Animal Science Papers and Reports vol. 37 (2019) no. 2, 195-208
Institute of Genetics and Animal Breeding, Jastrzębiec, Poland

Chemical composition, selected physicochemical properties and meat sensory characteristics in five types of emu muscles (*Dromaius novaehollandiae*)

Małgorzata Jakubowska[1], Mateusz Bucław[2]*, Danuta Majewska[2], Danuta Szczerbińska[2], Tadeusz Karamucki[1]

[1] West Pomeranian University of Technology Szczecin, Department of Immunology, Microbiology and Physiological Chemistry, Institute of Food Commodity Sciences, 45 Piastów, Szczecin 70-311, Poland

[2] West Pomeranian University of Technology Szczecin, Department of Poultry and Ornamental Birds Breeding, 29 Klemensa Janickiego St., 71-270 Szczecin, Poland

(Accepted April 29, 2019)

The aim of the study was to assess the basic chemical composition, selected physicochemical properties and sensory characteristics of emu meat depending on muscle type. The research was conducted on six male birds culled after reproductive use (at 15 years old). After culling, five types of muscles were isolated from the carcasses *(M. gastrocnemius pars externa, M. gastrocnemius pars interna. M. obturatorius medialis, M. flexor cruris lateralis* and *M. iliotibialis lateralis)*. The muscles were frozen and stored at -18°C for between one and two months. Defrosting was conducted at 0-4°C. Meat quality assessment included the measurement of pH_{24} and pH_u, WHC and colour parameters (L*, a*, b*). The basic chemical composition of meat, cooling, freezing and cooking losses were identified. Sensory assessment was conducted on broth (colour, flavour, clarity, palatability) and cooked meat (colour, flavour, clarity, juiciness, palatability). Individual muscles differed in protein, fat and water content. The *M. flexor cruris lateralis* muscle was the brightest, had the lowest water absorption capability and the highest pH of all examined muscles. The highest cooking losses during freezing and cool storage were observed in *M. obturatorius medialis.* All of the examined muscles had the required colour and smell. The largest tenderness and succulence as well as the best taste were observed in *M. flexor cruris lateralis* and *M. obturatorius medialis.* The broths obtained from all emu muscles were clear and had the appropriate colour, flavour and palatability.

KEYWORDS: emu / muscles / quality / physicochemical traits / sensory properties

*Corresponding author: mateusz.buclaw@zut.edu.pl

Products from animals native to tropical and sub-tropical areas have gained popularity across the world food markets. With an oversupply of meat coming from intensive farming, consumers tend to desire foodstuffs produced from animals fed GMO-free feeds or animals housed with access to pastures or grassy runs. Ratites, i.e. ostriches, emus and rheas managed this way are of particular interest of both farmers and consumers, as they provide meat low in fat [Cooper and Horbańczuk 2004, Cooper *et al.* 2007, Horbańczuk *et al*. 1998, 2007, 2008, Hoffman 2008, Nithyalakshmi and Preetha 2015].

The emu (*Dromaius novaehollandiae*) is the second largest bird in the world and the largest avian species native to Australia, where its commercial farming has been developing successfully since 1970s. Those birds have become a popular farming species on nearly every continent due to their excellent adaptability to various habitats and climates [Sales and Horbańczuk 1998, Sales et al. 1999, Sales 2007].

Initially, emus were farmed mostly for hide and fat, the latter product used for oil production. Meat, wrongly considered as greasy, was treated as a by-product. Later, however, emu meat was rediscovered as an edible food, its taste resembling young beef meat [Minnaar and Minnaar 1992]. Analyses have revealed that the meat is even of higher quality compared to other meat types, since despite the sensory similarity to red meat, emu meat has the properties of white meat, which led to the American Heart Association recommendation of it for human healthy diet [Pegg *et al*. 2006]. It has been demonstrated that emu meat is rich in protein and low in fat and cholesterol. Fatty acid profile is also very favourable and, moreover, this meat is rich in minerals (Ca, Fe, K, Mg, Na, P, Zn), vitamins (A, B2, B6, B12, E) and creatine [Pegg *et al*. 2006, Naveena *et al*. 2013].

Poultry meat present on the market usually originates from broilers, but also from adult laying hens on the completion of their laying period. Similarly, there is a possibility of using the emu meat from birds after their reproduction use. Ratites farmed for reproduction purposes spend many years on the farm. The peak laying performance for emu is observed at the age of 4-6 years [Szczerbińska *et al*. 2014]; however, birds are managed much longer and are not slaughtered until their egg production or hatching efficiency is substantially reduced. The literature lacks reports on sensory quality or processing value of emu meat produced from spent birds after completion of their reproduction life. Therefore, this study aimed to evaluate the chemical composition, selected physicochemical features and sensory quality of emu meat, depending on the type of muscle. This will broaden ~~our~~ the knowledge of the of this meat for food products, and supplement the available nutritional information on the meat of these production birds.

Material and methods

The material comprised emu males (6 birds) slaughtered at the age of 15 years at the end of their reproductive life. The birds were hatched and raised on an experimental

farm of the Department of Poultry and Ornamental Birds Breeding, the West Pomeranian University of Technology, Szczecin, Poland. All emus were managed in an open system, with unlimited access to pasture regardless of the weather and season. Birds were fed *ad libitum* standard complete feed pellets based on oats, maize, wheat and soybean meal, composed following nutritional recommendations for the species. The diet contained 18.00% total protein, 6.70% crude ash, 5.20% crude fibre, 2.10% crude fat and 10.63 MJ of net metabolizable energy (NME) in 1 kg of feed.

The birds fasted for 24 hours prior to slaughter, which was carried out by decapitation following stunning. The birds were stunned by means of impact on the head with a wooden stick. Stunned birds were trammelled, hung upside-down and bled by opening the jugular vein and the carotid artery located just behind the head.

After bleeding, feather removal and evisceration was performed, and carcasses were chilled at 4°C for 24 hours. Subsequently, 5 muscles (*M. gastrocnemius pars externa, M. gastrocnemius pars interna*, *M. obturatorius medialis*, *M. flexor cruris lateralis* and *M. iliotibialis lateralis*) were cut from either side of the carcass. Muscle identification was carried out according to Lamas *et al*. [2014].

The dissected muscles were wrapped in a double-layer plastic film and stored frozen at -18°C for two months. Thawing was carried out at 0-4°C. Muscles from the left side of the carcass were used for physicochemical assays, whereas those from the right side – for sensory analyses.

The left-side muscles were divided into two parts, one was weighed and used to measure cooling, freezing and cooking loss, while the other was used to determine pH, colour, and water-holding capacity.

Meat for chemical, pH and water-holding capacity analyses was minced twice using a mincer with 4-mm holes.

Chemical composition

The chemical component analysis of the meat involved determining the percentage of dry matter, total water, crude protein, fat and ash using conventional methods [AOAC 2007].

pH

The level of pH of the meat was measured 24 hours post-slaughter (pH_{24}) and directly after thawing (pHu), using a pH glass combination electrode (type ESAgP-302W) and a CyberScan pH 10 Meter (Eutech Instruments) in an aqueous extract (distilled water), after 1-hour extraction in 1:1 meat-to-water ratio.

Water-holding capacity (WHC)

WHC of the meat was determined by the methods of Grau and Hamm [1953], modified by Pohja and Niinivaara [1957]. A pair of parallel 300-mg samples was weighed to the nearest 0.001 g on an analytical scale on Whatman 1 blotting paper, placed between glass plates, which were weighed down with 2 kg for 5 minutes.

The boundaries of the pressed meat and the resulting drip stain were outlined on the blotting paper using an ink pencil. When dried, the area of both stains was measured and the drip was calculated from plane area differences. Water content was calculated by dividing the drip stain area (in cm^2) by sample weight (g). Subsequently, the percentage of free water content in total water (determined by dry matter) was calculated. WHC was expressed as a percentage of bound water in total water content.

Colour

The colour of the meat was measured using a MiniScan XE Plus 45/0 meter with a 31.8-mm port diameter, calibrated using white and black standard. The coordinates of the white standard were as follows: X = 78.5, Y = 83.3 and Z = 87.8 (for the D65 standard illuminant and 10° standard observer). Colour parameters for each sample were determined according to CIE L* a *b* (1976) with the illuminant/observer like D65/10°. The colour was measured on the internal surface of raw muscles previously stored at 4°C to oxygenate myoglobin within the surface layer of the muscle.

Cooling, freezing and cooking loss

A 100-g sample, 20-mm-thick, was cut from each leg muscle. The losses resulting from cooling, freezing and cooking were calculated. Determination of weight loss by weighing the samples before and after storage was performed using a Radwag electronic weighing scale to the nearest 0.01 g.

The samples were placed in the plastic bags and stored refrigerated at 4°C for 24 hours. The samples were then weighed and cooling drip loss was calculated. Next, muscles were frozen and stored at -18°C until further analyses. After thawing, drip loss was determined as the difference between sample weight before freezing and after 24-hour thawing at 4°C. Thawed meat was placed in tight, 500-ml glass containers, and 300 ml of water was added. The vessels were then placed in a water bath and heated to 85°C for 1 hour, according to the methods described by Baryłko-Pikielna *et al*. [1964]. As a result, cooking loss was calculated based on the difference in the sample weight before and after cooking.

Sensory assessment

The muscles taken from the right half-carcass were stored frozen at -18°C for 2 months for sensory evaluation. Thawed muscles weighing 300 g were placed in 1 litre glass jars and 600 ml of water was added. The jars were sealed and placed in a water bath until the temperature in the muscle reached 85°C, according to the method described by Baryłko-Pikielna *et al*. [1964].

The testing was conducted at the laboratory of the Institute of Food Commodity Sciences of West Pomeranian University of Technology Szczecin, equipped with individual stations. Throughout the tests, a temperature of 22°C (±0.5°C) was maintained in the laboratory by a controlled air-conditioning system. Incandescent lighting reached ca. 500 lx (ISO, 1988). The study participants consisted of six

individuals: three males and three females aged from 30 to 45 years. The panelists were trained according to Polish guidelines (ISO-8586-1:1999 and ISO 8586-2:1999). Upon assessing each sample, the panellists neutralised their taste with a sip of bitter, slightly cooled tea. The following characteristics were evaluated: (meat) colour, flavour, tenderness, juiciness and palatability and (broth) clarity, colour, flavour, palatability. A 5-point scale was used to score the quality of meat and broth, with 1 being the worst and 5 being the best score [PN-ISO-4121 1998].

Statistical analysis

The obtained results were subjected to statistical analysis involving calculating means ($\bar{x}$), mean standard deviation (SD) and performing one-way analysis of variance (ANOVA). Significance of differences between means ($\bar{x}$) was assessed using post-hoc Tukey's test at $P \leq 0.01$ and $P \leq 0.05$. Statistical analysis was performed using the Statistica 13.1 PL package [IBM Corp.2016].

Results and discussion

Chemical composition

The analysis of the chemical composition of emu muscles (Tab. 1) revealed a high water content (76.06% on average). Similar data were reported by Pegg *et al*. [2006]. Naveena *et al*. [2013] and Nithyalakshmi and Preetha [2015], who reported a slightly lower water content (73.80-74.79%). The lowest water content in our analyses was found in *M. obturatorius medialis* (74.93%), and the highest in *M. flexor cruris lateralis* (77.19%), the latter also showing the lowest protein content (20.91%). A similar protein content in emu meat was found by Pegg *et al*. [2006]. The *flexor cruris lateralis* muscle significantly differed from the other muscles, because it contained similarly high levels of protein (22.84-23.36%); this was also found by other authors who analysed emu meat [Naveena *et al*. 2013, Nithyalakshmi and Preetha 2015]. The highest fat content was found in *M. obturatorius medialis* (1.73%) and *M. flexor cruris lateralis* (1.78%), which differed significantly from the other muscles (0.90-0.98%). Some authors also reported low fat content in emu muscles, in the range of 0.84-1.40% [Pegg *et al*. 2006, Naveena *et al*. 2013]. As already mentioned, high protein content with low fat was characteristic of ratite meat and highly appreciated by consumers. Their levels usually averaged to 22.81% and 1.59% for protein and fat, respectively [Pereira *et al*. 2006, Romanelli *et al*. 2008]. In ostriches, however, protein and fat contents ranged from 21.00% and 0.49% in *M. iliofibularis*, respectively, [Wang *et al*. 2014] to 22.41% in *M. gastrocnemius* [Kuzelov *et al*. 2012] and 1.95% in *M. iliofibularis* [Hoffman *et al*. 2005]. It should also be noted that ratite meat had a higher protein content and lower fat compared to the generally considered lean and dietary turkey meat, where in the largest thigh muscle of males (*M. ilio tibialis*) protein content was 19.4-20.4% and fat 4.53-6.02% depending on the weight type [Damaziak *et al*. 2018]. No significant differences were found in ash content, which averaged

1.35% and was lower compared to data reported by other authors in the same species by 0.15 [Pegg *et al*. 2006] and 0.46 percentage points [Naveena *et al*. 2013].

pH

Muscle pH in 24 hours post-slaughter ranged from pH_{24} 5.67 in *M. obturatorius medialis* to pH_{24} 5.84 in *M. flexor cruris lateralis* (Tab. 2). The average pH_{24} for all muscles was 5.73. Berge *et al*. [1997] reported this parameter in unstressed emu to be 5.6, whereas the meat of emus exposed to pre-slaughter stress had a pH_{24} of 6.1.

Comparing to other ratites, fresh ostrich meat pH ranges between 5.43 and 5.73 [Paleari *et al*. 1998, Pegg *et al*. 2006]. Other studies on ostriches revealed meat pH_{24} ranging from 5.91 to 6.21 or even 6.67 [Sales and Mellet 1996, Van Schalkwyk *et al*. 2005, Hoffman *et al*. 2006].

According to Horbańczuk and Wierzbicka [2016, 2017], emu meat ~~is~~ was characterised by a relatively high final pH levels (6.0), which was responsible for its dark colour, high water-holding capacity and a relatively short shell life. These authors claimed that pH of emu meat made it resemble beef (sirloin – pH 5.8) rather than chicken (leg – pH 6.0).

The type of muscle appeared to have an influence on meat pH (Tab. 2). Final muscle pH averaged to 5.66 and was similar to the pH measured in emu muscles by Naveena *et al*. [2013]. Significantly higher acidity (pHu 5.76) was found in *M. iliotibialis lateralis*, in comparison to the other muscles, in which the values ranged from 5.59 to 5.66. According to Warris [2000], most animals exhibited the post-slaughter pH fall from about 7.00 to 5.5.

Water-holding capacity (WHC)

Water-holding capacity of emu muscles was on average 76.21% (Tab. 2). Significantly lower water-holding capacity was found in *M. flexor cruris lateralis* (71.94%), as compared to *M. obturatorius medialis* (80.57%). It is commonly known that the tissue's ability to hold water heavily depends on pH, functional status of muscle proteins and muscle structure. The acidity of all the analysed muscles was normal and did not reveal any protein degradation changes that could be the result of low pH. The lower WHC of *M. flexor cruris lateralis* could be associated with a low content of crude protein compared to the other muscles, where there was 1.93-2.45 pp more protein (Tab. 1).

Colour

The colour is a key qualitative characteristic of meat. It is shaped by the quantity of heme pigments and their chemical structure, meat structure (dependent on its chemical composition) and the post-mortem rate of pH decline [Brewer *et al*. 2001, Karamucki *et al*. 2013a]. Emu meat is usually dark, cherry red, rich in myoglobin (8.87 mg/g on average) [Naveena *et al*. 2013]. When compared to the other analysed muscles, *M. flexor cruris lateralis* (37.23) exhibited a significantly brighter colour

Table 1. Chemical composition of emu muscles – average (±SD)

Trait (%)	*M. gastrocnemius pars externa*	*M. gastrocnemius pars interna*	*M. obturatorius medialis*	*M. flexor cruris lateralis*	*M. iliotibialis lateralis*	Average value
Moisture	76.02 (0.45)	76.18 (0.70)	74.93^{A} (1.01)	$77.19^{A} \pm 0.87$)	76.00 (0.70)	76.06 (1.02)
Protein	23.10^{A} (0.38)	22.84^{B} (0.56)	23.36^{C}(0.90)	20.91^{ABCD} (0.61)	22.92^{D} (0.40)	22.62 (1.05)
Fat	0.98^{ab} (0.21)	0.94^{cd} (0.56)	1.73^{ace} (0.45)	1.78^{Abd} (0.49)	0.90^{Ae} (0.26)	1.27 (0.56)
Ash	1.26 (0.11)	1.42 (0.27)	1.43 (0.16)	1.44 (0.33)	1.21 (0.14)	1.35 (0.23)

aA... Within rows means bearing with the same superscripts differ significantly at: small letters – P≤0.05; capitals – P≤0.01.

Table 2. Physicochemical traits of emu muscles – average (±SD)

Item	*M. gastrocnemius pars externa*	*M. gastrocnemius pars interna*	*M. obturatorius medialis*	*M. flexor cruris lateralis*	*M. iliotibialis lateralis*	Average value
WHC (%)	75.74 (3.62)	76.24 (2.07)	80.57^{A} (3.79)	71.94^{A} (2.70)	76.57 (4.93)	76.21 (4.32)
pH_{24}	5.70 (0.17)	5.73 (0.21)	5.67 (0.21)	5.84 (0.16)	5.71 (0.20)	5.73 (0.19)
pHu	5.66^{A} (0.07)	5.66^{B} (0.04)	5.59^{C} (0.03)	5.76^{ABCD} (0.05)	5.65^{D} (0.02)	5.66 (0.07)
L*	27.57A (1.03)	26.22^{B} (1.30)	27.42C (2.66)	37.23^{ABCD} (2.36)	27.36^{D} (2.64)	29.16 (4.58)
a*	10.88^{A} (0.66)	10.17^{B}(0.84)	10.56^{C}(1.16)	14.67^{ABCD} (1.71)	10.16^{D} (1.41)	11.29 (2.07)
b*	7.01^{A} (0.22)	6.80^{Ba} (0.35)	8.12^{Ca} (0.71)	13.29^{ABCD} (1.24)	7.08^{BD} (0.62)	8.46 (2.59)

aA... Within rows means bearing with the same superscripts differ significantly at: small letters – P≤0.05; capitals – P≤0.01.

Table 3. Cooling, freezing and cooking loss of emu muscles – average (±SD)

Trait (%)	*M. gastrocnemius pars externa*	*M. gastrocnemius pars interna*	*M. obturatorius medialis*	*M. flexor cruris lateralis*	*M. iliotibialis lateralis*	Average value
Drip loss 24h	0.81^{ABa} (0.31)	0.82^{CDb} (0.30)	3.06^{AC} (1.09)	2.29^{ab} (0.75)	2.80^{BD} (0.95)	1.95 (1.20)
Freezing loss	8.67^{a} (2.28)	9.77 (1.46)	13.50^{a} (3.59)	10.42 (2.69)	11.70 (2.68)	10.81 (2.97)
Cooking loss	42.54 (2.92)	39.93 (2.95)	39.22 (1.65)	38.69 (4.09)	38.07 (2.37)	39.49 (3.14)

aA... Within rows means bearing with the same superscripts differ significantly at: small letters – P≤0.05; capitals – P≤0.01.

(L*, Tab. 2). The L* values of the other muscles, except for *M. flexor cruris lateralis*, were similar to those measured in ostriches by Hoffman and Fisher [2001], Majewska *et al*. [2009] and Poławska *et al*. [2011].

Many authors have claimed that there is a relationship between meat pH and its colour. At high pH, water is more tightly bound within the muscle, thanks to which the meat surface is more compact and less permeable to oxygen. In consequence,

there is less oxymyoglobin and more myoglobin on the muscle surface, which gives the muscle a darker tint [Hoffman *et al*. 2005, Karamucki *et al*. 2013a, 2013b]. In our study, this relationship could not be confirmed in *M. flexor cruris lateralis*. The muscle was characterised by the brightest colour and the highest pH_{24} and pHu from all the muscles examined. The brighter colour of this particular muscle may have been due to a more fragile muscle structure and higher intramuscular fat content, as well as its greater hydration (Tab. 1 and 2). This assumption was also confirmed by the results of sensory evaluation, as the muscle attained the highest score for tenderness (3.78 points), juiciness (3.63 points) and palatability (3.56 points) against all the muscles we examined (Tab. 4). However, the dark colour of the remaining muscles was most probably associated with the age of birds, as they were slaughtered at the age of 15 years. The age of birds influenced the colour of meat, older birds had a darker meat colour, which was related to a higher content of myoglobin and muscle structure [Hoffman and Fisher 2001, Fletcher 2002].

The intensity of redness (a*) was higher in *M. flexor cruris lateralis* (14.67) as compared to the other muscles (Tab. 2). The values were similar to those found in the emu muscle by Menon *et al*. [2014]. Lower values of this parameter was found in an eight-year-old emu, according to Berge *et al*. [1997].

The proportion of yellowness (b*) was significantly higher in the *M. flexor cruris lateralis* muscle (18.97), and this parameter was significantly lower in the remaining muscles (6.80 to 8.12) (Tab. 2). Lower values of this parameter were observed in the muscles of 4-year-old emus transported 6 hours before slaughter [Menon *et al*. 2014]. A lower proportion of yellow colour was also observed in the muscles of 14-month-old and 8-year-old ostriches [Hoffman and Fisher 2001, Hoffman *et al*. 2005]. The level of the b* parameter depends on the forms of myoglobin, muscular tissue structure and its pH. As a rule, the lower pH is accompanied by the greater yellowness of meat. In our study, it has not been confirmed, because muscles with low pH were less yellow compared to muscles with a higher pH. Presumably, such a large proportion of yellow colour in the *M. flexor cruris lateralis* muscle (14.67) was the effect of myoglobin forms and muscle structure. This meat could have contained more myoglobin than

Table 4. The results of sensory evaluation of cooked emu muscles (on a point scale) – average (±SD)

Item	*M. gastrocnemius pars externa*	*M. gastrocnemius pars interna*	*M. obturatorius medialis*	*M. flexor cruris lateralis*	*M. iliotibialis lateralis*	Average value
Colour	4.13^{Aa} (0.28)	4.07^{BC} (0.21)	4.55^{Ba} (0.21)	4.73^{ACb} (0.16)	4.37^{b} (0.18)	4.37 (0.32)
Flavour	3.93 (0.04)	3.90^{a} (0.14)	4.13^{ab} (0.21)	4.01 (0.07)	3.92^{b} (0.06)	3.98 (0.14)
Tenderness	1.80^{ABC} (0.28)	2.20^{DE} (0.25)	3.23^{ADa} (0.32)	3.78^{BEF} (0.33)	2.63^{CFa} (038)	2.73 (0.78)
Juiciness	2.07^{ABC} (0.16)	2.47^{Da} (0.39)	3.13^{Aa} (0.31)	3.63^{BDE} (0.25)	2.88^{CE} (0.46)	2.84 (0.63)
Palatability	2.90^{A} (0.20)	3.05^{a} (0.21)	3.34 (0.27)	3.56^{Aa} (0.34)	3.19 (0.27)	3.21 (0.34)

aA… Within rows means bearing with the same superscripts differ significantly at: small letters – $P \leq 0.05$; capitals – $P \leq 0.01$.

oxymyoglobin, because it was derived from spent animals (15-year-old) [Hoffman and Fisher 2001].

Cooling, freezing and cooking loss

Water-holding capacity of meat is responsible for weight loss occurring during storage and transport [Alvarado and Sams, 2002]. Water loss from the tissue after slaughter and during storage is associated with lower pH and muscle protein denaturation.

Cold storage resulted in significantly lower weight loss in *M. gastrocnemius pars externa* (0.81%) and *M. gastrocnemius pars interna* (0.82%), as compared with the other muscles (Tab. 3).

After a 2-month storage period, freezing loss in the analysed muscles reached 10.81% (Tab. 3). Significantly lower freezing loss was found in *M. gastrocnemius pars externa* (8.67%) compared with *M. obturatorius medialis* (13.50%). The results of our freezing loss experiment in *M. gastrocnemius pars externa* (8.4%) and *M. Iliofiburalis* (7.0%) were higher than those reported by Filgueras *et al*. [2011].

The ability of meat to retain endogenous water during thermal processing is a very important determinant of quality. Heat processing of meat is accompanied by water loss from muscle proteins, which results in the so-called thermal drip. Cooking loss recorded in our experiments ranged from 38.07% to 42.54% (Tab. 3). Similar results regarding cooking loss (100°C, 30 min) were reported by Filgueras *et al*. [2011] in *M. gastrocnemius pars interna* of the rhea (41.9%). On the other hand, Botha *et al*. [2007] reported lower thermal loss in *M. gastrocnemius pars externa* (36%) of the ostrich, with a 1-hour thermal processing at 80°C.

Meat sensory evaluation

The cooked meat of emu muscles proved to have an attractive colour and flavour, as the scores ranged between 3.90 and 4.73 points (Tab. 4). Significantly higher scores were achieved by *M. obturatorius medialis* (4.13 and 4.55 pts) and *M. flexor cruris lateralis* (4.01 and 4.73 pts) for colour and flavour, respectively.

Only two muscles exhibited the desired tenderness, *M. obturatorius medialis* and *M. flexor cruris lateralis*, with scores ranging from 3.23 to 3.78 pts. The other muscles were hard and obtained merely 1.80-2.63 pts. The type of muscle had a significant effect on meat tenderness. This has also been demonstrated in studies on emu and ostrich meat tenderness, as reported by other authors [Berge *et al*. 1997, Marks *et al*. 1998, Sales 1999, Girolami *et al*. 2003]. Meat tenderness evaluation scores may be influenced by intramuscular collagen content. According to Berge *et al*. [1997], the content of soluble collagen in emu meat ranged from 16 to 20%, depending on the type of muscle. The cross-linking of collagen in the muscle and the resulting meat texture increased with age [Fletcher 2002]. Physiological maturity was the basic factor of meat texture. Berge *et al*. [1997] reported that total collagen in the muscles of emu aged 6 to 20 months and older did not change, however, soluble collagen

decreased from 21 to 15%. The age of birds at slaughter (15 years) in our experiment was most probably the key factor that caused the meat to score so low in terms of tenderness. Hoffman and Fisher [2001] observed differences in shear force in cooked ostrich meat, with the values higher in older birds compared to younger individuals.

Similarly to the texture, significantly better juiciness was found only in two muscles, *M. obturatorius medialis* (3.13 pts) and *M. flexor cruris lateralis* (3.63 pts) compared to other muscles. Juiciness is an important characteristic of thermally processed meat, which is related to its water-holding capacity. The analysed muscles exhibited appropriate water-holding capacity (76.21%). Juiciness also depends on the method and duration of thermal processing [Akinwumi *et al*. 2013]. Exposure to prolonged heating may considerably dehydrate the meat, which deteriorates its juiciness; mild heating, on the other hand, promotes juiciness. *M. gastrocnemius pars externa*, *M. gastrocnemius pars interna* and *M. iliotibialis lateralis* muscles were characterised by poor juiciness in our experiment, which may have resulted from a low level of intramuscular fat compared to the other muscles (Tab. 1). According to Hoffman *et al*. [2005], fat is important for the impression of succulence in meat, because it enhances saliva secretion.

Emu muscles were not perceived as very tasty either. Significantly higher scores for cooked meat palatability were obtained only by *M. flexor cruris lateralis* (3.56 pts) compared to *M. gastrocnemius pars externa* (2.90 pts) and *M. gastrocnemius pars interna* (3.05 pts).

Daszkiewicz *et al*. [2005] indicated that a certain amount of intramuscular fat that causes marbling of the meat and loosening of the connective tissue is necessary in order to favourably shape the sensory characteristics of the meat. These authors demonstrated that cooked pork with the highest fat content (more than 2.5% fat in the tissue of the *longissimus dorsi* muscle) obtained significantly higher sensory quality scores compared to other groups.

There was no influence of muscle type on the sensory characteristics of broth produced from cooked emu meat (Tab. 5). The broth was fairly clear (3.85 pts), characterised by the right colour (3.95 pts), flavour (3.84 pts) and palatability (3.68 pts). The evaluated broth was characterised by good sensory attractiveness and obtained higher scores compared to cooked meat from which the broth was derived. The attractiveness of the broth was probably influenced by the method of heat

Table 5. The results of sensory evaluation of broth-cooked emu muscles (on a point scale) – average (±SD)

Item	*M. gastrocnemius pars externa*	*M. gastrocnemius pars interna*	*M. obturatorius medialis*	*M. flexor cruris lateralis*	*M. iliotibialis lateralis*	Average value
Clarity	3.60 (0.45)	3.60 (0.45)	4.27 (0.67)	4.21 (0.75)	3.55 (0.66)	3.85 (0.65)
Colour	4.31 (0.55)	4.04 (0.87)	3.65 (0.43)	3.92 (0.42)	3.83 (0.73)	3.95 (0.62)
Flavour	3.79 (0.14)	3.85 (0.08)	3.89 (0.17)	3.86 (0.10)	3.83 (0.10)	3.84 (0.12)
Palatability	3.74 (0.13)	3.71 (0.17)	3.54 (0.15)	3.84 (0.30)	3.56 (0.25)	3.68 (0.23)

treatment; the meat was placed cold water and subjected to heat treatment. Such a thermal treatment caused intensive extraction of meat components, such as amino acids, peptides, proteins and minerals. Broth obtained this way will have a high concentration of aromatic substances [Akinwumi *et al*. 2013], which will determine its higher sensory quality.

Conclusions

An effect of muscle type on the quality of emu meat was observed. The type of muscle influenced the formation of its proximate chemical composition. Individual muscles varied in protein, fat and water contents. The muscles were also different in terms of physicochemical properties. The significantly brightest colour, lowest water-holding capacity and a higher pH, as compared to other muscles, were found in the *M. flexor cruris lateralis* muscle. The highest refrigeration and freezing storage losses were recorded in the *M. obturatorius medialis* muscle.

Sensory analysis showed the effect of muscles on the organoleptic characteristics of cooked meat. All muscles were characterised by a desired colour and flavour. Among the evaluated muscles, *M. flexor cruris lateralis* and *M. obturatorius medialis* were characterised by the best tenderness, juiciness and palatability. The remaining muscles were harder, less juicy and less tasty. The resulting broth from boiled emu meat was tastier compared to cooked meat. The broth was clear, characterised by the appropriate colour, smell and flavour.

REFERENCES

1. AKINWUMI A.O., ODUNSI A.A., OMOJOLA A.B., AKANDE T.O., RAFIU T.A., 2013 – Evaluation of carcass, organ and organoleptic properties of spent layers of different poultry types. ***Botswana Journal of Agriculture and Applied Sciences*** 9, 3-7.
2. ALVARADO C.Z., SAMS A.R., 2002 – The role of carcass chilling rate in the development of pale, exudative turkey pectoralis. ***Poultry Science*** 81, 1365-1370.
3. AOAC, 2007 – Official methods of analysis of AOAC International. 18th edition, Association of Official Analytical Chemists, Arlington, USA.
4. BARYŁKO–PIKIELNA N., KOSSAKOWSKA T., BALDWIN Z., 1964 – Selection of the optimum method of beef and pork preparation for sensory evaluation. ***Roczniki Instytutu Przemysłu Mięsnego*** 1, 111-132.
5. 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 Science*** 2, 225-221.
6. BOTHA S.S., HOFFMAN L.C., BRITZ T.J., 2007 – Physical meat quality characteristics of hot-deboned ostrich (*Struthio camelus var. domesticus*) Muscularis gastrocnemius pars interna during post-mortem aging. ***Meat Science*** 75, 709-718.
7. BREWER M.J., ZHU L.G., BIDNER B., MEISINGER D.J., MC KEITH F.K., 2001 – Measuring pork color: efects of bloom time, muscle, pH and relationship to instrumental parameters. ***Meat Science*** 57, 169-176.
8. CIE, 1976 – Colourimetry: Official recommendations of the international commission on illumination. Paris: CIE 15 (E-1.3.1) Boreau Central de la Commission Internationale De L'Eclairage.

9. COOPER R.G., HORBAŃCZUK J.O., 2004 – Ostrich nutrition: a review from a Zimbabwean perspective. Monography. ***Revue Scientifique et Technique de L Office International Des Epizooites*** 23(3), 1033-1042.
10. COOPER R.G., TOMASIK C., HORBAŃCZUK J.O., 2007 – Avian Influenza in Ostriches (Struthio camelus). ***Avian and Poultry Biology Reviews***, 18 (3), 87-92.
11. DAMAZIAK K., PIETRZAK D., MICHALCZUK M., ADAMCZAK L., CHMIEL M., FLOROWSKI T., GOZDOWSKI D., NIEMIEC J., 2018 – Early and 24 h post-mortem thigh (ilio tibialis) muscle metabolism and meat quality in two genetic types of turkeys and their reciprocal crosses, raised under semi-confined conditions. ***British Poultry Science*** 59, 45-54.
12. DASZKIEWICZ T., BĄK T., DENABURSKI J., 2005 – Quality of pork with different intramuscular fat (IMF) content. ***Polish Journal of Food and Nutrition Sciences*** 1, 31-36.
13. 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 Science*** 64, 309-315.
14. GRAU R., HAMM R., 1953 **–** Eine einfache Methode zur Bestimmung der Wasserbindung im Muskel. ***Naturwissenschaften*** 40, 29-30.
15. HOFFMAN L.C., FISHER P., 2001 **–** Comparison of meat quality characteristics between young and old ostriches. ***Meat Science*** 59, 335-337.
16. HOFFMAN L.C., JOUBERT M., BRAND T.S. 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.
17. HOFFMAN L.C., BOTHA S.S., BRITZ T.J., 2006 **–** Sensory properties of hot-deboned ostrich *(Struthio camelus var. domesticus)* Muscularis gastrocnemius, pars interna. ***Meat Science*** 72, 734-740.
18. HOFFMAN L.C., 2008 **–** Value adding and processing of ratite meat: A review. ***Australian Journal of Experimental Agriculture*** 8, 1270-1275.
19. HORBAŃCZUK O.K., WIERZBICKA A., 2016 – Technological and nutritional properties of ostrich, emu, and rhea meat quality. ***Journal of Veterinary Research*** 60, 279-286.
20. FILGUERAS R.S, GATELLIER P., FERREIRA C., ZAMBIAZI R.C., SANTÉ-LHOUTELLIER V., 2011 **–** Nutritional value and digestion rate of rhea meat proteins in association with storage and cooking processes. ***Meat Science*** 89, 6-12.
21. FLETCHER D.L., 2002 **–** Poultry meat quality. ***World`s Poultry Science Journal*** 58, 131-145.
22. HORBAŃCZUK J.O., KAWKA M., SACHARCZUK M, COOPER R.G., BORUSZEWSKA K., PARADA P., JASZCZAK K., 2007 – A search for sequence similarity between chicken (Gallus domesticus) and ostrich (Struthio camelus) microsatellite markers. ***Animal Science Papers and Reports*** 25, 283-288.
23. HORBAŃCZUK J., SALES J., CELEDA T., KONECKA A., ZIĘBA G., KAWKA P., **–** Cholesterol Content and Fatty Acid Composition of Ostrich Meat as Influence by Subspecies. ***Meat Science*** 1998, 50, 385-388.
24. HORBAŃCZUK J.O, TOMASIK C, COOPER R.G., 2008 – Ostrich farming in Poland - its history and current situation after accession to the European Union. ***Avian Poultry and Biology Reviews*** 1, 65-71.
25. HORBAŃCZUK O.K., WIERZBICKA A., 2017 – Effects of Packaging Solutions on Shelf-Life of Ratite Meats. ***Journal of Veterinary of Research*** 61, 279-285.
26. KARAMUCKI T., GARDZIELEWSKA J., JAKUBOWSKA M., RYBAK K., GARCZEWSKA J., 2013a **–** The relationship between colour and pH in cold-stored quail breast muscle. ***Annals of Animal Science*** 13, 401-413.
27. KARAMUCKI T., JAKUBOWSKA M., RYBARCZYK A., GARDZIELEWSKA J., 2013b **–** The influence of myoglobin on the colour of minced pork loin. ***Meat Science*** 94, 234-238.

28. KUZELOV A., JORDANOSKI M., GACOVSKI Ž., TRAJČOVA D., 2012 – Carcass categorization and chemical composition of ostrich meat. ***Macedonian Journal of Animal Science*** 2, 67-69.
29. LAMAS L.P., MAIN R.P., HUTCHINSON J.R., 2014 – Ontogenetic scaling patterns and functional anatomy of the pelvic limb musculature in emus (*Dromaius novaehollandiae*). ***PeerJ*** , 2:e716.
30. MAJEWSKA D., JAKUBOWSKA M., LIGOCKI M.,TARASEWICZ Z., KARAMUCKI T., SALES J., 2009 – Physicochemical characterictics, proximate analysis and mineral copposition of ostrish meat as influenced by muscle. ***Food Chemistry*** 117, 207-211.
31. MARKS J., STADELMAN W., LINTON R., SCHMIEDER H., ADAMS R., 1998 – Tenderness analysis and consumer sensory evaluation of ostrich meat from different muscles and aging times. ***Journal of Food Quality*** 21, 369-381.
32. MENON D.G., DARIN C., BENNETT D.C., UTTARO B., SCHAEFER A.F., CHENG K.M., 2014 – Carcass yields and meat quality characteristics of adult emus *(Dromaius vaehollandiae)* transported for 6 h before slaughter. ***Meat Science*** 98, 240-246.
33. MINNAAR P., MINNAAR M., 1992 – The Emu Farmer's Handbook. Groveton, Texas: Induna Company.
34. NAVEENA B.M., SEN A.R., MUTHUKUMAR M., GIRISH P.S., PRAVEEN KUMAR Y., KIRAN M., 2013 – Carcass characteristics, composition, physico-chemical, microbial and sensory quality of emu meat. ***British Poultry Science*** 54, 329-336.
35. NITHYALAKSHMI V., PREETHA R., 2015 – Effect of cooking conditions on physico-chemical and textural properties of Emu *(Dromaius novaehollandiae)* meat. ***International Food Research Journal*** 22, 1924-1930.
36. PALEARI M.A., CAMISASCA S., BERETTA G., RENON P., CORSICO P., BERTOLO G., CRIVELLI, G., 1998 – Ostrich meat: physicochemical characteristics and comparison with turkey and bovine meat. ***Meat Science*** 48, 205-210.
37. PEGG R.B., AMAROWICZ R., CODE W.E., 2006 – Nutritional characteristics of emu (*Dromaius novaehollandiae*) meat and its value-added products. ***Food Chemistry*** 97, 193-202.
38. PEREIRA A.V., ROMANELLI P.F., SCRIBONI A.B., ORLANDINI F.P., 2006 – Slaughtering yield and composition of great rhea meat (*Rhea americana*). ***Ciência e Tecnologia de Alimentos*** 26, 632-638.
39. POHJA M.S., NIINIVAARA F.P., 1957 – Die Bestimmung der Wasserbindung des Fleisches mittels der Konstantdrückmethode. ***Fleischwirtschaft*** 9, 193-195.
40. PN-ISO-4121, 1998 – Analiza sensoryczna – Metodologia – Ocena produktów żywnościowych przy użyciu metod skalowania [Sensory analysis. Methodology. Evaluation of foodstuffs by using calibration methods].
41. POŁAWSKA E., MARCHEWKA J., COOPER R., SARTOWSKA K., POMIANOWSKI J., JÓŹWIK A., STRZAŁKOWSKA N., HORBAŃCZUK J., 2011 – The ostrish meat – An uptadated review. II. *Nutrive value.* ***Animal Science Papers and Reports*** 29, 89-97.
42. ROMANELLI P.F., TRABUCO E., SCRIBONI A.B., VISENTAINER J.V., DE SOUZA N.E., 2008 – Chemical composition and fatty acid profile of rhea (*Rhea americana*) meat. ***Archivos Latinoamericanos de Nutricion*** 58, 201-205.
43. SALES J., 2007 – The emu (*Dromaius novaehollandiae*): A review of its biology and commercial products. ***Avian and Poultry Biology Reviews*** 18, 1-20.
44. SALES J., MELLET F.D., 1996 – Post–mortem pH decline in different ostrich muscles. ***Meat Science*** 42, 235-238.
45. SALES J., 1999 – Slaughter and products. In The ostrich. Biology, production and health, edited by D.C. Deeming, 231–274. Oxon: CABI Publishing.
46. SALES J., HORBAŃCZUK J.O., 1998 – Ratite Meat. ***World's Poultry Science Journal*** 54, 1, 59-67.

47. SALES J., HORBAŃCZUK J.O., DINGLE J., COLEMAN R., SENSIK S., 1999 – Carcase characteristics of emus (Dromaius novaehollandiae). ***British Poultry Science*** 40, 145-147.
48. IBM CORP., 2016 – SPSS Statistics for Windows, version 23.0., New York, NY: IBM Corp.
49. SZCZERBIŃSKA D., MAJEWSKA D., TARASEWICZ Z., ROMANISZYN K., SAMMEL A., BUCŁAW M., 2014 – Emu (*Dromaius novaehollandiae*) laying performance and egg quality during a ten-year reproductive performance period. ***Electronic Journal of Polish Agricultural Universities***, 17(2*).*
50. VAN SCHALKWYK S.J., HOFFMAN L.C., CLOETE S.W.P., MELLET F.D., 2005 – The effect of feed withdrawal during lairage on meat quality characteristics in ostriches. ***Meat Science*** 69, 647-651.
51. WANG W., XIAO K., ZHENG X., ZHU D., YANG Z., TANG J., SUN P., WANG J., PENG K., 2014 – Effects of supplemental boron on growth performance and meat quality in african ostrich chicks. ***Journal of Agricultural and Food Chemistry*** 62, 11024-11029.
52. WARRISS P.D., 2000 – Meat science: An introductory text. New York, USA: CABI publishing, CAB International.