle in RJ and DC was higher with higher pH values. Among the breeds, the percentages of cooking loss of the breast muscles increased with age although with no significant difference (P>0.05) for DC at days 20 to 56 post hatch and at days 56 to 120 post hatch for CB (Table 2).

The increase in the content of collagen within the muscles with age (as shown in Table 1) was found to be directly associated with the increase in the percentage of cooking loss. The results showed similar pattern for all the three breeds evaluated, suggesting that collagen content is a prominent factor than the pH of the muscles in determining the cooking loss of muscles. In term of meat quality, slow growing birds like RJ and DC have high content of collagen in the meat which causes high water loss during cooking as compared to CB meat. Further study should be conducted to evaluate the nutrient contents of meat after cooking.

Correlation Study

The relationship between muscle tenderness and collagen quality remains still inconclusive (Liu *et al.*, 1996). The result shows a positive correlation between collagen composition and shear force value at all age evaluated, with more significant positive association shown in RJ and DC at older age (Table 3). The increase in the stability of thermal and mechanical collagen with the increase in age (Bailey & Light, 1989) may also be the reason for the difference in the shear force values between the breeds.

There was also an increasing pattern of positive correlation between cooking loss and muscle fibre diameter of the shear force value as the age increased in all the three breeds evaluated (Table 3). During cooking, the shrinkage of collagen, especially thermal stable collagen, squeezes the water out and also toughens the collagen which leads to higher shear force value. Cooking contributes to toughness (Kopp & Bonnet, 1987) and the contribution of myofiber is even more prominent at the temperature above 60°C, where the shrinkage also reduces muscle fibre volume to increase their toughness (Lepetit *et al*., 2000).

In this study, the diameter of muscle fibre also shows a positive correlation to the shear force value. The increase of diameter as the age of the birds increases (Table 1) leads to increased toughness or less tender meat (Table 2). This may due to

TABLE 3
Correlation between shear force, collagen, cooking loss and muscle fibre diameter of breast muscles in RJ, DC and CB at different ages

	Shear Force								
	Day20			Day56			Day120		
	RJ	DC	CB	RJ	DC	CB	RJ	DC	CB
Collagen	0.41	0.36	0.25	0.74*	0.57	0.69	0.81*	0.82*	0.43
Cooking loss	0.19	0.71	0.36	0.82*	0.40	0.24	0.72*	0.73*	0.64
Diameters	0.37	0.56	0.43	0.47	0.73*	0.49	0.61	0.71	0.71

* shows significant difference at $P<0.05$

the increased content of collagen in the meat as the age increased (Table 1).

CONCLUSION

The collagen composition, pH, cooking loss and shear force values in RJ and DC were found to be higher than the CB. Thus, the meat of Red jungle fowl and Malaysian Domestic chicken was less tender than that of the Commercial broiler. The muscle fibre diameters and glycogen reserved are the main factors contributing to muscle pH. The increasing pattern of the collagen contents within the muscle as the age increased was the reason for the increase in the percentage of cooking loss, suggesting collagen content as a more prominent factor than pH in determining the cooking loss of meat. There was also a positive correlation between the collagen composition and shear force value, as well as the increasing pattern in the positive correlation between cooking loss and muscle fibre diameter to shear force as the age increased in all the three breeds evaluated. This led to less tender meat. Thus, the diameter of muscle fibre could potentially lead to less tender meat. In this study, however, the collagen composition was the more prominent factor influencing meat tenderness than the diameter of the muscle fibre. The higher collagen content in the muscle results in tougher meat or less tender meat. Good quality meat should consist less collagen to produce less cooking loss and much tender meat. CB meat is much tender and has better quality than DC and RJ at the same age of evaluation. The age of the breeds is a very important factor influencing collagen content, and thus a further research on Malaysian Domestic chicken and Red jungle fowl should emphasise on chronological age in order to determine a suitable time to market the birds and fulfil customers' need for quality meat.

REFERENCES

Aberle, E. D., & Stewart, T. S. (1983). Growth of fiber types and apparent fiber number in skeletal muscle of broiler-and layer type chicken. *Growth*, *47*, 135-144.

Aberle, E. D., Forrest, J. C., Gerrard, D. E., & Mills, E. W. (2001). Principles of Meat Science (4th Edition). Dubuque, IA: Kendall and Hunt Publication Co. pp. 165-185.

Aini, I. (1990). Indigenous chicken production in South-east Asia. *World Poultry Science Journal, 46*, 51- 54.

Alvarado, C. Z., Wenger, E., & O'Keefe, S. F. (2005). Consumer perception of meat quality and shelf-life in commercially raised broilers compared to organic free range broilers. *Poultry Science, 84*(1), 129.

Amin Babjee, S. M. (2009). *The Red Jungle Fowl of Peninsular Malaysia*. Perpustakaan Negara Malaysia. pp. 20-35.

An, J. Y., Zheng, J. X., Li, J. Y., Zeng, D., Qu, L. J., Xu, G. Y., & Yang, N. (2010). Effect of myofiber characteristics and thickness of perimysium and endomysium on meat tenderness of chickens. *Poultry Science, 89*, 1750-1754.

Azahan, E. A., & Zahari, M. W. (1983).Observations on some characteristics of the carcass and meat of Malaysian 'kampung' chicken. *MARDI Research Bulletin, 11*, 225-232.

Barbut, S. (1997). Problem of pale soft exudative meat in broiler chickens. *British Poultry Science, 38*, 355–358.

Baily, A. J., & Light, N. D. (1989). Connective Tissue in Meat and Meat Product. *Meat Science, 2*, 1-28.

Bouton, P. E., Harris, P. V., Shorthose, W. R., & Baxter, R. I. (1973).A comparison of the effects of aging, conditioning and skeletal restraint on the tenderness of mutton. *Journal of Food Science*, *38*, 932-937.

Castellini, C., Mugnai, C., & Dal Bosco, A. (2002a). Effect of organic production system on broiler carcass and meat quality. *Italy Journal Food Science, 14*, 401–412.

Chambers, J. R. (1990). Genetic of growth and meat production in chicken. *Poultry Breeding and Genetics,* 559-643

Culioli, J., Touraille, C., Bordes, P., & Giraud, J. P. (1990). Carcass and meat quality in fowls given the "farm production label". *ArchivGeflugelkunde, 53*, 237–245.

Dawson, P. L., Sheldon, B. W., & Miles, J. J. (1991). Effect of aseptic processing on the texture of chicken meat. *Poultry Science, 70*, 2359–2367.

Dransfield, E. (1977). Intramuscular composition and texture of beef muscles. *Journal of the Science of Food and Agriculture, 28*, 833.

Dransfield, E., & Sosnicki, A. A. (1999). Relationship between Muscle Growth and Poultry Meat Quality. *Poultry Science, 78*, 743–746.

Duclos, M. J., Berri, C., & Le Bihan-Duval, E. (2007). Muscle Growth and Meat Quality. *Journal of Applied Poultry Research, 16*, 107–112.

Elini E. A., Tapsir, S., Sarmin, S., & Abu Kasim, A. (2010). Cost and return for local fowl rearing. *Economic Technology Management Review*, *5*, 41-49.

Farmer, L. J., Perry, G. C., Lewis, P. D., Nute, G. R., Piggot, J. R., & Patterson, R. L. S. (1997). Responses of two genotypes of chicken to the diets and stocking densities of conventional UK and Label Rouge production systems–II. Sensory attributes. *Meat Science, 47*, 77–93.

Fletcher, D. L. (2002). Poultry meat quality. *Journal of World's Poultry Science, 58*, 131–145.

Forrest, J. C., Aberle, E. D., Hedrick, H. B., Judge, M. D., & Merkel, R. B. (1975). Principles of Meat Science. San Francisco: W. H. Freeman and Company, pp. 42-54.

Fujii, J., Otsu, K., Zorzato, F., Deleon, S., Khanna, V. K., & Weiler, J. E. (1991). Identification of a mutation in porcine ryanodine receptor associated with malignant hyperthermia. *Science 253*, 448–451.

Hunsley, R. E., Vetter, R. L., Kline, E. A., & Burroughs, W. (1971). Effects of Age and Sex on Quality, Tenderness and Collagen Content of Bovine Longissimus Muscle. *Journal of Animal Science, 3*, 33-938.

Hofman, K. (1994). What is quality? Definition, measurement and evaluation of meat quality. *Meat Focus International, 3*, 73-82.

Klosowska, D. B., Rosinski, A., & Elminowska-Wenda, G. (1993). Microstructural characteristics of the pectoralis muscle of white Italian geese. 144–148. In *Proceedings of the XI European Symposium on the Quality of Poultry Meat*. Vol. 1. Tours, France, 144–148.

Kolar, K. (1990). Colorimetric determination of hydroxyproline as measure of collagen content in meat and meat products: NMKL collaborative study. *Journal of AOAC, 71*, 54-57.

Kopp, J., & Bonnet, M. (1987). Stress–strain and isometric tension measurements in collagen. In A. M. Pearson, T. M. Dutson, & A. J. Bailey (Eds.), *Advances in Meat Research*, *4*, 163–185.

Lawrie, R. A., & Ledward, D. A. (2006). Lawrie's Meat Science (7th Edition). Cambridge, England: Woodhead Publishing Limited.

Lee, H. F., & Lin. L. C. (1993). Studies on the general composition and characteristics of meat quality of the Taiwan country chicken and broiler. *Journal of Food Science (Taiwan) 20*, 103—111.

Lepetit, J., Grajales, A., & Favier, R. (2000). Modelling the effect of sarcomere length on collagen thermal shortening in cooked meat: consequence on meat toughness. *Meat Science, 54*, 239–250.

Liu, A., Nishimura, T., & Takahashi, K. (1996). Relationship between Structural Properties of Intramuscular Connective Tissue and Toughness of Various Chicken Skeletal Muscles. *Meat Science, 43*(1), 43-49.

Light, N. D., Champion, A. E., Voyle, C. A., & Bailey, A. J. (1985). The role of epimysial, perimysial and endomysial collagen in determining texture in six bovine muscle. *Meat Science, 13*, 137.

Mitchell, M. A., & Smith, M. W. (1991). The effects of genetic selection for increased growth rate on mucosal and muscle weights in the different regions of the small intestine of the Domestic Fowl (*Gallus domesticus*). *Comparative Biochemistry and Physiology*, *99*, 251-258.

Nakamura, Y. N., Iwamoto, H., Shiba, N., Mitachi, H., Tabata, S., & Nishimura, S. (2004). Developmental states of the collagen content, distribution and architecture in *pectoralis, iliotibialislateralis* and *puboischiofemoralis* muscles of male Red Cornish, New Hampshire and normal broilers. *British Poultry Science, 45*, 31-40.

Offer, G. (1991). Modeling of the formation of pale, soft and exudative meat effects of chilling regime and rate and extent of glycolysis. *Meat Science*, *30*, 157–184.

Petersen, J. B., Guzman Jr., M. R. D., and Wu, M. C. (1991). *Catalogue of the native poultry of Southeast Asia*. Food and Fertilizer Technology Center for Asian Pacific Region, Taiwan. Taiwan Livestock Research Institute. Taiwan, pp.35-45.

Rehfeldt, C., Feidler, I., Dietl, G., & Ender, K. (2000). Myogenesis and postnatal skeletal muscle cell growth as influence by selection. *Livestock Production Science, 66*(2), 177-188.

Reddy, G. K., & Chukuka, S. E. (1996). Simplified Method for analysis of Hydroxyproline in Biological Tissues. *Clinical Biochemistry, 29*(3), 225-229.

Remignon, H., Lefaucheur, L., Blum, J. C., & Ricard, F. F. (1993). Effect of divergent selection for body weight on three skeletal muscle characteristic in chicken. *British Poultry Science, 35*, 65-76.

Roberts, V. (2008). *British Poultry Standards* (6th edition). Oxford, United Kingdom: Blackwell Publishing, pp. 169-171.

Sazili, A. Q., Lee, G. K., Parr, T., Sensky, P. L., Bardsley, R. G., & Buttery, P. J. (2003). The effect of altered growth rates on the calpain proteolytic system and meat tenderness in cattle. *Journal of Meat Science, 66,* 195-201.

Salakova, A., Strakova, E., Valkova., V., Buchtova, H., & Steinhauserova, I. (2009). Quality Indicators of Chicken Broiler Raw and Cooked Meat Depending on Their Sex. *ActaVeterinaria Brno, 78*, 497-504.

Schreiweis, M. A., Hester, P. Y., Settar, P., & Moody, D. E. (2005). Identification of quantitative trait loci associated with egg quality, egg production and body weight in an F2 resource population of chicken. *Journal of Animal Genetics*, *37*, 106 – 112.

Sims, T. J., & Bailey, A.J. (1981). Relationship between structural properties of intramuscular tissue and toughness of various chicken skeletal muscle. *Meat Science, 2*, 29.

Smith, D. P., & Fletcher, D. L. (1988). Chicken breast muscle fibre type and diameter as influenced by age and intramuscular location. *Poultry Science*, *67*, 908–913.

Stevens, L. (1991). *Genetics and Evolution of the Domestic Fowl*. New York, USA: Cambridge University Press. pp. 125-131.

Van Laack, R. L., Liu, C. H., Smith, M. O., & Loveday, H. D. (2000).Characteristics of pale, soft, exudative breast meat. *Poultry Science, 79*, 1057–1061.

Wall, C. W., & Anthony, N. B. (1995). Inheritance of carcass variables when Giant Jungle Fowl and Broilers achieve a common physiological body weight. *Poultry Science*, *74*, 231-236.

Wattanachant, S., Benjakul, S., & Ledward, D. A. (2004). Composition, Colour and Texture of Thai Indigenous and Broiler Chicken Muscle. *Poultry Science*, *83*, 123-128.

Wood, J. D., Richardson, R. I., Nute, G. R., Fisher, A. V., Campo, M. M., & Kasapidou, E. (2003). Effects of Fatty acids on meat quality. *Meat Science, 66*, 21-32.