Effect of hot-deboning on the physical quality characteristics of ostrich meat

S.St.C. Botha[1,2], L.C. Hoffman[1#] and T.J. Britz[2]

[1] Department of Animal Sciences,
[2] Department of Food Science, University of Stellenbosch, P. Bag X1, Matieland 7602, South Africa

_____

Abstract

The effects of hot-deboning on the physical meat quality characteristics and shelf-life of ostrich *m. gastrocnemius, pars interna* (*gastroc)* and *m. iliofibularis* (*iliof*) were investigated during 42 days (d) of refrigeration. The hot-deboned *gastroc* was initially tougher than the cold-deboned muscles, while hot-deboning had no significant effect on the shear force of the *iliof*. After 14 d of refrigerated storage, there was no difference in tenderness between the hot- and the cold-deboned muscles. Hot-deboning caused significantly more purge ($3.4 \pm 2.33\%$) compared to cold-deboning ($2.1 \pm 2.06\%$) throughout the 42-day storage period. All muscle samples were acceptable in terms of Aerobic Plate Counts (APC $< 10^4$ cfu/g) and *E. coli* (*E. coli* $< 10^1$ cfu/g), based on the South African Standards for the microbiological monitoring of meat for refrigerated export. It was concluded that hot-deboning did not influence the shelf-life of ostrich muscles negatively.

_____

Introduction

Within the ostrich carcass, various muscles will have different rates of *post-mortem* temperature decline and subsequent pH profiles depending on their ratio and composition of fibre type, anatomical location of the muscle to the exterior, as well as their degree of insulation (Lawrie, 1998). In addition, when considering hot-deboning, the degree of cold-shortening will also differ in the various muscles due to different fibre type compositions. White, fast-twitch fibres are less susceptible to cold-shortening than red, slow-twitch fibres, since red fibres have a less well developed sarcotubular system, and thus a reduced ability to sequester and bind Ca^{2+} at low temperatures (Pearson & Young, 1989; Lawrie, 1998).

The largest muscle in the ostrich carcass is the *m. gastrocnemius* (which includes the *m. gastrocnemius, pars interna* and *pars externa*) followed by the *m. iliofibularis* (Marks *et al.*, 1998). However, the ostrich *m. iliofibularis* has the largest individual mass (Sales, 1996) and is located deeper within the ostrich leg than the *m. gastrocnemius*. Between intact muscles containing similar fibre types, *post-mortem* glycolysis and the rate of pH fall are fastest in those of larger mass and which are located deeper within the carcass. This is ascribed to higher initial *in vivo* temperatures when compared to muscles located at the periphery of the carcass (Lawrie, 1998). O'Halloran *et al.* (1997) and Hwang & Thompson (2001) both reported that fast glycolysing muscles have been noted to be more tender than slow glycolysing muscles. O'Halloran *et al.* (1997) also suggested that the increased tenderness of fast glycolysing muscles might be caused by early *post-mortem* proteolysis. The rate of *post-mortem* pH fall also influences the water-holding capacity of muscles (Lawrie, 1998).

Meat with a high *post-mortem* pH favours the rapid growth of spoilage bacteria during aging, leading to a decrease in shelf-life. Ostrich meat has been classified as an intermediate meat type between normal (pH < 5.8) and extreme DFD (dark, firm and dry) meat (pH > 6.2) (Sales & Mellett, 1996). Ostrich meat has a higher final pH compared to beef, mutton or pork (Sales & Mellett, 1996; Sales, 1994). It was suggested by Pollok *et al.* (1997) that vacuum-packed ostrich steaks should not be stored for more than 14 d, because the steaks would become microbiologically unacceptable after 21 d at 2 ºC. Nonetheless, it is the practice in the South African trade to keep vacuum packed ostrich steaks for +40 d at temperatures < 1 °C.

The aims of this study were firstly to investigate whether hot-deboning would cause toughening of the *m. iliofibularis* (*iliof*) expressed in terms of Warner-Bratzler shear force values. Secondly, to investigate the effects of hot-deboning on the physical quality characteristics of *m. gastrocnemius, pars interna* (*gastroc*) and *iliof* in terms of pH changes, purge (%) and cooking loss (%) during an extended refrigerated (-3 to 0 ºC)

storage of 42 d, a typical scenario within the ostrich meat industry. Thirdly, due to the high pH reported for ostrich muscles (Sales, 1994; Sales & Mellett, 1996), microbiological evaluations were conducted to determine whether hot-deboning would have detrimental effects on the shelf-life and consumer safety of the meat.

Materials and Methods

Eleven randomly selected, rested (lairage of 12 h) ostriches (*Struthio camelus* var. *domesticus*) between 10 to 14 months of age were slaughtered (net carcass weight; 42.7 ± 3.95 kg), as described by Wotton & Sparrey (2002), at an abattoir in Malmesbury, South Africa. This abattoir has been approved by the European Commission for export purposes. The *gastroc* from the left leg and *iliof* from the same leg were excised at *ca.* 2 h *post-mortem* to obtain hot-deboned muscles, and weighed 1.1 ± 0.12 kg and 1.6 ± 0.24 kg, respectively. These muscles were left in the refrigerator next to the intact carcasses for 24 h.

The *gastroc* and *iliof* in the right leg of the same carcasses were left intact. These muscles were refrigerated for 24 h at < 4 ºC before being excised to obtain cold-deboned muscles. They weighed 1.1 ± 0.15 kg and 1.7 ± 0.14 kg, respectively. The individual hot- and cold-deboned muscles were cut perpendicular to their fibres into ten 1.5 to 2.0 cm thick slices, which were vacuum-packed individually, weighed and randomly assigned to aging periods of 1, 2, 3, 5, 7, 14, 21, 28, 35 and 42 d *post-mortem* before being aged in a cold room running at -3 to 0 ºC. The HACCP records at the abattoir showed that the temperature of the refrigerator fluctuated between -3 and 0 ºC, and never exceeded 0 ºC.

Muscle temperature (ºC), pH, purge (%), cooking loss (%) and Warner-Bratzler shear force (N. 12.7 mm/diameter) measurements were recorded at the respective aging intervals after the muscle samples were transported in a cooler box from the abattoir to the laboratory facilities of the University of Stellenbosch, South Africa. Muscle temperature and pH were measured at room temperature (18 to 19 ºC), using a calibrated (standard buffers of pH 4.0 and 7.0) portable Crison 506 pH-meter, equipped with pH and temperature probes. At the time of pH measurement, all the samples were at an average temperature of 15.1 ± 3.56 ºC, as transportation of the samples from the abattoir to the laboratory on the cooler box took *ca.* 1 h. Thereafter the muscle samples were maintained at room temperature (18 to 19 ºC) until all physical measurements were obtained. This resulted in an increase in the temperature of the samples. It was argued that, since all the muscle samples were treated similarly at all times, this increase in sample temperature would not influence the main effects.

To determine the purge, muscle samples were weighed (82.1 ± 17.32 g and 116.0 ± 25.23 g for the *gastroc* and the *iliof*, respectively) after being removed from the vacuum package and blotted dry with tissue paper. Purge was then expressed as a percentage of the initial mass of the muscle sample.

Cooking loss was determined by placing the weighed raw meat samples (individually sealed in plastic bags) in a water bath (preheated to 80 ºC) for 1 h (Honikel, 1998). After an hour, the cooked meat was removed, allowed to cool under running water and the mass was recorded after excess water was blotted with tissue paper. Cooking loss was expressed as a percentage of the initial mass (80.2 ± 16.9 g and 111.6 ± 24.6 g for the *gastroc* and the *iliof*, respectively) of the sample.

The same muscle samples that were used to determine cooking loss, were stored overnight at 4 ºC before tenderness was determined the following day. Tenderness was assessed as described by Wheeler *et al.* (2001) and Honikel (1998), using a Warner-Bratzler device, with a load cell of 2.000 kN, attached to the Model 4444 Instron texture machine (Apollo Scientific cc, South Africa). The maximum shear force value (N. 12.7 mm/diameter) to shear a cylindrical core of cooked meat was recorded at a crosshead speed of 200 mm/min. Mean maximum shear force values were calculated from the shear force values recorded for seven cylindrical cores from each meat sample and used in the statistical analyses.

Meat samples were cut from both hot- and cold-deboned *gastroc* and *iliof* at respectively 24 h *post-mortem* and at day 42 to determine the Aerobic Plate Counts (APC), *Escherichia coli* (*E. coli*), Enterobacteriaceae (EBC) and *Pseudomonas.* Microbiological analyses were done by Quantum Analytical Service (Pty) Ltd. (12 Voortrekker Road, Malmesbury 7300, South Africa). For sample preparation, the meat samples were placed in individual filter bags, where each sample was made up to volume with 85% NaCl solution. The filter bags were then placed in a bag-mixer blender to crush and mix the meat samples to obtain meat suspensions from which further dilutions for microbiological testing were conducted. Dilutions of 10^{-1} were prepared for testing *Pseudomonas* (0.1 mL/petri dish) on pseudomonas selective agar, incubated

for 48 h at 35 ºC. Dilutions of 10^{-2} were prepared to test for Aerobic Plate Count (APC), using the petrifilm method #990.12, as listed in the AOAC (2002). The petrifilms were incubated for 48 h at 35 ºC before APC counts were obtained. For testing *E. coli* and EBC, dilutions of 10^{-1} were prepared and the respective Petri dish methods #996.02 and #998.08, as listed in the AOAC (2002), were used to obtain *E. coli* and EBC counts after incubation for 24 h at 35 ºC.

A split-plot experiment was performed in a completely randomised block design with 11 blocks (ostrich carcasses). The main plot treatments were a 2x2 factorial with factors: two deboning treatments (hot and cold) and two muscles (*gastroc* and *iliof*) and the sub-plot factor, *post-mortem* aging time (1, 2, 3, 5, 7, 14, 21, 28, 35 and 42 d). The data were subjected to a split-plot analysis of variance (ANOVA) using SAS version 8 statistical software (SAS, 1999). Shapiro-Wilk tests were performed for testing non-normality (Shapiro & Wilk, 1965). The percentage variation for the dependent variables was calculated from the sum of squares (SS) and total sum of squares as obtained from the factorial analysis of variance (ANOVA).

When deviations from normality were detected, outliers were removed until data were symmetrical or normally distributed (Glass *et al*., 1972). The removal of outliers from the data caused the degree of freedom (df) for error in the analysis of variance (ANOVA) to differ for the respective dependent variables: muscle pH, Warner-Bratzler shear force, percentage purge and percentage cooking loss. Student's t-Least Significant Difference was calculated at the 5% confidence level to compare means for significant effects (Ott, 1998).

Various trend lines were fitted to the pH values using Microsoft Excel (2004). The third order polynomial trend lines gave the best fit according to the calculated R^2-values. The function represented by the trend lines is depicted by the following equation:

$$y = ax^3 + bx^2 + cx + d$$

Where: y = pH values at time x; x = *post-mortem* aging time in days, and d = intercept.

Linear regression models were fitted to the purge values using SAS version 8.2 (SAS, 1999). The function of this model was:

$$y = a + bx$$

where: y = values at time x; a = intercept; x = *post-mortem* aging time in days; and b = slope.

The regression coefficients, intercept (a) and slope (b) of the fitted model were then analysed by analysis of variance (ANOVA) using SAS version 8.2 (SAS, 1999).

Pearson correlation coefficients [r-values at the 5% significance level (P)] were calculated with the use of statistical software Statistica version 6 (Statsoft, 2003), as well as using the linear regression procedure (Prod CORR) of SAS version 8.2 (SAS, 1999). In the cases where there were no significant differences in variables between hot- and cold-deboned muscles, correlation coefficients were calculated for the pooled values. Correlation coefficients were calculated from the raw data points for hot- and cold-deboned muscles respectively between the different variables (pH, Warner-Bratzler shear force, purge and cooking loss) as well as with storage time.

Results and Discussion

The non-normality (P < 0.0001) for the shear force values, pH data, percentage purge and cooking loss was all due to Kurtosis and therefore further analyses of the data were performed without transformation of the data (Ott, 1998).

There was a significant three-way interaction for the shear force values between muscle, deboning and aging, as well as a significant interaction between muscle and aging. However, the percentage of variance (Table 1) explained by three-way interactions was less than 3%. The percentage of variation explained by ostrich carcass (8.78%), muscle (11.5%) and aging (19.5%) was higher than the percentage of variation explained by the three-way (2.76%) and the two-way interaction (7.56%). The two-way interaction between muscle and aging, and the main effects, ostrich carcass, muscle, deboning and aging, will be discussed further.

The significant two-way interaction between muscle and aging indicated that, as the time of aging increased, the *gastroc* and the *iliof* differed in tenderness, as illustrated in Figure 1. An assumption of this experimental outlay is that muscles slices are similar. However, as can be seen in Figure 1, there are values that could be classified as outliers (e.g. see d 35), which would indicate that there was variation within the muscle. This variation could be caused by various factors such as fibre type, collagen content, etc. This phenomenon warrants further investigation. Nonetheless, throughout the 42-day aging period, both the hot- and the cold-deboned *gastroc* were tougher than the hot- and the cold-deboned *iliof*. Initial toughness (*ca.* 24 h *post-mortem*) was (P < 0.05) higher for the *gastroc* (77.0 ± 13.82 N. 12.7 mm/diameter) than for the *iliof* (68.6 ± 11.10 N. 12.7 mm/diameter). This greater toughness for the *gastroc* persisted up to 14 d *post-mortem*. In contrast to the findings of Sales (1994), similar results were found by Girolami *et al.* (2003) and Marks *et al.* (1998) where both Warner-Bratzler shear force values and taste panel scores indicated that the *gastroc* was tougher than the *iliof*. It has also been found that the *iliof* is more tender than the *gastroc* and *m. gastrocnemius medialis* in the Emu (Berge *et al.*, 1997).

On day 14 (Figure 1) there was no (P > 0.05) difference in tenderness between the hot-deboned *gastroc* (68.0 ± 12.89 N. 12.7 mm/diameter) and the hot-deboned *iliof* (62.3 ± 11.29 N. 12.7 mm/diameter), nor between the cold-deboned *gastroc* (59.5 ± 7.37 N. 12.7 mm/diameter) and the cold-deboned *iliof* (58.1 ± 9.78 N. 12.7 mm/diameter). Sales *et al.* (1996) found that the tenderness of *iliof* increased significantly from 3.5 d to 10.5 d during aging, while that of the *gastroc* did not increase any further in tenderness with an additional 7 d after the initial 3.5 d of aging. In this study, it was found that both the hot- and the cold-deboned *gastroc* and *iliof* increased in tenderness from day 3 to day 14, whereafter there was no further increase (P > 0.05) in tenderness up to day 42. On day 42 all the muscles were similar in tenderness (P > 0.05), indicating that aging up to 42 d *post-mortem* will offset the initial higher toughness of the *gastroc*.

Although hot-deboning had a significant effect on the Warner-Bratzler shear force values, the percentage of variance explained by deboning was less (2.58%) than the percentage of variation explained by muscle (11.47%), indicating therefore that the hot-deboned (77.0 ± 15.86 N. 12.7 mm/diameter) and the cold-deboned (69.8 ± 12.33 N. 12.7 mm/diameter) *gastroc* were tougher than respectively the hot-deboned (64.38 ± 12.88 N. 12.7 mm/diameter) and the cold-deboned (62.1 ± 13.93 N. 12.7 mm/diameter) *iliof* throughout the 42-day aging period. Nonetheless, it was observed that, within muscles, hot-deboning caused larger differences in tenderness between the hot- and the cold-deboned *gastroc* than for the *iliof*. After 24 h *post-mortem* (day 1), the hot-deboned *gastroc* (81.9 ± 17.04 N. 12.7 mm/diameter) were significantly tougher than the cold-deboned *gastroc* (72.0 ± 7.55 N. 12.7 mm/diameter), while there was no significant difference in the initial (day 1) tenderness between the hot-deboned (71.0 ± 11.51 N. 12.7 mm/diameter) and the cold-deboned *iliof* (66.2 ± 10.65 N. 12.7 mm/diameter). The insignificant difference in initial shear force values (as well as throughout the 42-day aging period) between the hot and the cold-deboned *iliof*, indicated that the risk of cold-shortening was not as great in this muscle as compared to the *gastroc*. Sales & Mellett (1996) also suggested that there is a risk of cold-shortening in the *gastroc* if this muscle is to be separated from the carcass and cooled at 30 - 45 min *post-mortem* but not in the *iliof*. Their results showed that the *iliof* reached a pH ≤ 6.2 at approximately 30 min *post-mortem*.

Aging caused the largest percentage of variation (19.5%) within Warner-Bratzler shear force values and had a significant effect on tenderness. Aging time (days) was poorly, but significantly correlated with the Warner-Bratzler shear force values (r = -0.250), indicating that tenderness increased as the aging time increased from day 1 to day 42 for all muscle samples. This poor regression was most probably due to the large variation in Warner-Bratzler shear force values noted.

It was also found that the Warner-Bratzler shear force values were poorly, but significantly correlated with pH (r = -0.187; P < 0.001), indicating that muscles with a higher pH were more tender. As the possibility exists that these two muscles may have different metabolic pathways, correlations between pH and Warner-Bratzler values within muscle were also conducted. The *iliof* showed an insignificant correlation (r = -0.117; P > 0.05), whilst the *gastroc* showed a significant negative correlation (r = -0.402; P < 0.001). This phenomenon warrants further investigation.

Table 1 Analysis of variance (ANOVA) of the dependent variables mean Warner-Bratzler shear force (N. 12.7 mm/diameter) and pH with ostrich carcass, muscle, deboning (debone) and aging time (d) as main effects, as well as the two- and three-way interactions between main effects, and the Shapiro-Wilk test for non-normality
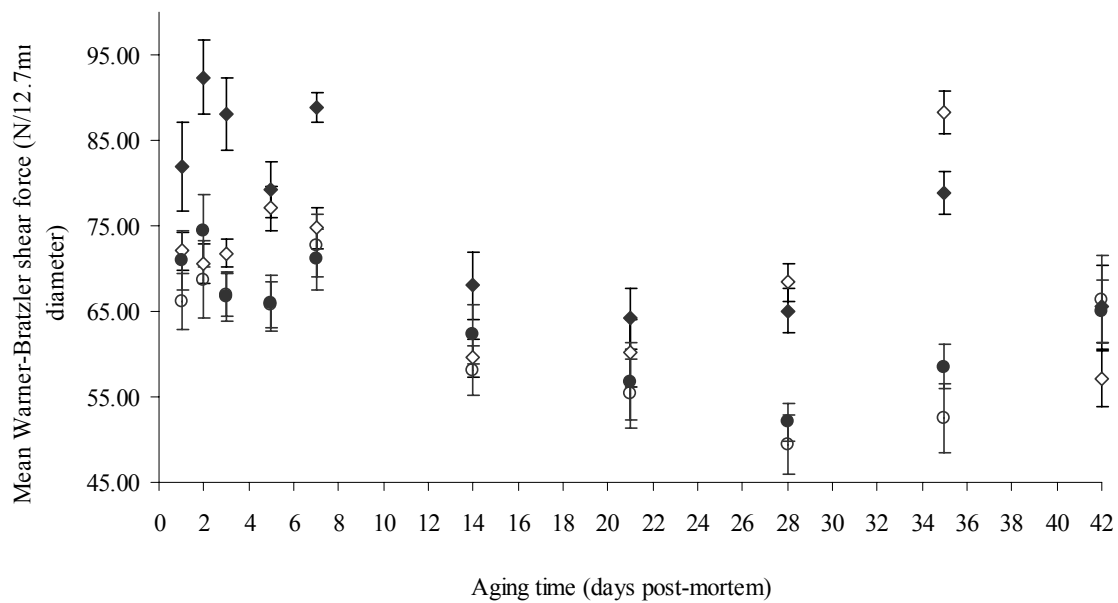
Source	Shear force (N. 12.7 mm/diameter)				pH			
	df	Mean Square	P	% of total variance	df	Mean Square	P	% of total variance
Ostrich carcass	10	826.063	0.0020	8.78	10	0.142	< 0.0001	26.53
Muscle	1	10790.459	< 0.0001	11.47	1	0.165	0.0003	3.09
Debone	1	2426.409	0.0021	2.58	1	0.033	0.0751	0.61
Muscle*Debone	1	746.083	0.0718	0.76	1	0.00098659	0.7515	0.004
Error a	30	214.155			30	0.00966178		
Aging	9	2038.470	< 0.0001	19.50	9	0.209	< 0.0001	35.25
Muscle*Aging	9	790.028	< 0.0001	7.56	9	0.020	< 0.0001	3.32
Debone*Aging	9	206.143	0.0678	1.97	9	0.006	0.1414	1.00
M*D*A	9	288.651	0.0082	2.76	9	0.003	0.7768	0.45
Error b	346	103.394		44.61	337	0.00386354		29.74
Shapiro-Wilk			0.0840				< 0.0001	

df – Degree of freedom
P – Probability value of F-ratio test
*Interaction between main effects
 M*D*A – Interaction between main effects Muscle, Debone and Aging

Figure 1 Warner-Bratzler shear force values (N. 12.7 mm/diameter) with standard error bars for the (♦) hot-deboned and the (◊) cold-deboned *m. gastrocnemius, pars interna,* and the (●) hot-deboned and the (○) cold-deboned *m. iliofibularis,* respectively at the individual aging days (1 d to 42 d)

The only significant interaction with muscle pH was observed between muscle pH and aging (Table 1), indicating that as the time of aging increased, the change in pH for the hot- and the cold-deboned *gastroc* differed (P < 0.05) from that of the hot- and the cold-deboned *iliof* (Figure 2). However, this interaction between muscle and aging caused only 3.3% of variation in pH compared to the 26.5% of variation caused by ostrich carcass and the 35.3% of variation caused by aging.
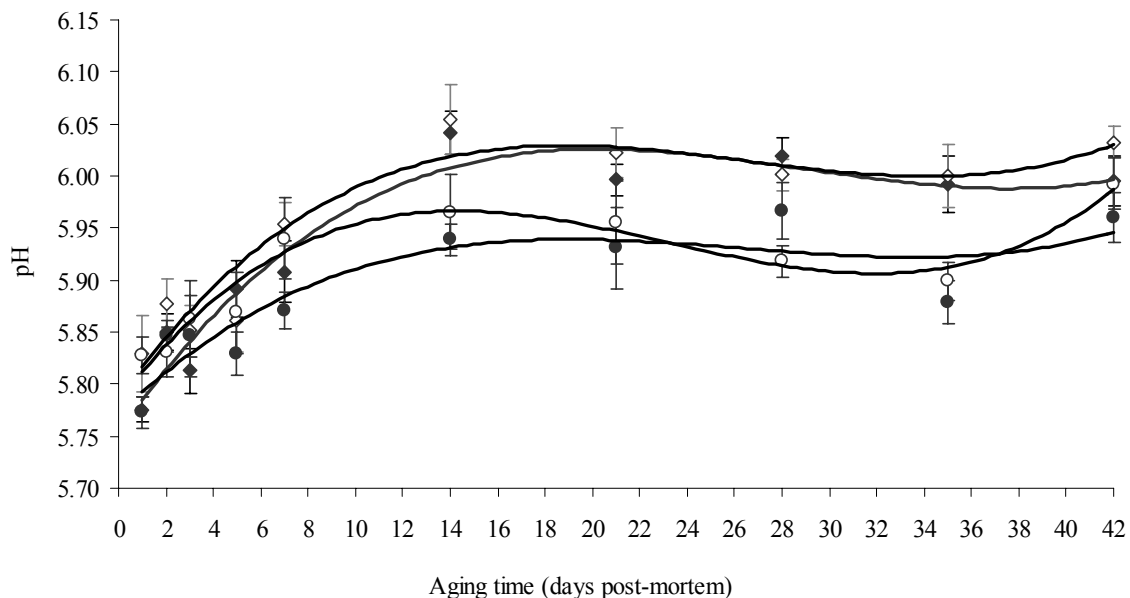
Figure 2 Third order polynomial trend lines (with standard error bars) for the change in pH over aging time (d) for respectively the (♦) hot-deboned ($y = 10^{-5}x^3 - 0.0013x^2 + 0.033x + 5.7525$; $R^2 = 0.9412$) and the (◊) cold-deboned ($y = 2 \times 10^{-5}x^3 - 0.0013x^2 + 0.0316x + 5.7866$; $R^2 = 0.9110$) *m. gastrocnemius, pars interna* and the (●) hot-deboned ($y = 10^{-5}x^3 - 0.0009x^2 + 0.0216x + 5.7719$; $R^2 = 0.8153$) and the (○) cold-deboned ($y = 2 \times 10^{-5}x^3 - 0.0015x^2 + 0.0301x + 5.7832$; $R^2 = 0.9453$) *m. iliofibularis*

The significant effect of deboning, where the hot-deboned muscles had significantly lower pH values (5.91 ± 0.11) throughout the 42-day storage period compared to the cold-deboned muscles (5.93 ± 0.12), caused only 0.61% of the variation in the pH data, and therefore ostrich carcass and aging are discussed further.

As expected, there were significant differences in pH between similar muscles from individual ostrich carcasses, indicating that the ostriches probably had different levels of *post-mortem* glycogen in these muscles. The differences in pH between the individual ostrich carcasses can most probably be explained by intrinsic variation found naturally between ostriches, as well as different levels of *ante mortem* stress and consequent differences in the levels of *post-mortem* muscle glycogen between the individual ostriches.

Aging had a significant effect on pH, with the pH increasing as the time of aging increased from day 1 to day 42 (Fig. 2). Muscle pH (pooled data) correlated positively ($P < 0.05$) with aging time ($r = 0.294$), where the pH increased from 5.8 ± 0.08 at day 1 to 6.0 ± 0.08 at day 42. The pH at 24 h *post-mortem* (pH_{24}) for *gastroc* and *iliof*, was higher ($P < 0.05$) in the case of the cold-deboned than the hot-deboned muscles, indicating that the rate of *post-mortem* pH change during the first 24 h *post-mortem* was faster in the cold-deboned muscles. In contrast to the difference in pH between the hot- and the cold-deboned muscles, the pH_{24} did not differ significantly between the hot-deboned *gastroc* (5.8 ± 0.04) and *iliof* (5.8 ± 0.05), nor between the cold-deboned *gastroc* (5.8 ± 0.12) and *iliof* (5.8 ± 0.06).

The analysis of variance (ANOVA) of percentage purge is presented in Table 2. Although there were significant two-way interactions between deboning and aging and between muscle and aging, the percentages of variation of respectively 4.13% and 1.29% caused by these interactions, were low compared to the percentages of variation caused by ostrich carcass (5.44%), muscle (10.11%), deboning (7.20%) and aging (16.43%); and therefore these are discussed further.

Table 2 Analysis of variance (ANOVA) of the effect of ostrich carcass, muscle, deboning (deboned) and aging time (d) on purge (%)

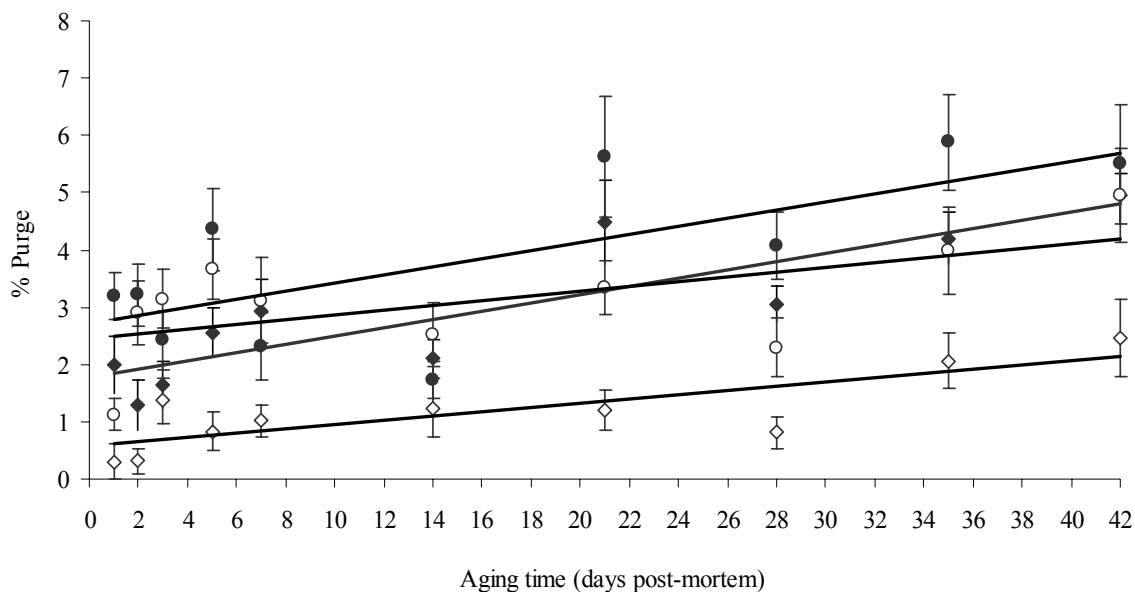|		Purge (%)		
Source	df	Mean Square	P	% of total variance
Ostrich carcass	10	12.278	0.0428	5.44
Muscle	1	228.259	< 0.0001	10.11
Debone	1	162.434	< 0.0001	7.20
Muscle*Debone	1	29.141	0.0274	1.29
Error a	30	5.4771935		
Aging	9	41.204	< 0.0001	16.43
Muscle*Aging	9	4.040	0.1819	1.61
Debone*Aging	9	10.361	0.0002	4.13
M*D*A	9	2.213	0.6292	0.88
Error b	356	2.877359		52.90
Shapiro-Wilk			0.0016	

df – Degree of freedom
P – Probability value of F-ratio test
*Interaction between main effects
M*D*A – Interaction between main effects Muscle, Debone and Aging

The specific muscle had a significant effect on purge, where the *gastroc* had less purge than the *iliof* (Fig. 3). As illustrated in Figure 3, the cold-deboned *gastroc* had the lowest percentage of purge, while the hot-deboned *iliof* had the highest percentage of purge throughout the 42-day aging period.

Figure 3 Linear trend lines (with standard error bars) fitted from day 1 to day 42 for the increase in percentage purge with *post-mortem* aging time (d) for respectively the (♦) hot-deboned (y = 0.0723 + 1.7818x; R^2 = 0.7445) and the (◊) cold-deboned (y = 0.0369 + 0.5795x; R^2 = 0.6360) *m. gastrocnemius, pars interna* and the (●) hot (y = 0.0713x + 2.707x; R^2 = 0.5081) and the (○) cold-deboned (y = 0.0417 + 2.4447x; R^2 = 0.3647) *m. iliofibularis*

Hot-deboning resulted in (P = 0.0001) both the *gastroc* and the *iliof* losing more moisture during the 42-day aging period compared to the cold-deboned muscles.

The analysis of variance (ANOVA) of the regression coefficients: intercept (a) and slope (b) of the linear model (y = a + bx) for purge is presented in Table 3. There was no significant interaction between muscle and deboning for the intercept or slope values. Therefore, muscle and deboning are discussed. From the data in Figure 3 it can be seen that the hot-deboned (2.0 ± 1.64%) and the cold-deboned (0.3 ± 1.00%) *gastroc* had a significant lower initial (day 1) purge than the hot-deboned (3.20 ± 1.38%) and the cold-deboned *iliof* (1.1 ± 0.89%). However, no significant difference in the rate of increase in purge was observed between the hot-deboned *gastroc* (0.0631 ± 0.0172) and the hot-deboned *iliof* (0.0704 ± 0.0667). Similarly, there was no significant difference in the rate of increase in purge between the cold-deboned *gastroc* (0.0369 ± 0.0304) and the cold-deboned *iliof* (0.0371 ± 0.0499). Irrespective of the main effect muscle, the time of deboning had a significant effect on the initial purge (intercept), as well as on the rate of increase in purge as the time of aging increased from day 1 to day 42.

Regarding the dependable variable, cooking loss (%), only muscle had a significant effect (Table 4), indicating that there were differences in cooking loss between the *gastroc* and the *iliof*. During the 42-day aging period, the hot-deboned *gastroc* (37.4 ± 3.25%) had higher (P < 0.05) cooking loss values than the cold-deboned muscles (36.3 ± 3.04%). In contrast, the hot-deboned *iliof* (39.8 ± 1.95%) showed less cooking loss (P < 0.05) than the cold-deboned *iliof* (40.7 ± 3.34%).

Hot-deboning had no significant effect on cooking loss, and therefore the cooking loss data for the hot- and the cold-deboned muscles from the *gastroc* and the *iliof* could be pooled (Table 5). The pooled data indicated that the *gastroc* (36.9 ± 3.18%) had significantly less cooking loss than the *iliof* (40.3 ± 2.75%). In contrast to the results obtained in this study for the cooking loss at 24 h *post-mortem* for the *gastroc* (37.6 ± 1.90%) and the *iliof* (40.3 ± 1.97%), Sales (1994) found no significant difference in cooking loss at 24 h *post-mortem* between the *gastroc* (35.8 ± 3.62%) and the *iliof* (36.0 ± 2.83%).

Table 3 Analysis of variance (ANOVA) of the regression coefficients: intercept (a) and slope (b) of the linear model (y = a + bx) for purge (%) with model, ostrich carcass and deboning (debone) as main effects, the two way interactions between main effects, as well as the Shapiro-Wilk test for non-normality

Source	df	Intercept (a)		Slope (b)	
		Mean Square	P	Mean Square	P
Ostrich carcass	10	2.159	0.0338	0.0024	0.2832
Muscle	1	22.687	< 0.0001	0.0002	0.7751
Debone	1	5.329	0.0221	0.0097	0.0313
Muscle*Deboning	1	3.037	0.0669	0.0001	0.7915
Error	30	0.915		0.0019	
Shapiro-Wilk			0.6425		0.7178

df – Degree of freedom
P – Probability value of F-ratio test
*Interaction between main effects

Table 4 Analysis of variance (ANOVA) of the dependent variable cooking loss (%) with ostrich carcass, muscle, deboning (debone) and aging time (d) as main effects, as well as the two and three way interactions between main effects, and the Shapiro-Wilk test for non-normality

		Cooking loss (%)		
Source	df	Mean Square	P	% of total variance
Ostrich carcass	10	41.828157	0.2424	8.40
Muscle	1	1240.030957	< 0.0001	24.91
Debone	1	0.469319	0.9023	0.01
Muscle*Debone	1	107.540187	0.0706	2.15
Error a	30	30.595778		
Aging	9	6.933060	0.3356	0.85
Muscle*Aging	9	6.218176	0.4235	1.34
Debone*Aging	9	3.443916	0.8257	0.95
M*D*A	9	3.928779	0.7589	0.81
Error b	346	6.097088		60.58
Shapiro-Wilk			< 0.0001	

df – Degree of freedom
P – Probability value of F-ratio test
*Interaction between main effects
M*D*A – Interaction between main effects Muscle, Debone and Aging

Table 5 Mean (± standard deviation) cooking loss (%) and Chroma (C*), pooled over the 42-days aging period, for respectively the hot-deboned (Hot *m. gastro*) and the cold-deboned *m. gastrocnemius*, *pars interna* (Cold *gastroc*); and hot-deboned (Hot *iliof*) and the cold-deboned *m. iliofibularis* (Cold *iliof*)

Parameter	Hot *gastroc*	Cold *gastroc*	Hot *iliof*	Cold *iliof*
Cooking loss (%)	37.41 [a] ± 3.25	36.34 [b] ± 3.04	39.81 [c] ± 1.95	40.73 [d] ± 3.34

[abcd] Different superscripts differ at P < 0.05 within rows.

No significant correlation was found between purge and pH (r = -0.064; P = 0.1960) for both the *gastroc* and the *iliof*. There was a significant positive correlation between cooking loss and purge (r = 0.178;

P < 0.001), showing that as the purge increased, the cooking loss also increased as the time of aging increased. However, the pH had a larger effect on cooking loss than on purge.

In contrast to Sales (1994), who found no significant differences in moisture content or in cooking loss between the *gastroc* and *iliof*, results from this study showed a significant higher purge and cooking loss for the *iliof* compared to the *gastroc*. The lower water holding capacity of the *iliof* can be explained by the larger areas of exposed surface in the pre-packaged cuts (Lawrie, 1998), since the *iliof* in the ostrich leg is the muscle with the largest individual mass (Sales, 1994), resulting in this muscle to lose more moisture during storage *post-mortem* than the *gastroc*. Sales (1994) reported an individual mass of 1.2 ± 0.28 kg for the *iliof*, compared to 0.7 ± 0.19 kg for the *gastroc*. Similarly, results from this study also indicated that the *iliof* (1.7 ± 0.19 kg) had a higher (P < 0.05) individual mass than the *gastroc* (1.1 ± 0.14 kg).

The microbiological results for APC, *E. coli*, EBC, and *Pseudomonas* from respectively the hot- and the cold-deboned *gastroc* and *iliof* at 24 h *post-mortem* and day 42 of the aging period, are summarised in Table 9. Although APC of 2 800 cfu/g at 24 h *post-mortem* were found for two of the hot-deboned *gastroc* samples, no difference in APC was found between the hot-deboned and the cold-deboned *gastroc*, neither at 24 h *post-mortem* nor on day 42. Similarly, at 24 h *post-mortem* and at day 42, the *iliof* showed no difference in APC between the hot-deboned and the cold-deboned muscles. It can also be seen from Table 9 that there were no differences in *E. coli*, EBC and *Pseudomonas* counts between the hot-deboned and the cold-deboned muscles, neither between *gastroc* and *iliof*. With the exception of hot-deboned *gastroc* for *Pseudomonas* and cold-deboned *iliof* for APC, muscle samples showed no increase in microbial counts from 24 h *post-mortem* to day 42. Similarly, Otremba *et al.* (1999) found no significant increase in APC from initial counts up to 7 d *post-mortem* in both whole and ground ostrich muscles. Taylor *et al.* (1980-81) also indicated that hot-deboning of beef muscles had no significant effect on the initial levels of contamination for *E. coli*, EBC and APC. Their results also indicated little or no growth on the hot-deboned meat cuts during *post-mortem* storage. In contrast, Otremba *et al.* (1999) indicated an increase in growth from day 7 to day 28 of refrigerated storage at 0 ± 2 ºC. However, in the present study the muscle samples were stored at lower temperatures (-3 to 0 ºC), which might explain the small increase in microbial growth throughout the 42-day aging period. All the muscle samples from this study were within the South African Standards for the microbiological monitoring of meat (Quantum Analytical Services) for refrigerated (< 10 000 cfu/g) export, as determined by APC. The *E. coli* counts from all the muscles were also below the South African Standards for the microbiological monitoring of refrigerated meat (< 10 cfu/g).

Table 9 Microbiological counts (colony forming units per gram sample, i.e. cfu/g) for Aerobic Plate Counts (APC), *E. coli*, Enterobacteriaceae (EBC) and *Pseudomonas* from respectively the hot-deboned (Hot *gastroc*) and the cold-deboned *m. gastrocnemius*, *pars interna* (Cold *gastroc.*) and the hot-deboned (Hot *iliof*) and the cold-deboned *m. iliofibularis* (Cold *iliof*) at 24 h *post-mortem* and day 42 of the 42-day aging period

24 h *post-mortem*	Hot *gastroc*	Cold *gastroc*	Hot *iliof*	Cold *iliof*
APC (cfu/g)	< 1000	< 1000	< 2000	< 500
E. coli (cfu/g)	< 10^1	< 10^1	< 10^1	< 10^1
EBC (cfu/g)	< 10^1	< 10^1	< 10^1	< 10^1
Pseudomonas (cfu/g)	< 1000	< 100	< 100	< 100
42 d *post-mortem*				
APC (cfu/g)	< 1000	< 1000	< 1000	< 1000
E. coli (cfu/g)	< 10^1	< 10^1	< 10^1	< 10^1
EBC (cfu/g)	< 10^1	< 10^1	< 10^1	< 10^1
Pseudomonas (cfu/g)	< 100	< 100	< 100	< 100

Conclusions

Hot-deboning did not have the same effect on the *m. iliofibularis* as on the *m. gastrocnemius*, *pars interna* in terms of tenderness as determined by Warner-Bratzler shear force values. Initially, hot-deboning

caused the *m. gastrocnemius*, *pars interna* to be significantly tougher than the cold-deboned muscles. However, there were no significant differences in shear force between the hot-deboned and the cold-deboned *m. iliofibularis*. Irrespective of deboning procedures, the *m. gastrocnemius*, *pars interna* were tougher than the *m. iliofibularis*. However, after 42 d of aging, all muscles were similar in tenderness. Deboning at 1 h *post-mortem* caused both the *m. gastrocnemius*, *pars interna* and the *m. iliofibularis* to have significantly lower pH values throughout the 42-day storage period compared to the cold-deboned muscles. With the lower pH values for the hot-deboned muscles, hot-deboned *m. gastrocnemius*, *pars interna* and hot-deboned *m. iliofibularis* both had more purge throughout the 42-day aging period than the cold-deboned *m. gastrocnemius*, *pars interna* and cold-deboned *m. iliofibularis*. Investigation of the difference in early *post-mortem* (first 24 h *post-mortem*) pH changes within the *m. gastrocnemius*, *pars interna* and *m. iliofibularis* would help elucidate the differences in the physical meat quality attributes found for different ostrich muscles.

In this study no evidence was found that hot-deboning at 1 h *post-mortem* caused an increase in bacterial contamination prior to vacuum-packaging. However, higher temperatures or longer conditioning periods prior to vacuum-packaging and chilling may show adverse effects on microbiological quality, and therefore hot-deboning and vacuum packaging during slaughter practices require careful control. It is concluded that, although ostrich muscles attain a higher pH throughout *post-mortem* storage and may possibly have a greater risk of microbiological spoilage, the microbial results indicated that both the hot-deboned and cold-deboned ostrich muscles were suitable for export after aging for 42 d, as APC counts were below the South African Standards for the microbiological monitoring of meat for refrigerated ($< 10\,000$ cfu/g) export; as well as the counts for *E. coli* (refrigerated: < 10 cfu/g).

Acknowledgements

References

AOAC, 2002. Official Methods of Analysis (17th ed.). Association of Official Analytical Chemists, Inc., Arlington, Virginia, USA.

Berge, P., Lepetit, J., Renerre, M. & Touraille, C., 1997. Meat quality traits in the Emu (*Dromaius novaehollandiae*) as affected by muscle type and animal age. Meat Sci. 45, 209-221.

Girolami, A., Marsico, I., D'Andrea, G., Braghieri, A., Napolitano, F. & Cifuni, G.F., 2003. Fatty acid profile, cholesterol content and tenderness of ostrich meat as influenced by age at slaughter and muscle type. Meat Sci. 64, 309-315.

Glass, G.V., Peckhan, P.D. & Sanders, J.R., 1972. Consequences of failure to meet assumptions underlying the fixed effects analyses of variance and covariance. Rev. Edu. Res. 42, 237-288.

Honikel, K.O., 1998. Reference methods for the assessment of physical characteristics of meat. Meat Sci. 49, 447-457.

Hwang, I.H. & Thompson, J.M., 2001. The interaction between pH and temperature decline early *post-mortem* on the calpain system and objective tenderness in electrically stimulated beef *longissimus dorsi* muscle. Meat Sci. 58, 167-174.

Lawrie, R.A., 1998. Meat Science. 6th ed., Pergamon Press, New York, USA.

Marks, J., Stadelman, W., Linton, R., Schmieder, H. & Adams, R., 1998. Tenderness analysis and consumer sensory evaluation of ostrich meat from different muscles and different aging times. J. Food Quality 21, 369-381.

Offer, G., 1991. Modelling of the formation of pale, soft and exudative meat: Effects of chilling regime and rate and extent of glycolysis. Meat Sci. 30, 157-184.

O'Halloran, G.R., Troy, D.J. & Buckley, D.J., 1997. The relationship between early post-mortem pH and the tenderisation of beef muscles. Meat Sci. 45, 239-251.

Otremba, M.M., Dikeman, M.E. & Boyle, E.A.E., 1999. Refrigerated shelf life of vacuum-packaged, previously frozen ostrich meat. Meat Sci. 52, 279-283.

Ott, R.L., 1998. An introduction to Statistical Methods and Data Analysis. Duxbury Press, Belmont, California, USA. pp. 807-837.

Pearson, A.M. & Young, R.B., 1989. Post-mortem changes during conversion of muscle to meat. In: Food Science and Technology, Muscle and Meat Biochemistry. Eds. Schweigert, B.S. & Taylor, S.L., Academic Press, Inc., New York, USA. pp. 391-425.

Pollok, K.D., Miller, R.K., Hale, D.S., Angel, R., Blue-McLendon, A., Baltmanis, B., Keeton, J.T. & Maca, J.V., 1997. Quality of ostrich steaks as affected by vacuum-packaged storage, retail display and differences in animal feeding regimen. In: American Ostrich, official publication of the American Ostrich Association, Research Issue. pp. 46-52.

Sales, J., 1994. Identification and improvement of quality characteristics of ostrich meat. Ph.D dissertation, University of Stellenbosch, South Africa.

Sales, J., 1996. Histological, biophysical, physical and chemical characteristics of different ostrich muscles. J. Sci. Food. Agric. 70, 109-114.

Sales, J. & Mellett, F.D., 1996. Post-mortem pH decline in different ostrich muscles. Research note. Meat Sci. 42, 235-238.

Sales, J., Mellett, F.D. & Heydenrych, H.J., 1996. Ultrastructural changes in ostrich muscle during post-mortem aging. S. Afr. J. Food. Sci. Nutr. 8, 23-25.

SAS, 1999. SAS/STAT User's Guide, Version 8, 1st printing, Volume 2. SAS Institute Inc, SAS Campus Drive, Cary, North Carolina 27513, USA.

Shapiro, S.S. & Wilk, M.B., 1965. An analysis of variance test for normality (complete samples). Biometrika 52, 591-611.

Statsoft Inc., 2003. Statistical Software, Statistica Version 6, Statsoft Inc., 2300 East 14th St., Tulsa, OK, USA, 74104.

Swatland, H.J., 2004. Progress in understanding the paleness of meat with a low pH. S. Afr. J. Anim. Sci. 34 (6, Suppl. 2), 1-7.

Taylor, A.A., Shaw, B.G. & MacDougall, D.B., 1980-81. Hot-deboning beef with and without electrical stimulation. Meat Sci. 5, 109-123.

Wheeler, T.L., Shackelford, S.D. & Koohmaraie, M., 2001. Shear force procedures for meat tenderness measurement. [WWW document]. URL: http://www.ars.usda.gov/

Wotton, S. & Sparrey, J., 2002. Stunning and slaughter of ostriches. Meat Sci. 60, 389-39.