Asian-Aust. J. Anim. Sci.
Vol. 20, No. 1 : 106 - 111
January 2007
www.ajas.info

Effect of the Length of Feed Withdrawal on Weight Loss, Yield and Meat Color of Broiler

D. H. Kim, Y. M. Yoo, S. H. Kim, B. G. Jang, B. Y. Park, S. H. Cho, P. N. Seong, K. H. Hah J. M. Lee, Y. K. Kim and I. H. Hwang*
National Livestock Research Institute, RDA, Suwon 441-350, Korea

ABSTRACT : The current study was conducted to determine the optimum length of feed withdrawal for pre-harvest broilers. A total of three hundred broilers were sampled from an industrial population, and 30 chicks for each weight group (e.g., 1.5 and 2.5 kg) were randomly assigned to feed withdrawal treatments for 0, 3, 6, 9 and 12 h. Weight loss, yield, muscle pH, objective meat color and weights of gastro intestinal contents, crop, gizzard, provenriculus, small intestine, caecum, and rectum were determined. Live weight loss was significantly ($p<0.05$) increased as length of feed withdrawal extended. A significant ($p<0.05$) carcass yield for both 1.5 and 2.5 kg groups coincided after 9 and 6 h feed withdrawal, respectively. Net weights of intestinal contents for crop and gizzard were significantly ($p<0.05$) reduced by 6 h, and the reduction for proventriculus and small intestine occurred from 3 h. A noticeable effect of feed withdrawal on pH for breast muscle at 3 h *postmortem* occurred only when chicks were fasted for 3 h of which pH (6.05) was significantly ($p<0.05$) higher than that for other groups including the control (5.74). There was a linear tendency of higher lightness (Hunter L* value) numerically for chicks fasted for longer periods. The highest coefficient of determinations of regression models to estimate weight loss as a function of fasting period and body weights were achieved, when the models included both linear and quadratic terms for fasting period, and linear term for both 1.5 (R^2 = 0.76) and 2.5 kg (R^2 = 0.78) body weight groups. Given the practical aspect, approximately 1.5 kg of body weight is dominant, weight loss could be predicted by the following function: live weight loss = 26.6-0.28×(fasting period)^2+12.34×pasting period-0.012×body weight, R^2 = 0.76. Current data implied that the optimum fasting time for pre-slaughter chicks varied depending on slaughter weight; 6 and 9-h fasting were recommendable for 2.5 and 1.5 kg chicks, with little effect on objective meat color. (**Key Words** : Feed Withdrawal, Weight Loss, Meat Color, Broiler)

INTRODUCTION

Consumers' demands and expectations on safety and high quality for chicken meat have been elevated at the wake of the incidence of bird influenza across the world. Pathogenic microorganisms such as Salmonella and Campylobacter residue in gastro intestinal track, and cause the cross-contamination of meat during the process of slaughter and processing (Corrier et al., 1999). For the same reason feed withdrawal of chicks prior to harvest is being considered a significant practice to ensure meat hygiene as feed could be one of the primary source of pathogenic contamination associated with gastro-intestinal content and its excrement (Hargis et al., 1995).

Furthermore, poultry industry has been well aware of the importance of pre-harvest feeding regime, because it is a significant factor affecting chicken's meat quality, through its effect on initial glycogen loading at the time of *postmortem* anaerobic glycolysis. It has been well documented that glycogen content in muscle tissue determines the rate and extent of pH decline during the onset of rigor mortis (Hwang et al., 2003). Given the predominant white muscle of chicks with a limited capacity of glycogen storage, feeding regime prior to slaughter is of particular importance for optimum *postmortem* glycolytic rate and consequently for the production of favorable high quality meat (Lyon and Buhr, 1999).

From the industrial point of view, however, economic aspect of feed withdrawal cannot be overlooked because this basically results in weight loss and yield (Duke et al., 1997). Previous studies (Duke et al., 1997; Randall et al., 1994) have demonstrated that weight loss of chicks varied depending on age, gender, energy content in feeds, length of

* Corresponding Author: I. H. Hwang. Institute of Rare Earth for Biological Application, Chonbuk National University, Jeonju, 561-756, Korea. Tel: +82-(0)63-270-2605, Fax: +82-(0)63-270-2612, E-mail: inho.hwang@chonbuk.ac.kr
Received March 18, 2006; Accepted April 19, 2006

feed withdrawal, and/or transport condition. It has been shown that reduction in carcass yield associated with feed withdrawal was largely attributed to moisture loss and fat decomposition (Norhcutt and Savage, 1996; Reisenfeld et al., 1981). A short period of feed withdrawal (approximately 6 h) prior to slaughter resulted in weight loss, but that had a limited effect on yield as being associated with the excrement of gastro internal content. However, further increase in the withdrawal decreased yield due to reduction in moisture content and fat decomposition (Veerkamp, 1986). Taking the above reasons into account, chicken industry across the world has attempted to determine the optimum length of feed withdrawal, under their industrial environment, to secure the best yield-with ensuring meat safety.

While feed withdrawal program between countries varies largely due to the differences in final weight, feed composition, feeding program and regulation (Bilgili, 2002), accessible information under Korean industrial circumstances are meager. Current study was, therefore, designed to determine and identify the optimum length of feed withdrawal for Korean chicken industry.

MATERIALS AND METHODS

Animal, experimental design and treatment

A total of three hundred broilers (150 birds for 1.5 kg body weight, 150 birds of 2.5 kg body weight) were sampled from an industrial population, and 30 chickens for each weight groups were randomly assigned to feed withdrawal treatments for 0, 3, 6, 9 and 12 hours, respectively, while preventing from access to water. Initial body weight was determined for all chicks immediately prior to the treatment. Chicks were transported for approximately 1.5 h to the experimental abattoir in the National Livestock Research Institute by the conventional transport system (i.e., 30 chicks/crate). During the treatment, chicks were held in their own crate of which average temperature and humidity were 20°C and 70%, respectively. After slaughtering and disembowelling, carcasses were chilled at 4°C during the experimental period. Knife-removable abdominal fat pad and tissues were trimmed off from each carcass, and both carcass and gastro intestinal content weights were determined.

Determination of objective measurements

Weight loss was calculated from weight difference between before and after the treatment, and expressed as percentage. Percentage of yield was calculated from carcass weight *versus* live weight determined before the treatment. Weight of gastro intestinal contents, crop, gizzard, proventriculus, small intestine, caecum, and rectum were determined immediately after slaughtering process where excessive water was removed from each organelle using a commercial paper towel (Wipe All L20, U-Han Kimberly Co.). pH was determined for breast fillet and thigh at 1, 3 and 12 h *postmortem* using a portable pH meter (pH*K21, NWK Co. Germany) and noted as pH_1, pH_3 and pH_u, respectively. Meat color was determined on the surface of breast fillet after a 30 min blooming time at 4°C using a Chroma meter (CR301, Minolta Co. Japan), standardized on the white board of y = 92.4, x = 0.3136 and y = 0.3196.

Statistical analysis

Least square mean and standard error of each treatment for weight loss, carcass yield, weight of gastrointestinal content, muscle pH and meat color were calculated by applying the ANOVA procedure, and effects of the treatment on each characteristic were evaluated by the Duncan procedure at the probability level of 0.05, against residual error term (SAS, 1996). Regression coefficients to estimate weight loss as a function of fasting period were calculated by applying the general linear model. Inclusion of live weight into the model was also examined to evaluate its effect on the prediction level (coefficients of determination) (SAS, 1996).

RESULTS AND DISCUSSION

Feed withdrawal prior to slaughter is one of the most important critical control point (CCPs) across the world including Korean chicken industry because that reduces cross contamination of pathogenic microorganisms originated from animal excreta (Kim et al., 2004). However, extended length of period weakens intestinal tracks, raising a risk of exploding during slaughtering process. Furthermore, that also causes increase in pH of intestinal tracks, which consequently provides favorable environment for pathogenic microorganisms (Hinton et al., 1998). Other interesting aspects of industries are weight and yield loss as a result of excessive feed restriction (Lyon et al., 1991). The optimum length of feed restriction time should be such that allows chicks to emit intestinal contents without affecting the yield.

Table 1 presents the effects of feed withdrawal on live weight loss, carcass yield, and weight of gastro intestinal content as a function of length of the period (0, 3, 6, 9 and 12 h). The results showed that live weight loss was significantly ($p<0.05$) increased as length of feed withdrawal was extended from 0 to 12 h prior to slaughter for both 1.5 and 2.5 kg groups. An average loss per hour was approximately 11.5 g for both body weight classes, and resulted in a total of 138 g loss (approximately 6.3%) after 12 h of the experimental period. When length of feed withdrawal was same, higher weight group showed a greater weight loss: 1.5 and 2.5 kg groups resulted in 116

Table 1. Least square mean and standard deviation for live weight loss (percentage), carcass yield and weight of gastro intestinal content as a function of the length of feed withdrawal

	Length of feed withdrawal (h)				
	0	3	6	9	12
Live weight loss (g) (percentage)					
1.5 kg	$0.00^{e,*}$	50.37 ± 17.60^{d}	70.43 ± 17.61^{c}	91.46 ± 22.91^{b}	115.96 ± 31.8^{a}
	(0.00)	(3.03 ± 0.98)	(4.10 ± 0.95)	(5.32 ± 1.46)	(6.81 ± 1.76)
2.5 kg	0.00^{e}	74.48 ± 23.43^{d}	97.10 ± 27.46^{c}	129.12 ± 27.48^{b}	153.14 ± 42.45^{a}
	(0.00)	(2.74 ± 0.94)	(3.72 ± 0.93)	(4.96 ± 1.21)	(5.86 ± 1.69)
Overall	0.00^{e}	68.37 ± 24.39^{d}	87.77 ± 27.49^{c}	112.8 ± 31.61^{b}	138.4 ± 42.45^{a}
	(0.00)	(2.81 ± 0.95)	(3.85 ± 0.95)	(5.12 ± 1.32)	(6.24 ± 1.76)
Carcass yield (%)					
1.5 kg	68.2 ± 2.15^{a}	66.9 ± 1.47^{a}	67.4 ± 2.39^{a}	67.8 ± 1.67^{a}	65.2 ± 1.63^{b}
2.5 kg	70.0 ± 1.95^{ab}	70.0 ± 1.84^{ab}	70.2 ± 1.53^{a}	69.0 ± 1.54^{c}	69.2 ± 1.84^{c}
Overall	69.5 ± 2.13^{a}	69.4 ± 2.15^{a}	69.4 ± 2.21^{a}	68.5 ± 1.69^{b}	67.8 ± 2.59^{b}
Weight of gastro intestinal content (g)					
Crop	12.57 ± 14.18^{a}	11.26 ± 31.56^{ab}	0.57 ± 1.58^{b}	0.05 ± 0.12^{b}	0.12 ± 0.43^{b}
Gizzard	19.68 ± 9.22^{a}	16.23 ± 4.61^{ab}	14.49 ± 6.51^{b}	13.54 ± 5.72^{b}	11.5 ± 4.08^{b}
Preventriculus	1.15 ± 1.04^{a}	0.52 ± 0.6^{b}	0.38 ± 0.38^{b}	0.18 ± 0.27^{b}	0.31 ± 0.48^{b}
Small intestine	36.04 ± 11.32^{a}	12.71 ± 8.21^{b}	10.57 ± 5.28^{b}	10.4 ± 5.14^{b}	8.75 ± 3.58^{b}
Cecum	4.36 ± 2.84	5.05 ± 3.98	4.76 ± 3.01	3.95 ± 2.42	3.46 ± 2.24
Rectum	0.78 ± 0.63	0.81 ± 0.6	0.55 ± 0.25	0.6 ± 0.52	0.58 ± 0.42

* Means bearing different letters within the same raw significantly differ ($p<0.05$).

and 153 g loss after 12 h, respectively. On the other hand, a significant ($p<0.05$) carcass yield for both 1.5 and 2.5 kg groups coincided after 9 and 6 hours feed withdrawal, respectively. The results implied that feed withdrawal prior to entering slaughtering process for 6 to 9 h would be the optimum practice under the Korean industry circumstance. The prime reason for the assumption was driven from the fact that longer than 9 h could lead to economic loss for chicken farmers. Current study did not determine glycogen content in muscle tissue. However, previous studies (Reisenfeld et al., 1981; Bigili, 2002) showed that a significant reduction in live weight occurred after 6 h of feeding restriction, and that was associated with the excretion of intestinal wastes and so the yield was not at all affected. On the other hand, after 6 h, reduction in yield was driven from glycogen depletion in muscle tissue, followed by fat decomposition. The rationale was further evidenced by changes in gastro intestinal content during the fasting periods (Table 1). Net weights of intestinal contents for crop and gizzard were significantly ($p<0.05$) reduced by 6 h, and the reduction for proventriculus and small intestine occurred from 3 h. After this period, there was no noticeable change in measurable weight which simulated the previous report (Northcutt and Savage, 1996).

Korean chicken farmers are practically reluctant to enforcing feed withdrawal prior to slaughter because they believe transport period from farm to abattoir including waiting period gives an enough fasting period. For the reason, feed withdrawal period varied depending on the length of transit and waiting hours at the abattoir. In fact, industrial observation revealed that amount of crop in ingluvies after eviscerate was very limited (data not shown). However, the observation did not mean that feed withdrawal was satisfactorily performed by farmers, and cross-contamination of pathogenic microorganisms was prevented. On the other hand, the empty ingluvies was rather expected from the chickens when long transit and waiting periods were taken into account and cross-contamination originated from chicken's excretes could occur during transportation and waiting periods (Northcutt and Savage, 1997). This notion could be supported by the fact that chicks are generally slaughtered within 6 hours after loading at farm under Korean industrial situation and, as shown in Table 1, carcass yield was not decreased by a 6-h fasting.

Meat color, which is in part the reflectance of water-holding capacity (Pearson and Young, 1989), is the most important quality traits determining consumers' preference (Warner et al., 1997; Rosenvold and Andersen, 2003). Both changes in muscle pH during the onset of *rigor mortis*, and ultimate pH have a significant effect on meat quality because these imply the rate of *postmortem* metabolism in muscle tissue, and subsequently govern protein denaturation and water-holding capacity (Hwang et al., 2003). As feed withdraw prior to slaughter has a great effect on glycogen content in muscle tissue and the rate and extent of

Table 2. Least square mean and standard deviation for pH at 1 (pH_1), 3 (pH_3) and 12 (pH_u) hours *postmortem* and Hunter color dimensions for pectorial and thigh muscles as a function of the length of feed withdrawal

	Length of feed withdrawal (hours)				
	0	3	6	9	12
Pectorial muscle					
pH_1	6.00±0.09*	6.17±0.10	5.99±0.12	6.00±0.17	6.09±0.25
pH_3	5.74±0.18^b	6.05±0.15^a	5.93±0.15^b	5.86±0.21^b	5.97±0.14^b
pH_u	5.72±0.18^b	5.97±0.21^a	5.96±0.10^a	5.77±0.19^b	5.77±0.09^b
Thigh muscle					
pH_1	6.28±0.14	6.36±0.12	6.37±0.11	6.33±0.22	6.36±0.20
pH_3	6.21±0.28	6.31±0.24	6.28±0.25	6.25±0.35	6.26±0.34
pH_u	6.24±0.24	6.20±0.37	6.31±0.19	6.24±0.37	6.15±0.45
Pectorial muscle					
Hunter L*	49.56±2.34	49.16±2.73	48.67±2.81	48.45±1.38	47.10±4.20
Hunter a*	-0.03±1.12	-0.32±0.81	-0.60±1.03	-0.46±1.20	0.75±1.64
Hunter b*	10.47±1.41	12.06±2.33	11.18±2.69	9.75±2.38	9.07±3.68
Thigh muscle					
Hunter L*	49.56±2.34	49.16±2.73	48.67±2.81	48.45±1.38	47.10±4.20
Hunter a*	-0.03±1.12	-0.32±0.81	-0.60±1.03	-0.46±1.20	0.75±1.64
Hunter b*	10.47±1.41	12.06±2.33	11.18±2.69	9.75±2.38	9.07±3.68

* Means bearing different letters within the same row significantly differ ($p<0.05$).

Table 3. Regression coefficients and coefficients of determination (R^2) for the effects of feed withdrawal period (FWP) and/or live body weight on weight loss

Body weight	Independent variables*				R^2
	Intercept	FWP	FWP×FWP	Body weight	
1.5 kg					
	26.64	12.34	-0.28	-0.01221	0.76
	6.31	12.27	-0.27	NI[1]	0.76
	26.16	8.97	NI	-0.00881	0.75
	11.37	9.00	NI	NI	0.75
2.5 kg					
	-34.57	-0.76	21.20	0.01572	0.78
	6.50	-0.78	21.24	NI	0.77
	-24.03	NI	12.09	0.01714	0.74
	11.37	NI	9.00	NI	0.75
Overall					
	-49.23	18.53	-0.61	0.02376	0.76
	7.443	18.53	-0.65	NI	0.70
	-39.71	11.20	NI	0.02457	0.73
	19.65	10.71	NI	NI	0.67

[1] Not included in the model.

* Models included animal as a random term.

postmortem glycolysis, we measured changes in pH and objective meat color for both pectorial and thigh muscles (Table 2). The data revealed that a noticeable effect of feed withdrawal on pH of breast muscle at 3 h *postmortem* occurred only when chicks were fasted for 3 h of which pH (6.05) was significantly ($p<0.05$) higher than that for other groups including the control (5.74). At 12 h *postmortem*, both 3- and 6-hour treatments showed significantly ($p<0.05$) higher pH (5.97 and 5.96, respectively) than other groups. Lyon and Buhr (1999) reported that feed withdrawal reduced the time course of rigor development. On the basis of the previous study, we faced difficulty to understand underlying rationale of the current results; why the 3-h group at 3 h *postmortem* and 3- and 6-h groups at 12 h *postmortem* resulted in the slowest rate of rigor development. In more depth insight, the difference in pHs between the treatment groups was limited in spite of the statistical significance. Taking an early study (Kotula and Wang, 1994) who reported that the effect of feed restriction on slowing down the rate of rigor development occurred after 36-h treatment, the current data might be in part contributed to the length of fast period. On the other hand, it was of particular interest that the treatment, regardless of fasting length, had no effect on pH in thigh muscle, implying that glycogen content and *postmortem* metabolic rate in leg muscle was not affected by the fasting treatment.

As discussed previously (Pearson and Young, 1985; Hwang et al., 2003), metabolic rate of pH had a significant effect on meat color. However, we could not detect any significant effect of the fasting treatment prior to slaughter on objective meat color dimensions (Table 2). In fact, there was numerically a linear tendency to have a higher lightness (Hunter L* value) for chicks fasted for longer periods, but the differences with relatively large deviations were not significant at 0.05% probability level by the Duncan multi comparing procedure. On the other hand, the results demonstrated that feed withdrawal within 12 h had a limited effect on meat color.

From the practical point of view in terms of reducing economic losses due to live weight, it is in a great demand to find out an optimum length of feed withdrawal period. Although previous studies identified a number of significant determinants of weight loss including initial body weight (Duke et al., 1997), temperature (May and Deaton, 1989), stress strength (Randall et al, 1994) and light intensity (May et al., 1990), current study attempted to estimate weight loss by applying the most important two parameters (e.g., fasting period and body weight). Table 3 presents quadratic and linear regression coefficients for weight loss as a function of the length of feed withdrawal and live body weight, and their coefficients of determination. The highest coefficient of determination was achieved when the model included linear and quadratic terms for fasting period and linear terms for initial weight for both 1.5 ($R^2 = 0.76$) and 2.5 kg ($R^2 = 0.78$) groups. Early pioneering studies (Veerkamp, 1978; Fletcher and Rahn, 1982) showed that weight loss caused by feed withdrawal was linearly related to fasting time, and they developed a linear regression for predicting weight loss as a function of fasting time. Up on this, current study demonstrated the values the same after glancing through the previous studies under Korean industrial circumstance. It was thought that the prime reason for the improvement of prediction rate by including quadratic and linear terms was related to the greater weight loss at early period of feed withdrawal, which was largely contributed to weight loss of gastro intestinal content, as previously discussed in Table 1. Given the practical aspect where approximately 1.5 kg of body weight is dominant, weight loss could be predicted by applying the following function; live weight loss = $26.6-0.28\times(\text{fasting period})^2+12.34\times\text{pasting period}-0.012\times\text{body weight}$, $R^2 = 0.76$.

IMPLICATIONS

The current study demonstrated that the length of feed withdrawal has a significant effect on both weight loss and yield, and the optimum fasting time for pre-slaughter chicks varied depending on slaughter weight; 6 and 9-h fasting were recommendable for 2.5 and 1.5 kg chicks, respectively. In general terms, postmortem metabolic rate and objective meat colors were little influenced by the length of pre-harvest feeding restriction up to 12 hours. Quadratic models to estimate weight loss as a function of length of feed withdrawal and initial body weight developed for Korean chicken industry.

REFERENCES

Bilgili, S. F. 2002. Slaughter quality as influenced by feed withdrawal. World's Poult. Sci. J. 58:123-131.

Corrier, D. E., J. A. Byrd, B. M. Hargis, M. E. Hume, R. H. Bailey and L. H. Stanker. 1999. Presence of *salmonella* in the crop and ceca of broiler chickens before and after preslaughter feed withdrawal. Poult. Sci. 78:45-49.

Duke, G. E., B. Maureen and S. Noll. 1997. Optimum duration of feed and water removal prior to processing in order to reduce the potential for fecal contamination in turkeys. Poult. Sci. 76:516-522.

Fletcher, D. L. and A. P. Rahn. 1982. The effect environmentally modified and conventional housing types on broiler shrinkage. Poult. Sci. 61:67-74.

Hargis, B. M., D. J. Caldwell, R. L. Brewer, D. E. Corrier and J. R. Deloach. 1995. Evalution of chiken crop as a source of *Salmonella* contamination for broiler carcasses. Poult. Sci. 74:1548-1552.

Hinton, A. Jr., R. J. Bujr and K. Ingram. 1998. Feed withdrawal and carcass microbiological counts. Proc. Georgia Poult. Conference, Athens, GA.

Hwang, I. H., C. E. Devine and D. L. Hopkins. 2003. The biochemical and physical effects of electrical stimulation on beef and sheep meat tenderness. Meat Sci. 65:677-691.

Kim, D. H., H. S. Chae and K. M. Jang. 2004. Implications of feed withdrawal in meat safety and quality. Kor. J. Food Sci. Anim. Resour. 24:202-208.

Kotula, K. L. and Y. Wang. 1994. Characterization of broiler meat quality factors as influenced by feed withdrawal time. J. App. Poult. Res. 3:103-110.

Lyon, C. E. and R. J. Buhr. 1999. Biochemical basis of meat texture. In: Poultry Meat Science, (Ed. R. I. Richardson and G. C. Mead) CAB International, Oxfordshire, England, pp. 99-126.

Lyon, C. E., C. M. Papa and R. L. Jr. Wilson. 1991. Effect of feed withdrawal on yields, muscle pH and texture of brother breast meat. Poult. Sci. 70:1020-1025.

May, J. D. and J. W. Deaton. 1989. Digestive tract clearance of broilers cooped or deprived of water. Poult. Sci. 68:627-630.

May, J. D., S. L. Branton, J. W. Deaton and J. D. Simmons. 1988. Effect of environmental temperature and feeding regimen on quantity of digestive tract contents of broilers. Poult. Sci. 67:64-71.

May, J. D., B. D. Lott and J. W. Deaton. 1990. The effect of light and environmental temperature on broiler digestive tract contents after feed withdrawal. Poult. Sci. 69:1681-1684.

Northcutt, J. K. and S. I. Savage. 1996. Managing feed withdrawal: The broiler's last meal. Broiler Industry, September, pp. 24-27.

Northcutt, J. K., S. I. Savage and L. R. Vest. 1997. Relationship between feed withdrawal and viscera condition of broilers. Poult. Sci. 76:410-414.

Pearson, A. M. and R. B. Young. 1989. Muscle and Meat Biochemistry. San Diego: Academic Press.

Randall, J. M., W. V. Sreader and A. M. Meehan. 1994. Vibration on poultry transporters. Worlds Poult. Sci. J. 50:64-65.

Reisenfeld, G., A. Berman and S. Hurnitz. 1981. Glucose kinetics and respiratory metabolism in fed abd fasted chickens. Comp. Biochem. Phys. 70A:223-227.

Rosenvold, K. and H. J. Andersen. 2003. Factors of significance for pork quality-a review. Meat Sci. 69:219-237.

SAS. 1996. SAS/STAT user's guide, 8^{th} ed. SAS Institute Inc. Cary NC USA.

Veerkamp, C. H. 1978. The influence of fasting and transport on yield of broilers. Poult. Sci. 57:634-638.

Veerkamp, C. H. 1986. Fasting and yields of broilers. Poult. Sci. 65:1299-1304.

Warner, R. D., R. G. Kauffman and M. L. 1997. Greaser Muscle protein changes post mortem in relation to pork quality traits. Meat Sci. 45:339-352.