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REGULAR ARTICLES

Meat quality, skin damage and reproductive performance of ostriches exposed to extensive human presence and interactions at an early age

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Abstract
The effect human presence and interactions performed after hatch to 3 months of age has on ostrich meat quality, skin damage and reproductive performance at a later age was investigated in 416-day-old ostrich chicks. The chicks were allocated to one of the three treatments, which varied with regard to exposure to human presence and care for 3 months post-hatch: HP1—extensive human presence with physical contact (touch, stroking), gentle human voice and visual contact; HP2—extensive human presence with gentle human voice and visual contact without physical contact; S—standard control treatment, where human presence and visual contact were limited to routine management, feed and water supply only. Carcass attributes (carcass weight, dressing percentage and drumstick weight), meat quality traits (pH, colour and tenderness) and skin traits (skin size, skin grading and number of lesions) were evaluated on twenty-four 1-year-old South African Black (SAB) ostriches. Reproductive performance (egg production, average egg weight, number of clutches, clutch size, chick production, average chick weight, fertility and hatchability percentage) were recorded for the first three breeding seasons of 23 SAB pair-bred females from this study. No differences in carcass attributes, meat quality, skin traits and reproductive performance were found between treatments ($P > 0.05$). It was evident that exposure of day-old ostriches to extensive human presence and interaction as chicks did not influence carcass attributes, meat quality or skin traits at slaughter age, but more importantly, it did not compromise their reproductive performance.

Keywords Human–animal relationship · Animal welfare · Production · *Struthio camelus* · Meat quality

Introduction

The ostrich industry of South Africa is the major producer of ostrich products worldwide contributing up to 70% of all the ostrich products (Brand and Jordaan 2011). Income in the ostrich industry is derived mainly from the sales of major products such as feathers, leather and meat (Cloete et al. 2008). Compared with beef and chicken, ostrich meat is considered rich in protein and low in cholesterol, while the leather is preferred in the fashion industry owing to its unique appearance (Cooper 2001; Poławska et al. 2011a; Al-Khalifa and Al-Naser 2014). A large amount of ostrich products from the South African ostrich industry are exported to the European Union (EU), while a small proportion remains in the local market (Brand and Jordaan 2011). The EU has strict requirements regarding farm animal welfare which greatly influence the trade of animal products (Glatz 2011). The quest for improving animal welfare is further driven by the willingness of consumers to pay for products from animals that experienced humane care (Miranda-de la Lama et al. 2017). Therefore, it is imperative for the ostrich industry to maintain animal welfare standards in order to be competitive in the market.

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A series of studies in other livestock industries have revealed that animal welfare and productivity can be improved by integrating positive human–animal interactions within the daily livestock management (Rushen et al. 1999; Hemsworth 2003; Hemsworth et al. 2011). For instance, interacting positively with sows resulted in increased litter size compared with negative interactions (Hemsworth et al. 1994). Furthermore, egg production from White Leghorn layers was improved by exposing hens to regular human presence, while it was lower for hens that received limited human presence (Barnett et al. 1994). Day to day interactions between humans and sheep or cattle, as well as how the interactions are perceived by such animals, may also affect meat quality post-slaughter (Hemsworth et al. 2011). Specifically, long stressful encounter results in secretion of cortisol hormone as a stress response mechanism which leads to dark, firm and dry meat owing to higher pH and depleted muscle glycogen (Hemsworth et al. 2011; Chulayo et al. 2012). It was shown in commercial veal farms that calves that experienced positive human interactions had lower meat pH and their meat was lighter in colour than calves that experienced limited human care and interactions (Lensink et al. 2001). In contrast, a short stressful encounter soon before slaughter may result into pale, soft and exudative meat as a consequence of low meat pH from the conversion of glycogen to lactic acid (Terlouw 2005; Adzitey and Nurul 2011). Hence, both short-term and long-term stress can negatively affect meat quality (Adzitey and Nurul 2011), and could potentially be influenced by human–animal interactions.

Positive human–bird interactions at an early age in ostriches have already been demonstrated to benefit survival, weight gain and physiological stress-coping mechanisms (Wang et al. 2012; Muvhali et al. 2018, 2020). However, it is feared that in adult life, such birds may direct their sexual repertoires towards humans instead of their mates (Bubier et al. 1998) and therefore exhibit compromised reproduction performance (Bubier et al. 1998). Glatz and Miao (2008) and Glatz (2011) have subsequently also emphasized the need to study how human–ostrich relationship affects the welfare and production in these birds. Although multiple research papers have been published on ostrich production performance under commercial farming settings, the method of rearing used was characterised by limited human and bird interactions (Cloete et al. 2006, 2012; Engelbrecht et al. 2009; Cloete and Brand 2014; Bonato et al. 2017). These studies recorded low and variable egg production as well as variable leather quality as a result of skin damage, but there is currently no evidence of whether this state of affair is inherent to farmed ostriches or whether production and product quality traits later in life could be influenced by early habituation to human presence.

It was hypothesised that, if human presence and interactions of chicks can benefit stress-coping mechanisms of juvenile ostriches as demonstrated in Muvhali et al. (2018), then production performance may be improved rather than compromised. Thus, this study aimed at investigating the effect of human presence and interactions at an early age (from hatch to 3 months of age) has on carcass attributes, meat quality traits and skin traits in juvenile birds, as well as reproductive performance of sexually mature ostriches.

Materials and methods

Study area and sampling population

This study was conducted at the Oudtshoorn Research Farm of the Western Cape Department of Agriculture, South Africa (33° 63′ S, 22° 25′ E). The birds used in this study were obtained as day-old chicks from eggs that were collected from breeding pairs maintained at the research farm and incubated together to synchronize hatching. The breeding pairs were of three purebred ostrich strains; South African Blacks (SAB), Zimbabwean Blues (ZB), Kenyan Reds (KR) and the reciprocal crossbred combinations of SAB with ZB and KR. Management practices on the farm have been reported (Bunter and Cloete 2004; Cloete et al. 2008).

Treatment

Over two breeding seasons (2013 and 2015), 416-day-old chicks (hatched in two batches) of mixed sex were randomly allocated to one of the three treatments, which varied in the amount of human presence (HP) and interactions with the chicks. The treatments and duration of human exposure have been detailed by Muvhali et al. (2018, 2020). Briefly, the first treatment involved supplying chicks with additional human presence along with regular physical interactions (touching and stroking), gentle human voice and visual contact (HP1: $N = 68$ and 76 for 2013 and 2015, respectively). In the second treatment, additional human presence, gentle human voice and visual contact were supplied, with no physical interactions (HP2: $N = 66$ and 70 for 2013 and 2015, respectively). The third treatment, which was the standard husbandry practice for ostrich chicks used at the Oudtshoorn Research Farm (S: $N =$ 66 and 70 for 2013 and 2015, respectively), was used as the control, with human presence and interactions limited to the routine management and supply of feed and fresh water (Bunter 2002). Chicks in the HP1 and HP2 treatments were exposed to a total of 343 h of human presence and interaction to 3 months of age. In the first week after hatching, they received human presence for 100% of the daylight hours, which was decreased gradually until week 8 of the experiment, when they were only visited for 1 h in the morning and another hour in the afternoon. In comparison, chicks in the S treatment were exposed to a total of approximately 48 h of human presence, mostly limited to general management such as feed and water supply, during the 3 months of treatment. Feed and clean water were supplied ad libitum during daytime to all chicks. At 3 months of age, HP1, HP2 and S chicks were all mixed together into one flock, with human contact limited to the provision of food and water. All the birds in this study were exposed to additional human presence between the age of 8 and 13 months when behavioural tests and reactivity tests towards humans were performed (Muvhali et al. 2018). Although Muvhali et al. (2018, 2020) revealed breed differences for birds exposed to the treatments as in this study, the comparison of breeds was not possible in the present study due to the limited number of ZB, KR and other reciprocal crosses birds being available for slaughter and breeding, as well as the limited capacity and facilities in terms of working force and breeding camps available. Therefore, only SAB ostriches were used for this study on slaughter and reproduction traits.

Meat quality and carcass attributes

A total of twenty-four 1-year-old birds from the 2015 group (4 males and 4 females from each treatment) were slaughtered at an EU-approved commercial abattoir to study the effect of treatments on meat quality. Slaughter birds were fed an ostrich finisher diet (11.10 MJ/kg dry matter and 133 g/kg protein) from the age of 7 months until slaughter. An experienced independent contractor was hired a day before slaughter to transport the birds to the abattoir in Oudtshoorn (Klein Karoo International PTY LTD), which is situated < 10 km away from the study location. On arrival at the abattoir, the birds were kept together for overnight in roofed kraals and allowed free access to clean drinking water. On the next morning, the birds were weighed individually (recorded as slaughter weight) and slaughtered following the standard slaughter procedure at the abattoir. The birds were identified after slaughter by linking the slaughter sequence number with the farm tag number, which corresponded to the treatment.

Meat pH and temperature of the left big drum muscle (*Muscularis gastrocnemius, pars interna*) were measured 45 min (pH_i) and 24 h (pH_u) after exsanguination using a portable pH meter and digital thermometer (Comark PDQ 400). Hot carcass weight was recorded approximately 30 min after exsanguination, while cold carcass weight was recorded 24 h later. The hot weight of the right drumstick (thigh) was also recorded approximately 40 min after exsanguination. Dressing percentage was calculated as cold carcass weight expressed as a percentage of live slaughter weight. The big drum and fan fillet (*Muscularis iliofibularis*) muscles were removed from the drumstick, vacuum packed and transported in cooler boxes to Stellenbosch University for further meat quality analysis, which was done 48 h after slaughter. Meat colour measurements for both muscles were taken with a CIELAB colour meter (colour-guide 45°/0° colorimeter; BYK-Gardner GmbH, Gerestried, Germany) directly on the meat surface after a blooming period of 30 min during which the cut muscle was exposed to the air. The lightness (L^*), redness (a^*) and yellowness (b^*) parameters were recorded, while the hue angle ($H°$) and chroma (C^*) were calculated as: $H° = \tan^{-1}\left(\frac{b^*}{a^*}\right) \times 57.29$ (expressed in degrees) and $C^* = \sqrt{(a^{*2} + b^{*2})}$. Small meat samples of approximately 100 g from both muscles for all 24 slaughtered birds were weighed, put in inflated plastic bags and cooked in a water bath at 80 °C for 60 min in order to reach an internal temperature of 75 °C. The bags were then taken out and cooled at ± 4 °C, after which the samples were blotted dry with paper towels, taking care not to use any added pressure. After weighing, the cooked samples were used to determine tenderness. A minimum of six samples was taken from each meat sample by using a sharp, stainless steel borer with a diameter of 1.27 cm to remove six cylinders in the direction of the muscular fibres. The samples were then sheared perpendicular to the fibre direction using a V-shaped cutting blade attached to an Instron 3344 (Universal, Norwood, USA) with a Warner Bratzler blade to determine the shear force in kilogramme. Lastly, meat proximate composition attributes were measured on thawed meat samples following the methods of the AOAC International (2002) as follows: moisture content by oven drying a 2.5-g homogenized meat sample at 100 °C for 24 h; dry matter percentage, derived from moisture loss; crude protein content, measured using the Dumas combustion method; lipid content by ether extraction from a 5-g homogenized meat sample and lastly ash content was determined by placing a 2.5-g moisture free sample in a furnace at 500 °C for 6 h.

Skin traits

The skin was removed from the carcass at the abattoir and transported to the nearby tannery, where each skin was tagged with a microchip and linked to the slaughter number (sequence) of the bird. All skins were cured and processed using the same bulk tannery process. After processing, skin size (dm^2) was measured and skin grades allocated by qualified personnel. Skin grades were assigned following the National Ostrich Processors of South Africa grading standards based on the number of lesions in the crown area and the section of the crown area where defects/damage was present (Meyer 2003). The number of scratches and kick marks on the skins was quantified as an indication of skin damage due to aggressive behaviour (Meyer 2003). Treatment was unknown to the skin graders and the principal investigator recording all traits to eliminate bias.

Reproductive performance

To evaluate the effect of husbandry treatments on reproduction performance, a total of fourteen 2-year-old South African

Black (SAB) ostrich females from the 2013 treatment group (7 × HP1 and 7 × S) and nine 2-year-old females from the 2015 group (4 × HP1 and 5 × S) were randomly allotted to pair breeding paddocks for their first three breeding seasons, respectively. The males used for mating were of the same age, breed and from the same treatment as their paired females. Due to limited camp availability, only HP1 and S birds were used to compare the most extreme treatments in terms of human presence and interactions (i.e. extensive vs. limited human interaction, respectively). These two treatments (HP1 and S) were most likely to differ statistically, based on results from previous studies (Muvhali et al. 2018, 2020). The breeding pairs were fed a balanced ostrich breeder diet (10.90 MJ/kg dry matter and 180.9 g/kg protein). The diet was mixed and pelleted at the research farm and fresh water was available to the birds ad libitum. Egg collection was done twice a day (morning and afternoon) and the camp number from which the egg was collected was recorded followed by weighing using an automated scale (Precisa, XT 4200 C). Egg production per female, average egg weight, number of clutches and clutch size were calculated. Any sequence of succeeding eggs laid within 4 days of each other indicated a clutch. A break in lay of more than 4 days was considered the end of a clutch since female ostriches lay an egg every second day (Bunter 2002). Eggs were subsequently incubated artificially in weekly batches (eggs collected over a week period) for 42 days and candled to monitor development at 21 and 35 days of incubation, according to the routine practice of the hatchery at the research farm (Brand et al. 2008). Lack of embryonic development during candling was used to indicate infertile eggs, while visible embryonic development (including eggs with early or late embryonic deaths, chicks that died after pipping and live hatched chicks) indicated fertilized. Fertility was recorded per female as the proportion of fertilized eggs from the total number of eggs produced. Broken eggs, abnormal shells and underweight eggs (< 1200 g) were not incubated (non-incubated eggs) and their fertilization status was therefore unknown. Such eggs were consequently excluded in the fertility analysis by deducting them from the total number of eggs. Moreover, eggs that were found rotten during candling had their fertilization status indicated as unknown and were also not included in the fertility analysis. The hatched chicks were used to calculate hatchability percentage from fertilized eggs that were incubated. Chick production per female and the average chick mass at hatch were expressed as a trait of the female.

Statistical analysis

The data was analysed using SAS, version 9.3 (Statistical Analysis System (SAS) 2012). A completely randomised design with 3 × 2 × 2 factorial arrangement of treatments was used to evaluate the effect of husbandry treatment, sex and muscle type on ostrich meat quality. A general linear model (GLM) procedure was used to test the effects of husbandry treatment, sex and their interaction on meat traits (slaughter weight, pH_i, pH_u, hot and cold carcass weight, drumstick weight and dressing percentage). In the analysis, initial pH (pH_i) was used as a linear covariate for ultimate pH (pH_u). Another GLM was performed with husbandry treatment, sex, muscle type and their interactions as fixed effects while meat colour and meat proximate composition traits were used as dependent variables.

The effect of husbandry treatment, sex and their interaction on skin traits, lesions present on the skin surface, skin size and skin grade was evaluated using the generalized linear mixed model (GLMM). Skin grade data was subjected to an ordered logit model where the cumulative logit link function was applied on the data.

A GLMM model was fitted to investigate the effect of husbandry treatment and breeding season (first, second and third breeding season) on female reproductive performance. Total egg production per female, average egg weight per female, number of clutches, clutch size, total chick production and average chick weight per female were used as dependent variables. Another GLMM was performed with fertility and hatchability percentage (transformed using the arcsine function) as dependent variables; however, untransformed means for these variables were reported. Husbandry treatment, year (year in which the females were hatched i.e. 2013 or 2015) and breeding season (first, second and third breeding season), as well as their interaction, were entered as fixed factors to compare production performance. Repeated records on the same bird were accounted for by using bird identity as a random variable during all analyses. The data was considered statistically significant at $P < 0.05$ and the Tukey pairwise comparison was applied for mean separations.

Results

Meat quality and carcass attributes

Overall means (± SE) for slaughter weight, pH_i, pH_u, hot carcass weight, cold carcass weight, drumstick weight and dressing percentage were 98.6 ± 2.25 kg, 5.72 ± 0.07, 5.47 ± 0.03, 47.1 ± 0.94 kg, 45.7 ± 0.9 kg, 17.2 ± 0.28 kg and 46.7 ± 1.18%, respectively. Neither husbandry treatment, sex, nor the interaction between these factors had a significant effect on any of these traits ($P > 0.05$; Table 1). Overall means recorded for meat lightness, redness, yellowness, hue angle and chroma were 30.5 ± 0.28, 15.1 ± 0.19, 7.82 ± 0.21, 27.4 ± 0.76° and 17.1 ± 0.18, respectively. There was no significant effect of husbandry treatment and sex on any of the meat colour traits ($P > 0.05$). However, muscle type had a significant effect ($P < 0.05$) on the lightness, redness and hue angle (Table 2).

Table 1 Means and standard errors (SE) for meat and carcass traits of 24 South African Black ostriches (4 males and 4 females per husbandry treatment) as affected by husbandry treatment (varying in the degree of human–bird interaction) and sex

Physical meat traits	Husbandry treatment			SE	*P* value	Sex		SE	*P* value
	HP1	HP2	S			Male	Female		
Slaughter weight (kg)	102.1	98.8	94.9	3.97	0.45	96.2	101	3.24	0.31
pH_i	5.85	5.61	5.71	0.06	0.40	5.72	5.74	0.10	0.89
pH_u	5.49	5.41	5.47	0.05	0.37	5.46	5.46	0.04	0.78
Hot carcass weight (kg)	46.1	48.6	46.5	1.50	0.33	45.4	48.6	1.22	0.10
Cold carcass weight (kg)	44.7	44.4	44.8	1.45	0.34	44.1	47.2	1.18	0.08
Drumstick weight (kg)	17.3	17.3	16.9	0.28	0.73	16.9	17.4	0.39	0.37
Dressing (%)	44.3	48.1	47.8	2.13	0.38	46.2	47.3	1.73	0.68

HP1 birds were exposed to extensive human presence along with regular physical contact (touching and stroking) and gentle human voice; HP2 birds were exposed to extensive human presence, gentle human voice and visual contact, but no physical contact; S birds had human presence limited to the routine supply of feed and fresh water

The fan fillet was lighter (higher L^* value) with a higher hue angle compared with the big drum muscle ($P < 0.05$). The big drum muscle was redder than the fan fillet muscle as indicated by its higher a^* value ($P < 0.05$; Table 2), but no significant effect of muscle type was observed on the yellowness (b^*) or chroma ($P > 0.05$).

The overall means (± SE) for moisture, dry matter, protein, lipid and ash percentages were 74.2 ± 0.33%, 25.8 ± 0.33%, 23.4 ± 0.32%, 1.93 ± 0.08% and 1.41 ± 0.14%, respectively. The meat proximate composition was not influenced by husbandry treatment, muscle type or sex, with the exception of the lipid percentage, which was higher for the fan fillet compared with the big drum (Table 2). A significant interaction between husbandry treatment and muscle type was recorded for meat moisture, dry matter and protein content ($P < 0.05$; Table 3). The big drum muscle of the HP1 birds had a lower moisture content ($P < 0.05$; Table 3) compared with other treatments, while the fan fillet of S birds had similar values ($P > 0.05$). Additionally, the big drum of HP1 birds had higher ($P < 0.05$) dry matter and protein contents than other treatments, but again similar ($P > 0.05$) values to that of the fan fillet of S birds (Table 3).

Overall shear force as a measure of meat tenderness was recorded as 6.9 ± 0.18 kg. There was no significant effect of

Table 2 Means and standard errors (SE) for meat colour traits and proximate composition of the big drum (*Muscularis gastrocnemius, pars interna*) and fan fillet (*Muscularis iliofibularis*) muscles from 24 South African Black ostriches (4 males and 4 females per husbandry treatment) as affected by husbandry treatment and sex

Meat colour and proximate traits	Husbandry treatment			SE	*P* value	Sex		SE	*P* value	Muscle type		SE	*P* value
	HP1	HP2	S			Male	Female			Big drum	Fan fillet		
L^*	30.5	30.6	30.4	0.46	0.96	30.8	30.1	0.38	0.22	29.6[a]	31.4[b]	0.37	0.02
a^*	14.9	15.4	14.9	0.33	0.40	15.1	15.1	0.27	0.95	15.5[b]	14.6[a]	0.26	0.02
b^*	7.74	8.05	7.64	0.36	0.71	7.76	7.87	0.29	0.79	7.40	8.22	0.29	0.06
Hue (°)	27.6	27.46	27.2	1.28	0.98	27.2	27.7	1.05	0.77	25.5[a]	29.4[b]	1.04	0.01
Chroma	16.8	17.45	16.8	0.31	0.28	17.1	17.1	0.26	0.86	17.3	16.8	0.25	0.20
Moisture (%)	73.5	74.6	74.4	0.52	0.31	73.9	74.4	0.43	0.43	72.9	74.5	0.43	0.33
Dry matter (%)	26.5	25.4	25.6	0.52	0.31	26.1	25.6	0.43	0.43	26.1	25.5	0.43	0.33
Protein (%)	23.9	22.9	23.5	0.51	0.37	23.5	23.3	0.42	0.71	23.9	22.9	0.42	0.10
Lipid (%)	2.05	1.95	1.79	0.12	0.30	2.02	1.83	0.10	0.16	1.69[a]	2.17[b]	0.10	0.01
Ash (%)	1.21	1.34	1.67	0.23	0.35	1.49	1.31	0.19	0.48	1.22	1.59	0.19	0.17

HP1 birds were exposed to extensive human presence along with regular physical contact (touching and stroking) and gentle human voice; HP2 birds were exposed to extensive human presence, gentle human voice and visual contact, but no physical contact; S birds had human presence limited to the routine supply of feed and fresh water

[a,b] Means with different superscripts within a row are significantly different ($P < 0.05$)

Table 3 Means and standard errors (SE) of the interaction effects of husbandry treatment with muscle type for meat proximate composition and husbandry treatment and sex for meat tenderness (kg) of 24 South African Black ostriches (4 males and 4 females per husbandry practice). All meat proximate composition means, except for dry matter, are on dry matter basis

Meat proximate composition	HP1		HP2		S		SE	*P* value
	Big drum	Fan fillet	Big drum	Fan fillet	Big drum	Fan fillet		
Moisture (%)	72.1^{a}	74.9^{b}	74.7^{b}	74.6^{b}	74.9^{b}	73.9^{ab}	0.73	0.04
Dry matter (%)	27.9^{b}	25.1^{a}	25.3^{a}	25.4^{a}	25.1^{a}	26.1^{ab}	0.73	0.04
Protein (%)	25.5^{b}	22.3^{a}	23.1^{a}	22.7^{a}	23.3^{a}	23.7^{ab}	0.73	0.04
Lipid (%)	1.87	2.24	1.74	2.17	1.47	2.11	0.16	0.70
Ash (%)	1.26	1.16	1.23	1.44	1.17	2.17	0.32	0.23
Tenderness (kg)	Male	Female	Male	Female	Male	Female		
	7.77^{bc}	6.26^{a}	6.70^{abc}	6.80^{ac}	6.28^{a}	7.40^{bc}	0.42	0.01

HP1 birds were exposed to extensive human presence along with regular physical contact (touching and stroking) and gentle human voice and visual contact; HP2 birds were exposed to extensive human presence, gentle human voice and visual contact, but no physical contact; S birds had human presence and voice limited to the routine supply of feed and fresh water

[a,b,c] Means with different superscripts within a row are significantly different ($P < 0.05$)

husbandry treatment on meat tenderness ($P > 0.05$), but a significant interaction between sex and husbandry treatment was recorded for meat tenderness ($P < 0.05$; Table 3). In the HP1 group, male ostriches had less tender meat than females, while males in the S group had more tender meat than males from the HP1 group. No such difference was observed in the HP2 group. Conversely, in the S group, male ostriches had more tender meat than females. Lastly, no difference in meat tenderness was recorded between HP2 and S birds ($P > 0.05$).

Skin traits

The overall means (± SE) for the quantified lesions on the skin surface, skin grading and skin size were 31.9 ± 2.50, 3.6 ± 0.2 and 144 ± 0.93 dm^2, respectively. No significant difference was observed in any of these traits between husbandry treatments, sexes or their interaction ($P > 0.05$; Table 4).

Reproduction

The overall means (± SE) for total egg production, average egg weight (g), number of clutches and clutch size recorded were 49.2 ± 2.82, 1396 ± 27.2 g, 5.67 ± 0.44 and 13.8 ± 2.06. The average total chick production per female and mean chick weight (g) recorded were 25.3 ± 2.5 and 873 ± 12.1 g. Fertility and hatchability amounted to 68.9 ± 4.22% and 69.9 ± 3.53%, respectively. Non-incubated eggs (abnormal or underweight) were evenly distributed across treatments (HP1: 7.71 ± 2.23; S: 6.70 ± 2.25; $P > 0.05$). Treatment had no significant effect on total egg production, average egg mass, number of clutches, clutch size, fertility, hatchability, chick production or average chick weight during the birds' first three breeding seasons ($P > 0.05$; Table 5). During the third breeding season, overall higher average egg weight, less clutches per female, higher chick production and higher average chick weight were recorded than in the first breeding season ($P < 0.05$; Table 6). No such differences were however observed between the second and third breeding seasons ($P > 0.05$; Table 6). Finally, no significant interaction between husbandry treatment and breeding season as well as hatching year and treatment on reproductive traits was recorded ($P > 0.05$).

Table 4 Means and standard errors (SE) depicting the effects of husbandry treatment and sex on skin traits of 24 South African Black ostriches (4 males and 4 females per husbandry treatment)

Skin traits	Husbandry treatment			SE	*P* value	Sex		SE	*P* value
	HP1	HP2	S			Male	Female		
Skin size (dm^2)	142	145	145	1.55	0.34	143	145	1.20	0.22
Skin grading	3.63	3.75	3.50	0.26	0.50	3.67	3.58	0.14	0.69
Number of lesions	32.1	34.9	28.6	4.76	0.66	32.4	32.3	3.89	0.85

HP1 birds were exposed to extensive human presence along with regular physical contact (touching and stroking) and gentle human voice; HP2 birds were exposed to extensive human presence, gentle human voice and visual contact, but no physical contact; S birds had human presence limited to the routine supply of feed and fresh water

Table 5 Least square means (± SE) for total egg production, average egg weight, number of clutches, number of eggs per clutch, incubated eggs, fertility percentage, hatchability percentage, chick production and average chick weight of 24 South African Black ostrich females as influenced by husbandry treatment

Traits	Husbandry treatment		*P* value
	HP1	S	
Total egg production	54.4 ± 5.47	42.4 ± 5.03	0.11
Average egg weight (g)	1425 ± 50.3	1386 ± 44.9	0.57
Number of clutches	5.52 ± 0.64	5.81 ± 0.62	0.49
Number of eggs per clutch	16.4 ± 3.16	11.5 ± 2.67	0.23
Incubated eggs	50.9 ± 5.14	39.4 ± 4.74	0.11
Fertility (%)	60.7 ± 6.44	76.4 ± 5.29	0.19
Hatchability (%)	69.5 ± 5.52	70.4 ± 4.60	0.70
Chick production	24.7 ± 5.13	23.7 ± 4.74	0.89
Average chick weight (g)	892 ± 27.3	862 ± 25.7	0.43

HP1 birds were exposed to extensive human presence along with regular physical contact (touching and stroking), gentle human voice and visual contact; S birds had human presence and voice limited to the routine supply of feed and fresh water

Discussion

Meat quality and carcass attributes

This study revealed that physical meat traits and meat colour traits of ostriches at slaughter were not affected by previous method of rearing birds as chicks involving varying degrees of interaction with humans during the first 3 months after hatch. This finding corroborates with other studies in veal calves (Lensink et al. 2000) and large white pigs (Terlouw et al. 2005), where meat quality traits were not affected by the method of rearing which incorporated interactions with humans prior to slaughter. The findings that meat pH and meat colour were not affected by treatment in this study may be explained in several ways: Firstly, the sample size may have been too small to accurately estimate the effect of treatment on meat traits. Secondly, it could be that the treatments were performed far apart from the slaughtering period, therefore not showing an effect of treatment at slaughter age. Thirdly, birds from all treatment groups underwent behavioural tests involving reactivity and docility towards human handlers (Muvhali et al. 2018). This additional exposure to human presence may have overshadowed the early treatment effects on the meat quality traits recorded at a slaughter. Fourthly, the pre-slaughter stress at the abattoir may have been too high and thus might have overridden any prolonged treatment effects (Terlouw et al. 2005). In comparison with the literature, the mean pH in this study was lower while meat lightness was higher which may indicate that ostriches may have encountered acute short-term stress soon before they were slaughtered (Hoffman and Fisher 2001; Van Schalkwyk et al. 2005). Indeed, several stress-inducing factors under abattoir conditions have been identified, such as noxious smells, unusual machinery noise and the novel unfamiliar environment that could mask treatment effects (Warriss 2000; Terlouw et al. 2005). Lastly, the interactions humans have with ostriches as chicks might just not affect meat quality traits, regardless. However, to refute or confirm this reasoning, future studies with a larger sample size may be recommended, while also limiting post-treatment human–ostrich interactions which could potentially mask early treatment effects.

Significant interactions between treatment and muscle type were recorded for most proximate characteristics of the meat in this study. Also, treatment significantly interacted with sex for meat tenderness. However, overall proximate values recorded in this study (protein, dry matter, lipids and ash content) were notably higher than those summarised in the ostrich literature (Hoffman et al. 2005; Majewska et al. 2009; Poławska et al. 2011a, b). The meat tenderness value reported

Table 6 Least square means (± SE) of total egg production, average egg weight, number of clutches, eggs per clutch, incubated eggs, fertility percentage, hatchability percentage, chick production and average chick weight of 24 South African Black ostrich females over the first three breeding seasons

Traits	Breeding season			*P* value
	First	Second	Third	
Total egg production	45.9 ± 4.55	50.7 ± 4.82	48.5 ± 5.29	0.65
Average egg weight (g)	1310 ± 43.6[a]	1439 ± 45.9[bc]	1468 ± 55.4[c]	0.02
Number of clutches	6.74 ± 0.81[a]	5.50 ± 0.71[ab]	4.38 ± 0.63[b]	0.02
Eggs per clutch	9.17 ± 1.62	14.33 ± 2.90	19.74 ± 6.21	0.10
Incubated eggs	38.9 ± 4.41	49.1 ± 4.62	47.5 ± 5.17	0.13
Fertility (%)	56.4 ± 7.56	69.8 ± 6.48	85.9 ± 5.99	0.09
Hatchability (%)	70.2 ± 6.76	69.7 ± 4.55	70.1 ± 7.37	0.11
Chick production	17.2 ± 3.95[a]	24.8 ± 4.09[ab]	30.5 ± 4.42[b]	0.01
Average chick weight (g)	859 ± 19.4[a]	877 ± 19.5[ab]	896 ± 21.6[b]	0.04

[a,b,c] Means with different superscripts within a row are significantly different ($P < 0.05$)

in the present study was lower than values for ostriches found in the literature (Poławska et al. 2011b; Leygonie et al. 2012) and specifically lower than that of long-term stressed birds (Van Schalkwyk et al. 2005). The differences in meat tenderness among studies may be as a result of variation in techniques to evaluate this meat trait, as well as effects of age, breed and muscle type, which have all been shown to influence meat tenderness (Hoffman and Fisher 2001; Balog and Almeida Paz 2007). The current study sheared meat samples perpendicular to the muscle fibre, while Van Schalkwyk et al. (2005) and Leygonie et al. (2012) sheared their meat samples parallel to the muscle fibre. Also, earlier studies often slaughtered birds at a relatively older age of around 14 months (Hoffman and Fisher 2001; Balog and Almeida Paz 2007; Leygonie et al. 2012). The current study revealed that the fan fillet muscle was lighter in colour (higher L^* value) than the big drum muscle, while the big drum muscle was much redder in colour (higher a^* value) than the fan fillet. The difference between muscles with regard to lightness (L^*) and redness (a^*) in the current study supports the findings of Sales (1996), who reported that the big drum was highly pigmented compared with the fan fillet.

Skin traits

Skin traits were not affected by treatment, sex or the interaction between these two factors. The small sample size for this study probably contributed to these results. Furthermore, skin damage was not affected by treatment. Since treatment groups were mixed from 3 months onwards, there was limited time for treatment effects to reflect on the skins at slaughter. However, treatment could have benefitted early skin damage, resulting in improved grading at slaughter (Meyer 2003).

Reproduction

While other livestock industries promote positive human–animal relationships as a result of evidence in improving productivity in respectively chickens and pigs (Zulkifli and Siti Nor Azah 2004; Wang et al. 2020), it was unclear whether it would be beneficial to rear ostrich chicks in this way. In ostriches, a previous study indicated that human presence and interactions during rearing may compromise reproductive performance since such birds were shown to direct their sexual behaviour towards humans rather than towards their mates (Bubier et al. 1998). Thus, such behaviour could negatively affect fertility of eggs as well as chick production. However, the present study shows that reproductive performance of birds that experienced human presence and interactions at an early age were similar to that of birds that had limited human exposure. It was demonstrated that human–ostrich interactions at an early age do not seem to have any negative impact on reproductive performance at sexual maturity. Interestingly, female ostriches in this study (both the HP1 and S treatment birds) produced on average more eggs and chicks per season than numbers reported previously for 2-year-olds i.e. 20–25 eggs/female and 5–9 chicks/female (Cloete et al. 2006; Cloete and Brand 2014). The females reported in the cited literature were reared using the standard husbandry practice for ostriches with limited human presence and contact (similar to the S treatment in this study) and originated from the same flock from which birds used in the current study descended from. The recorded improvement that seems to be demonstrated by females from the S treatment in the current study compared with females in the literature may reflect selection success for genetic improvement, since selection for high egg and chick production is currently practised in this resource flock (Cloete et al. 2006, 2008, 2012; Cloete and Brand 2014) and both egg and chick production in ostriches has been shown to be heritable, variable and able to respond to selection (Cloete et al. 2008, 2012). The smaller sample size in this study could have contributed to the lack of significant differences in reproduction between treatments. The presented absolute treatment means show that it would be worthwhile to investigate this further with larger numbers of birds. Lastly, the birds in this study were paired by treatment. It may be necessary in the future to vary these factors in a larger experimental design to evaluate female reproductive performance and behaviour (in both males and females) in different mating systems. This important aspect necessitates further research to clarify human–animal relationships and their effects on ostriches.

Conclusions

It can be concluded that human presence and gentle interactions with ostrich chicks up to 3 months of age do not have an effect on slaughter traits at 12 months of age. Since this result may be due to the small sample size of the present study, some alternative approaches for future studies were suggested, including limiting further human–ostrich interactions post-treatment. Reproductive performance of female ostriches also did not differ significantly between birds exposed to various treatments of human presence and interactions at an early age. The obtained results seem to suggest that early human presence and care in ostrich chicks would not compromise the onset of reproduction. Overall, the results of this study suggested that positive human–ostrich interactions early in life may form an integral part of ostrich chick rearing practice in commercial farming setting without negatively affecting subsequent production performance. However, the small sample size probably contributed to the lack of significant differences and large standard errors. Further studies need to include more birds from each treatment, while also evaluating the reproductive performance of such birds under a flock mating system, which is the common type of mating system used in commercial ostrich farming.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the Western Cape Department of Agriculture's Departmental Ethical Committee for Research on Animals (ref no.: R13/81). All human participants entered this study voluntarily with full information about what it entailed for them to take part, and gave their consent before they participated in the study.

References

Adzitey, F. and Nurul, H., 2011. Pale soft exudative (PSE) and dark firm dry (DFD) meats: causes and measures to reduce these incidences - a mini review, International Food Research Journal, 18, 11–20.

Al-Khalifa, H. and Al-Naser, A., 2014. Ostrich meat: Production, quality parameters, and nutritional comparison to other types of meats, Journal of Applied Poultry Research, 23, 784–790.

AOAC International, 2002. Official methods of analysis (17th edition). Arlington, Virginia, USA: Association of Official Analytical Chemists Inc.

Balog, A. and Almeida Paz, I.C.L., 2007. Ostrich (*Struthio camelus*) carcass yield and meat quality parameters, Brazilian Journal of Poultry Science, 9, 215–220.

Barnett, J.L., Hemsworth, P.H., Hennessy, D.P., Mccallum, T.H. and Newman, E.A., 1994. The effects of modifying the amount of human contact on behavioural, physiological and production responses of laying hens, Applied Animal Behaviour Science, 41, 87–100.

Bonato, M., Malecki, I.A., Brand, Z. and Cloete, S.W.P., 2017. Developing a female-only flock for artificial insemination purposes in ostriches: Progress and future directions, Animal Reproduction Science, 180, 85–91.

Brand, T.S. and Jordaan, J.W., 2011. The contribution of the South African ostrich industry to the national economy, Applied Animal Husbandry and Rural Development, 4, 1–7.

Brand, Z., Cloete, S.W.P., Brown C.R. and Malecki, I.A., 2008. Systematic factors that affect ostrich egg incubation traits, South African Journal of Animal Science, 38, 315–325.

Bubier, N.E., Paxton, C.G.M., Bowers, P. and Deeming, D.C., 1998. Courtship behaviour of ostriches (*Struthio camelus*) towards humans under farming conditions in Britain, British Poultry Science, 39, 477–481.

Bunter, K.L., 2002. The genetic analysis of reproduction and production traits recorded for farmed ostriches (*Struthio camelus*), Ph.D. dissertation, University of New England, Armidale, Australia.

Bunter, K.L. and Cloete, S.W.P., 2004. Genetic parameters for egg-, chick- and live-weight traits recorded in farmed ostriches (*Struthio camelus*), Livestock Production Science, 91, 9–22.

Chulayo, A.Y., Tada, O. and Muchenje, V., 2012. Research on pre-slaughter stress and meat quality: A review of challenges faced under practical conditions, Applied Animal Husbandry and Rural Development, 5, 1–6.

Cloete, S.W.P. and Brand, Z., 2014. Genetic parameters for early reproduction traits in ostriches, In ´Proceedings, 10th World Congress of Genetics Applied to Livestock Production, in conjunction with the American Society of Animal Science´, p. 860, Vancouver, BC, Canada.

Cloete, S.W.P., Bunter, K.L., Lambrechts, H., Brand, Z., Swart, D. and Greyling, J.P.C., 2006. Variance components for live weight, body measurements and reproductive traits of pair-mated ostrich females, British Poultry Science, 47, 147–158.

Cloete, S.W.P., Engelbrecht, A., Olivier, J.J. and Bunter, K.L., 2008. Deriving a preliminary breeding objective for commercial ostriches: an overview, Australian Journal of Experimental Agriculture, 48, 1247–1256.

Cloete, S.W.P., Brand, T.S., Hoffman, L., Brand, Z., Engelbrecht, A., Bonato, M., Glatz, P.C. and Malecki, I.A., 2012. The development of ratite production through continued research, World's Poultry Science Journal, 68, 323–334.

Cooper, R.G., 2001. Ostrich (*Struthio camelus var. domesticus*) skin and leather: A review focused on Southern Africa, World's Poultry Science Journal, 57, 157–178.

Engelbrecht, A., Hoffman, L.C., Cloete, S.W.P. and Van Schalkwyk, S.J., 2009. Ostrich leather quality: a review, Animal Production Science, 49, 549–557.

Glatz, P.C., 2011. Welfare issues associated with ratite husbandry practices, in: Glatz, P., Lunam, C., Malecki, I (Eds), The Welfare of Farmed Ratites, Springer-Verlag, Berlin, Heidelberg, Germany, pp. 111–130.

Glatz, P.C. and Miao, Z.H., 2008. Husbandry of ratites and potential welfare issues: a review, Australian Journal of Experimental Agriculture, 48, 1257–1265.

Hemsworth, P.H., 2003. Human–animal interactions in livestock production, Applied Animal Behaviour Science, 81, 185–198.

Hemsworth, P.H., Coleman G.J. and Barnett, J.L., 1994. Improving the attitude and behaviour of stockpersons towards pigs and the consequences on the behaviour and reproductive performance of commercial pigs, Applied Animal Behaviour Science, 39, 349–362.

Hemsworth, P.H., Rice, M., Karlen, M.G., Calleja, L., Barnett, J.L., Nash, J. and Coleman, G.J., 2011. Human–animal interactions at abattoirs: Relationships between handling and animal stress in sheep and cattle, Applied Animal Behaviour Science, 135, 24–33.

Hoffman, L.C. and Fisher, P., 2001. Comparison of meat quality characteristics between young and old ostriches, Meat Science, 59, 335–337.

Hoffman, L.C., Joubert, M., Brand, T.S. and Manley, M., 2005. The effect of dietary fish oil rich in n-3 fatty acids on the organoleptic, fatty acid and physicochemical characteristics of ostrich meat, Meat Science, 70, 45–53.

Lensink, B.J., Fernandez, X., Boivin, X. and Pradel, P., 2000. The impact of gentle contacts on ease of handling, welfare, and growth of calves and on quality of veal meat, Journal of Animal Science, 78, 1219–1226.

Lensink, B.J., Fernandez, X., Cozzi, G., Florand, L. and Veissier, I., 2001. The influence of farmers' behavior on calves' reactions to transport and quality of veal meat, Journal of Animal Science, 79, 642–652.

Leygonie, C.T., Britz, J. and Hoffman, L.C., 2012. Meat quality comparison between fresh and frozen/thawed ostrich *M. iliofibularis*, Meat Science, 91, 364–368.

Majewska, D., Jakubowska, M., Ligocki, M., Tarasewicz, Z., Szczerbińska, D., Karamucki, T. and Sales, J., 2009. Physicochemical characteristics, proximate analysis and mineral composition of ostrich meat as influenced by muscle, Food Chemistry, 117, 207–211.

Meyer, A., 2003. Behaviour and management of ostriches in relation to skin damage on commercial ostrich farms, M.Sc. thesis, University of the Witwatersrand, Johannesburg, South Africa.

Miranda-De la lama, G. C., Estevez-Moreno, L. X., Sepúlveda W.S., Estrada-Chavero, M.C, Rayas-Amor A.A., Villarroel M. and María, G.A., 2017. Mexican consumers' perceptions and attitudes towards farm animal welfare and willingness to pay for welfare friendly meat products, Meat Science, 125, 106–113.

Muvhali, P.T., Bonato, M., Engelbrecht, A., Malecki, I.A., Hough, D., Robinson, J.P., Evans N.P. and Cloete, S.W.P., 2018. The effect of extensive human presence at an early age on stress responses and reactivity of juvenile ostriches towards humans, Animals, 8, 175.

Muvhali, P.T., Bonato, M., Engelbrecht, A., Malecki, I.A. and Cloete, S.W.P., 2020. Extensive human presence and regular gentle handling improve growth, survival and immune competence in ostrich chicks, Journal of Applied Animal Welfare Science, 23, 95–107.

Poławska, E., Marchewka, J., Cooper, R.G., Sartowska, K., Pomianowski, J., Jóźwik, A., Strzałkowska, N. and Horbańczuk, J.O., 2011a. The ostrich meat – an updated review. II. Nutritive value, Animal Science Papers and Reports, 29, 89–97.

Poławska, E., Marchewka, J., Krzyżewski, J., Bagnicka, E. and Wójcik, A., 2011b. The ostrich meat – an updated review. I. Physical characteristics of ostrich meat, Animal Science Papers and Reports, 29, 5–18.

Rushen, J., Depassille', A.M.B. and Munksgaard, L., 1999. Fear of people by cows and effects on milk yield, behaviour and heart rate at milking, Journal of Dairy Science, 82, 720–727.

Sales, J., 1996. Histological, biophysical, physical and chemical characteristics of different ostrich muscles, Journal of the Science of Food and Agriculture, 70, 109–119.

Statistical Analysis System (SAS), 2012. Base SAS® 9.3 Procedures Guide: Statistical Procedures, Second Edition. Cary, NC: SAS Institute Inc.

Terlouw, C., 2005. Stress reactions at slaughter and meat quality in pigs: genetic background and prior experience: A brief review of recent findings, Livestock Production Science, 94, 125–135.

Terlouw, E.M.C., Porcher J. and Fernandez, X., 2005. Repeated handling of pigs during rearing. II. Effect of reactivity to humans on aggression during mixing and on meat quality. Journal of Animal Science, 83, 1664–1672.

Van Schalkwyk, S.J., Hoffman L.C., Cloete S.W.P. and Mellett, F.D., 2005. The effect of feed withdrawal during lairage on meat quality characteristics in ostriches, Meat Science, 69, 647–651.

Wang, M.D., Cloete, S.W.P., Dzama, K., Bonato, M. and Malecki, I.A., 2012. Foster parenting, human imprinting and conventional handling affects survival and early weight of ostrich chicks, South African Journal of Animal Science, 42, 123–130.

Wang, C., Chen, Y., Bi, Y., Zhao, P., Sun, H., Li, J., Liu, H., Zhang, R., Li, X. and Bao, J., 2020. Effects of long-term gentle handling on behavioral responses, production performance, and meat quality of pigs. Animals, 10, 330

Warriss, P.D., 2000. Meat science: An introductory text, Wallingford, England: CABI.

Zulkifli, I. and Siti Nor Azah, A., 2004. Fear and stress reactions, and the performance of commercial broiler chickens subjected to regular pleasant and unpleasant contacts with human beings. Applied Animal Behaviour Science, 88, 77–87.

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