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# Nutritional characteristics of emu (*Dromaius novaehollandiae*) meat and its value-added products

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**Abstract**

The objectives of the present study were to ascertain the nutritional value (i.e., macro and microconstituents) of emu (*Dromaius novaehollandiae*, Latham) meat and a value-added product derived therefrom. The contents of creatine, creatinine and phosphocreatine in fresh emu meat and the impact of processing on these bioactives during the production of jerky were of particular interest. For comparative purposes, a beef counterpart was prepared. The proximate compositional data indicated that the macroconstituents of emu meat and the fabricated jerky product were not so different from their beef analogues. Analysis of the microconstituents in emu samples revealed that the levels of a number of nutritionally important oil- and water-soluble vitamins and minerals were typical of those for red meat species. The creatine content in emu meat (29.3 mg/g dry matter) was similar to that of beef; slightly higher creatine levels were detected, however, in the emu jerky (22.8 mg/g dry matter) compared to its beef counterpart, and these were significant ($P < 0.01$) when the data was analysed on a dry weight basis. This demonstrates a potential for the emu meat snack to be considered as a functional food for athletes looking for performance enhancement, and who are interested in consuming greater quantities of creatine from a natural food source.


*Keywords:* Emu meat; Jerky; Creatine; Minerals; Vitamins; Ergogenic dietary aid; Functional food; Compositional analysis

## 1. Introduction

Game and exotic meats are gaining more attention in the marketplace, and an increasing number of markets are capitalising on this interest. This stems from the fact that consumers are more sophisticated and health-conscious; consequently, the all natural/organic segment is growing faster than typical grocery and meat products (Loomis-Vierck, 2001). One such example is the meat from ratites (i.e., ostrich, emu, rhea, cassowary and kiwi): it is perceived and marketed as a healthy alternative to other red meats due to its leanness, low cholesterol content and a favourable fatty acid profile (Sales & Horbanczuk, 1998). The intramuscular lipids of emu drumstick meat were found to contain greater levels of linoleic (C18:2 $\omega$6), arachidonic (C20:4 $\omega$6), α-linolenic (C18:3 $\omega$3) and docosahexaenoic (C22:6 $\omega$3) acids than those of chicken drumstick and beef steak. The ratio of polyunsaturated fatty acids to saturated ones was 0.72, which is higher than chicken meat at 0.57 and beef at 0.3 (Wang, Sunwoo, & Sim, 2000). Analysis of the lipid constituents from ostrich meat revealed that it contained 16.5% polyunsaturated $\omega$3 fatty acids (Sales, 1998).

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Farmed emu (*Dromaius novaehollandiae*, Latham) is a viable livestock and a farm diversification option. As a specialty livestock, emus offer three main products: fat [oil], meat and hides. A typical emu to market will weigh 37 kg at 15–18 months, and yield 11.8 kg of boneless red meat, 7.7 kg of fat and 0.56–0.65 square metres of hide (W.E. Code, personal communication). Emu oil has received attention for its possible therapeutic, notably anti-inflammatory, and cosmetic benefits (Craig-Schmidt, Brown, & Smith, 1994; Politis & Dmytrowich, 1998; López et al., 1999; Code & Tiefisher, 2000). Consequently, several emu oil markets are already in place unlike meat markets (Craig-Schmidt, 1997). Emu meat is a red meat and serves as a better source of haem iron than beef. Berge, Lepetit, Renerre, and Touraille (1997) reported that the meat pigment content in emu varied between different muscles (i.e., from 22.0 to 29.0 μg/g tissue) and increased by animal age from 6 to 14 months. Consumption of emu meat is recommended by the American Heart Association because of its low fat (4.7 g/100 g cooked product), comprising only 25% saturated fatty acids, and cholesterol (87 mg/100 g cooked product) contents (University of Wisconsin-Madison, 2000). Development of such markets will ensure a profitable return to the emu farmer; hence, further research on emu meat and value-added products derived therefrom (e.g., meat snacks such as jerky) could greatly facilitate this option. Moreover with the proliferation of high protein diets such as the Atkins Diet, snacking on meat products is nowadays just as common as munching on potato chips or cookies (White, 2004).

The sports nutrition market may offer a specialty niche market to emu producers. As with so many market statistics, estimates of the size of the sports nutrition market vary widely, depending on the types of products included and distribution channels. The Nutrition Business Journal, for example, reported that sports nutrition products – in the form of supplements, bars and drinks – racked up $4.7 billion in consumer sales in 1999, a 10% rise over 1998. Emu meat has been touted as a good source of protein, B vitamins, bioavailable iron and creatine. Throughout history, athletes have searched for performance-enhancing agents. Creatine (*N*-[aminoiminomethyl]-*N*-methyl glycine) has been marketed as a nutritional supplement, catering to the needs of athletes looking for a performance edge. There is some scientific evidence that creatine is ergogenic when taken in sufficient quantities (Toler, 1997; McKenna, Morton, Selig, & Snow, 1999), but the claim is controversial and still highly debated. Creatine is usually supplied as a monohydrate salt and is available at health and natural food stores. In human beings, creatine from exogenous sources, such as meat and fish, was reported to be readily absorbed from the gut (Crim, Calloway, & Margen, 1976; Harris, Söderlund, & Hultman, 1992) and that repeated large doses of creatine monohydrate for three or more days were shown to increase its content in skeletal muscle by 10–40% (Harris et al., 1992). The administration of smaller doses of creatine for longer periods, such as 30 days, results in similar increases in the total muscle creatine store (Balsom, Söderlund, & Ekblom, 1994). Consequently, creatine is used by a large number of fitness and muscle building enthusiasts.

Supplementation of creatine in the diet was found to increase cellular levels of this nitrogenous compound as well as its phosphorylated counterpart in muscle tissue, thereby enhancing muscular strength (Febbraio, Flanagan, Snow, Zhao, & Carey, 1995; Gordon et al., 1995). Although results are contradictory, the overall evidence suggests that creatine supplementation may be associated with an augmentation of lean body mass and increased performance during quick-burst, high-intensity activities (Wildman, Ciliberti, & Sanders, 2003). The mechanisms behind its benefits involve creating kinases, enzymes which foster the formation of adenosine triphosphate (ATP) and phosphocreatine, and energy liberating/recycling compounds in muscles. In its phosphorylated form, creatine is directly involved in maintaining low adenosine diphosphate (ADP) concentrations at sites of energy utilisation, and in the transfer of high energy phosphate from mitochondria. Wyss and Kaddurah-Daouk (2000) provide a comprehensive review of the many intriguing facets of creatine and creatinine (i.e., the end product of creatine catabolism) metabolism, encompassing the pathways and regulation of creatine biosynthesis and degradation, species and tissue distribution of the enzymes and metabolites involved, and of the inherent implications for physiology and human pathology. Although creatine supplementation has been shown to enhance short-term, high-intensity exercise performance, data indicate that creatine supplementation does not enhance aerobic exercise performance. While creatine supplementation will likely increase high-intensity strength performance (i.e., power lifting) in many athletes, there are few data to support its use by endurance athletes.

The objectives of this study were to ascertain the nutritional value (macro and microconstituents) of emu meat and a jerky product derived from it. Of particular interest were the contents of creatine, phosphocreatine and creatinine in fresh emu meat, a formulated jerky batter as well as the resultant cooked product, and the impact of processing on these bioactives.

## 2. Materials and methods

### 2.1. General supplies

All solvents used for the chromatography were HLPC grade, unless otherwise specified. The creatine, creatinine, phosphocreatine standards and

tetrabutylammonium hydrogen sulphate were obtained from Sigma–Aldrich Canada Ltd. (Oakville, ON). Perchloric acid (70%), nitric acid (70%), potassium hydroxide, potassium dihydrogenphosphate ($KH_2PO_4$), potassium hydrogencarbonate ($KHCO_3$), and Gelman nylon acrodisc 0.45 μm filters were purchased from VWR International (Mississauga, ON).

### 2.2. Meat samples

Fresh emu meat was obtained from the International Specialty Production Emu Co-operative Ltd. (ISPECL, Carlyle, SK). The birds (24) were electrically stunned and their necks were cut for exsanguination, where after the feathers and skin were removed. The carcasses were then chilled for > 12 h at 0 to 4 °C, after which the leg and thigh muscles (leg – *M. gastrocnemius pars interna*, *M. fibularis longus*, *M. gastrocnemius pars externa*; thigh – *M. iliofemoralis externus*, *M. iliofibularis*, *M. femorotibialis*, *M. femorotibialis medius*, *M. iliofemoralis*, *M. iliotibialis cranialis*, *M. flexor cruris lateralis*, *M. iliotibialis lateralis*; Mellett, 1994) were excised from the 24 carcasses, packaged and then shipped to the pilot plant facilities of the Department of Applied Microbiology and Food Science at the University of Saskatchewan in Saskatoon.

Fresh beef inside rounds (aged for 21 days) from young Canada Grade A carcasses were purchased from a beef packer (XL Meats, Calgary, AB). The *semimembranosus* muscles were removed and trimmed of all visible fat and connective tissue before processing.

### 2.3. Preparation of emu and beef jerkies

With the exception of one, all additives employed in the jerky formulation were available from the supplies of the product development section of the Meat Group in the Department of Applied Microbiology and Food Science, University of Saskatchewan. The dried plum puree (*i.e.*, prune juice concentrate and dried plums – a humectant) was acquired from Sunsweet Growers Inc. (Yuba City, CA). The emu muscles supplied by ISPECL were trimmed of their epimysial connective tissue (i.e., silver skin) and then ground through a 3/16″ plate with a four-blade knife using a Biro grinder/food mixer (AMFG Model 24, Marblehead, OH). The comminuted muscles were weighed and transferred to a Glass vacuum tumbler/mixer (Type VSM-150, Frankfurt, Germany). All dry ingredients to be used in the jerky product were preweighed and kept separate. Sodium chloride and curing salt (i.e., Prague powder) were added to the comminuted meat and mixed in for 2 min at 24 rpm. The water, remaining dry ingredients and the dried plum puree were then added and mixed for 4 min at 24 rpm. The meat batter was transferred to a Handtmann VF 80 vacuum-filling machine (Biberach/Riss, Germany) and stuffed as strips approximately 33 mm × 3 mm onto stainless steel screens coated with vegetable oil. The trolley holding the product was transferred to an Alkar Batch Oven (Alkar, Lodi, WI) and thermally processed until a water activity of less than 0.85 was recorded in three randomly selected samples; the formulation for the jerky product is listed in Table 1.

Table 1
Developed jerky formulation

| Ingredients | Formulation (%) |
|---|---|
| Ground meat (either emu meat or beef) | 88.57 |
| Sugars (different industrial types) | 5.00 |
| Dried plum puree | 3.00 |
| Sodium chloride | 1.80 |
| Water | 1.00 |
| Prague powder (i.e., cure) | 0.28 |
| Black pepper | 0.20 |
| Garlic powder | 0.10 |
| Sodium erythorbate | 0.05 |
| Total | 100 |

Samples of the ground emu meat, formulated jerky batter and final cooked product were acquired. For comparative purposes, a beef jerky was prepared in a similar fashion, as described above, from beef inside rounds. Samples were used as collected for proximate analyses; portions were also lyophilised using a Free Zone 12 liter Freeze Dry System (Model 77540) connected to a FreeZone Stoppering Tray Dryer Freeze System (Model 79480, Labconco Corporation, Kansas City, MO) and then stored in sealed glass vials in a desiccator at 4 °C until analysed.

### 2.4. Proximate analysis

The following chemical constituents were determined on samples of the lean ground meat, batter and processed jerkies according to official methods of analysis of AOAC International (2003): moisture content by air drying ca. a 2-g test sample at 102 °C to a constant weight (950.46 B, see p. 39.1.02); ash content by igniting ca. a 3–5-g test sample in a muffle furnace at 550 °C until light gray ash results (920.153, see p. 39.1.09); crude protein content by the classical macro Kjeldahl method using cupric sulphate Kjeltabs instead of mercuric oxide ones (981.10, see p. 39.1.19); and fat (crude) content by petroleum ether extraction using a Goldfisch apparatus (960.39 (a), see p. 39.1.05). The carbohydrate content was determined by an iodometric titration methodology described in official method FO-32 from the Canadian Health Protection Branch (1981); the percent reducing sugars, calculated as dextrose equivalents, were reported. The percent sodium chloride in the meat samples was determined by a modified Volhard method using a digital titrator (Hach Company, Loveland, CO), as

described in the company's systems for food, feed and beverage analysis procedures manual (Hach, 1990). All analyses were conducted in triplicate.

The pH values of fresh emu meat or beef, formulated jerky batters as well as the resultant cooked products were measured in triplicate with a Fisher Accumet 915 pH Meter (Fisher Scientific Ltd., Nepean, ON) using a combination pH electrode on a homogenate of 20-g sample in 80-mL deionised water. Water activity of emu and beef jerkies was determined using a Decagon CX-2 water activity meter (Decagon Devices, Inc., Pullman, WA). Jerky samples were randomly selected from the Alkar batch oven, coarsely chopped with a knife and transferred to a sample cup (filling only to the half-way mark). Measurements were made after the unit had been calibrated with a saturated sodium chloride solution. When water activity readings of 0.85 or less were recorded from three randomly selected jerky samples, the thermal processing cycle was terminated.

### 2.5. Mineral analysis

Minerals were determined from the lyophilised meat preparations using a microwave digestion of each sample followed by an inductively-coupled plasma atomic emission spectroscopy (ICP-AES) protocol. Approximately 2.5 g of sample, accurately weighed to four-decimal places, were transferred to a Teflon microwave acid digestion bomb (Parr Instrument Company, Moline, IL). Five millilitres of 50% (v/v) $HNO_3$ were added and the sample was digested using a microwave oven. The length of time for digestion in the closed vessel was determined according to a time–pressure program based on the vapour pressure generated from each sample matrix. The digest was diluted to a final volume of 25 mL with deionised water. An aliquot was injected into the argon plasma stream of an ICP-AES unit (Thermo Jarrell Ash Trace 61E Axial ICP, Franklin, MA) after which the emission spectra of 25 elements were optically measured and the content of each determined using the unit's computer controlled system. The minerals analysed for by ICP-EAS were aluminium, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, phosphorus, potassium, selenium, silver, sodium, strontium, titanium, vanadium, zinc and zirconium.

The content of iodine in samples was determined by neutron activation analysis using a Slowpoke 2 nuclear reactor at SRC Analytical (Saskatoon, SK). Samples were placed in polyethylene vials, capped and then irradiated. After a period of time, to allow for decay of short-lived isotopes, the gamma activity of irradiated samples was measured using a 12% intrinsic germanium detector and multichannel analyser system. The detection limit for iodine was determined by calculating the peak area for $^{128}I$ versus the background counts adjacent to the peak. Only a peak with at least three times the square root of the background noise was considered to be detectable.

### 2.6. Creatine, creatinine and phosphocreatine analysis

#### 2.6.1. Sample preparation

Samples of freeze-dried fresh meat, batter and jerky from each batch were pulverised using a clean mortar and pestle. Muscle metabolites were extracted according to Harris, Hultman, and Nordesjö (1974) with modifications. Briefly, 60 mg of lyophilised sample were blended with 5 mL of 0.7 M perchloric acid using a Kinematica Polytron homogeniser (Model PT 10/35 with PTA-10 S generator, Brinkmann Instruments [Canada] Ltd., Rexdale, ON) two times at high speed for 30 s. Samples were transferred to 4-dram glass vials and then centrifuged using an IEC clinical centrifuge (Model CL, International Equipment Co., Needham Heights, MA). The supernatant was neutralised to pH 6.7 with 1.2 mL of 3 M $KHCO_3$. Extracts were passed through a 0.45 μm filter and then analysed by HPLC. Standards of creatine, creatinine and phosphocreatine were prepared in the neutralised perchloric acid at concentrations ranging from 20 to 1000 μM.

#### 2.6.2. Chromatography

The contents of creatine, creatinine and phosphocreatine were determined by isocratic reversed-phase ion-pairing high performance liquid chromatography (HPLC) according to Dunnett, Harris, and Orme (1991). A Waters HPLC system was employed and consisted of the following components: a Waters 600 controller, a 600R multi-solvent delivery system, a 996 photodiode array detector (DAD), a 715 Ultra Wisp sample processor and Millenium software. Conditions of separation entailed an analytical $C_{18}$ LUNA column (5 μm, 4.6 × 250 mm, Phenomenex, Torrance, CA); mobile phase was an aqueous solution of $KH_2PO_4$ [14.7 mmol/L, 2.0 g/L] and tetrabutylammonium hydrogen sulphate [2.3 mmol/L, 0.8 g/L] adjusted to pH 5.0 with KOH; a flow rate of 1 mL/min; an injection volume of 10 μL; and the detector was set at 210 nm. The mobile phase was prepared freshly each day, passed through a 0.45 μ filter and degassed. Concentrations of creatine, creatinine and phosphocreatine were determined by comparing sample peak heights to those of external standards.

### 2.7. Vitamin analysis

Lyophilised samples of fresh emu meat, the formulated jerky batter and the resultant cooked product were analysed for their vitamin contents. Official methods from the United States Pharmacopoeia: The National

Formulary (1999) were used to extract and analyse the oil- and water-soluble vitamins in the samples; in all cases, an HPLC assay was employed. For determining the content of vitamin A (USP 24-NF 19, see method 3 on p. 2346), a standard silica HPLC column using a mobile phase of *n*-hexane and isopropanol (92:8 v/v) with detection at 325 nm was used; for vitamins E and $K_1$ (modified USP 24-NF 19, see p. 2346), a standard $NH_2$ HPLC column using a mobile phase of *n*-hexane and isopropanol (99:1 v/v) with detection at 254 nm was used; for vitamin $D_3$ (USP 24-NF 19, see method 1 on p. 2346) a standard $NH_2$ HPLC column using a mobile phase of *n*-hexane and isopropanol (99:1, v/v) with detection at 265 nm was used; for vitamin $B_{12}$ (USP 24-NF 19, p. 2364), a standard $C_{18}$ reversed-phase HPLC column using a mobile phase of water:methanol (65:35 v/v) with detection at 550 nm was used; for folic acid (USP 24-NF 19, p. 2366), a standard $C_{18}$ reversed-phase HPLC column using a composite mobile phase (i.e., 2 g of monobasic potassium phosphate in 650-mL water, 12 mL of 25% tetrabutylammonium hydroxide in methanol, 7.0 mL of 3 N phosphoric acid and 240 mL of methanol, adjusted to pH 7.0) with detection at 280 nm was used; and for biotin (USP 24-NF 19, see method 1 on p. 2363), a standard $C_{18}$ reversed-phase HPLC column using a composite mobile phase (i.e., 85 mL of acetonitrile, 1 g of sodium perchlorate and 1 mL of 85% phosphoric acid followed by dilution with water to 1000 mL) with detection at 200 nm was used.

### 2.8. Data analysis

Emu and beef jerky products were prepared in three separate batches. Samples of fresh comminuted meat, jerky batter and thermal processed jerky product were taken from each batch. A portion from each was lyophilised and then ground to a fine powder using a clean mortar and pestle. Proximate analyses were carried out on samples in their natural state, whereas lyophilised powders were used for mineral, vitamin and bioactives (i.e., creatine, creatinine and phosphocreatine) analyses. HPLC results of the bioactives were subjected to an analysis of variance using the general linear model procedures of the SPSS statistical package (SPSS 11.0.1 for Windows, SPSS Inc., Chicago, IL) and significance levels between treatments were assessed at $P < 0.01$.

## 3. Results and discussion

During the product development phase of this study, four emu jerky formulations were developed and tested. The formulation deemed to afford the best taste/flavour and texture to the end product, as assessed by the product development team of the Meat Group, is reported in Table 1. The end product was slightly sweeter than is typical for a commercial jerky (as described by the Meat Group's certified Product Development Specialist), but this was to counteract some of the harshness from the salt, and incorporated the dried plum puree to create a tasty product. Representatives of ISPECL (i.e., untrained panellists) also tested the emu jerky for its acceptability before any of the chemical analyses were performed; the resultant value-added emu meat product was deemed to be a great success. A proprietary cooking schedule and addition of a humectant (i.e., the dried plum puree) were employed in the jerky manufacture to help create a softer more chewable product. Destruction of vitamins, amino acids, peptides and bioactive constituents in the jerky can occur during processing. For this reason, the basic chemical composition and content of bioactives (i.e., in this case: creatine, creatinine and phosphocreatine) of the fresh meat, jerky batter before thermal processing and cooked end product were measured. Such data will address the question as to whether or not processing affected the macro and microconstituents of emu meat during the preparation of the value-added meat product. A parallel beef product was prepared for comparative purposes, because meat snacks prepared from beef, notably beef jerky, account for 80% of the market (White, 2004).

From a basic science perspective, it would have been desirable to investigate the levels of phosphocreatine, creatine and creatinine in individual muscles of emu for use in a value-added meat product (*e.g.*, jerky). From the industrial standpoint, however, this is not practical, as there is no single muscle from the emu large enough to be used for such a purpose. Comparisons between ostrich and emu meat are often made, but one must remember that emus are half the size of ostriches. Muscles of the emu are much smaller than those of the ostrich and are covered by a significant amount of silver skin, which has to be removed before further processing. For these reasons, emu meat does not lend itself to whole muscle cuts and is therefore typically ground (W.E. Code, personal communication). On occasions, however, the fan muscle (*M. iliofibularis*) is excised and sold as a solid cut, but this is not common practice so for the purposes of this study, all muscles from the emu's leg and thigh were utilised in the jerky formulation.

Compositional information on emu jerky could assist with getting the product into niche markets such as those for athletes, health food stores or specialty gourmet food shops. The proximate compositional analysis of emu meat and beef and the jerkies prepared therefrom is presented in Table 2. The moisture, crude protein and crude fat contents for the fresh emu meat utilised in this study were similar to those reported by Berge et al. (1997), which ranged from 75.0% to 76.1%, 20.4% to 21.1% and 0.9% to 1.2%, respectively.

Table 2
Proximate compositional analysis of emu meat and beef and the jerkies prepared therefrom

| Assay[a] | Emu Meat | | | Beef | | |
|---|---|---|---|---|---|---|
| | Fresh | Batter | Jerky | Fresh | Batter | Jerky |
| Moisture (%) | 76.7 ± 0.4[a] | 70.6 ± 0.2[i] | 29.8 ± 0.7[x] | 74.4 ± 0.3[b] | 70.1 ± 0.5[i] | 29.5 ± 0.3[x] |
| Crude protein (%$N\times$ 6.25) | 20.2 ± 0.3[b] | 18.3 ± 0.3[i] | 43.9 ± 0.3[x] | 21.6 ± 0.3[a] | 18.7 ± 0.3[i] | 44.2 ± 0.4[x] |
| Crude fat (%) | 1.4 ± 0.2[a] | 1.2 ± 0.3[i] | 2.7 ± 0.4[x] | 1.7 ± 0.2[a] | 1.2 ± 0.2[i] | 2.8 ± 0.3[x] |
| Carbohydrate (% dextrose equivalent) | 0.4 ± 0.05[a] | 6.0 ± 0.3[i] | 14.5 ± 0.3[x] | 0.4 ± 0.05[a] | 5.9 ± 0.3[i] | 14.5 ± 0.3[x] |
| Ash (%) | 1.5 ± 0.09[a] | 3.0 ± 0.03[i] | 7.1 ± 0.06[x] | 1.3 ± 0.2[a] | 2.9 ± 0.06[i] | 7.0 ± 0.1[x] |
| *Total* | 100.2 | 99.1 | 98.0 | 99.4 | 98.8 | 98.0 |
| Energy (kcal/100 g) | 95.0 | 108.0 | 257.9 | 103.3 | 109.2 | 260.0 |
| Sodium chloride (%) | 0.23 ± 0.02[a] | 1.94 ± 0.1[i] | 4.69 ± 0.3[x] | 0.26 ± 0.02[a] | 1.82 ± 0.1[i] | 4.58 ± 0.3[x] |
| pH | 5.43 ± 0.02[a] | 5.49 ± 0.01[i] | 5.53 ± 0.02[x] | 5.30 ± 0.01[b] | 5.29 ± 0.01[j] | 5.46 ± 0.02[y] |
| Pigment content (mg/100 g cooked product)[b] | 5.0 | n/a | n/a | 2.4 | n/a | n/a |

[a] Results are mean values ± standard deviation of triplicate determinations. Means with different letters (a,b; i,j; x,y) in each row corresponding to the counterpart meat system (i.e., either fresh, batter or jerky) are significantly ($P < 0.05$) different.
[b] n/a – not applicable. Data are expressed as mg iron/100 g of cooked product according to University of Wisconsin-Madison (2000).

The pH value of 5.43 for fresh emu meat was a bit lower than the ultimate pH values (i.e., 5.52 to 5.66) measured in emu muscles by Berge et al. (1997). In general, the pH for emu meat is lower than those found in the breast or leg muscles of the conventional poultry species, viz. 5.6–6.0 and 6.0–6.4, respectively (Touraille, Kopp, Valin, & Richard, 1981; Barbut, 1993). Significant differences ($P < 0.05$) were noted when comparing the pH values of fresh emu meat and beef, formulated jerky batters and the resultant cooked jerkies. Proximate analysis revealed only the moisture and crude protein contents for fresh emu meat and beef to be significantly ($P < 0.05$) different from one another. The beef employed in this study comprised slightly more protein than emu. Although this is a minor point, it could be somewhat important if one wanted to compare creatine levels in the beef and emu on an equal protein basis. The University of Wisconsin-Madison (2000) study on alternative meats found beef to contain less protein than emu meat (cf. 25.0 vs. 28.4 g protein/100 g of cooked product), but of course the crude protein content determined in the proximate analysis is dependent upon how much intramuscular and adipose tissue is associated with the sample analysed. Of the meat from deer, ostrich, emu, bison, cattle, turkey and elk reported in the University of Wisconsin-Madison study (2000), emu meat was found to be the richest source of protein and haem iron (cf. 5.0–3.4 mg iron/100 g of cooked product for both venison and ostrich meat).

After incorporating the additives to the formulation, the carbohydrate and sodium chloride contents in the batters and jerky products increased, as denoted by higher percent dextrose equivalent and percent NaCl contents, respectively. For the batter and jerky, however, the proximate composition percentages did not quite add up to 100 after all the analyses were performed. This is because the carbohydrate content was reported as percent dextrose equivalents and not as percent difference, which is common for meat products. The carbohydrate assay employed only determines the content of reducing sugars in the product and does not reflect all carbohydrate material added from starch and non-reducing sugar constituents of the spices, sugars, and dried plum puree. The jerky strips were thermally processed until the end product achieved a water activity of 0.85 or less, as determined by the Decagon CX-2 water activity meter. Attaining a value of 0.85 or less denotes that the jerky is shelf-stable and that there is no fear of microbial spoilage. The proximate analysis reflected the low moisture contents in both the emu and beef jerkies, which were not significantly ($P > 0.05$) different from one another; simultaneously, there was a marked increase in the protein and carbohydrate percentages. Based on the compositional analysis, one can unequivocally state that the jerkies represent a good source of protein. The question for this study remains, however, as to the effect of processing on the creatine, creatinine and phosphocreatine levels.

Table 3 presents the content of some oil- and water-soluble vitamins in fresh emu meat, the formulated jerky batter and the resultant cooked product. Because the compositional analysis of macro and microconstituents is influenced by the moisture content in the sample, the results are presented on a dry weight basis; thus, comparisons can easily be made. Concerning the oil-soluble vitamins: only vitamins A and E were detected in fresh emu meat, the batter and jerky product. Assuming that there is no destruction of vitamin A during thermal processing, its endogenous content in muscle tissue should remain constant. A higher level was detected in the batter and jerky end product; this indicates that vitamin A is being incorporated into the formulation from an exogenous source (i.e., the dried plum puree). On the other hand, there is no supplementation of vitamin

Table 3
Content of oil- and water-soluble vitamins in fresh emu meat, the formulated jerky batter and the cooked product[a]

| Vitamins | Emu Meat | | |
|---|---|---|---|
| | Fresh | Batter | Jerky |
| *Oil-soluble vitamins (μg/g d.m.)* | | | |
| Vitamin A | 0.203 | 1.03 | 0.966 |
| Vitamin E | 3.66 | 3.87 | 3.98 |
| Vitamin $D_3$ | n/d | n/d | n/d |
| Vitamin $K_1$ | n/d | n/d | n/d |
| *Water-soluble vitamins (μg/g d.m.)* | | | |
| Vitamin $B_{12}$ | n/d | n/d | n/d |
| Folic acid | n/d | 9.26 | 11.23 |
| Biotin | n/d | n/d | 12.5 |

[a] Detection limits for vitamins A, E, $D_3$, $K_1$, $B_{12}$ as well as folic acid and biotin are as follows: 0.021, 0.100, 0.021, 0.100, 0.200, 1.36 and 2.4 μg/g, respectively. Data are averages of duplicate determinations; a third assay was performed only if marked differences existed between the first two. n/d – not detected; d.m. – dry matter.

E during batter preparation, as the content of vitamin E in the fresh meat, batter and resultant cooked jerky product is approximately the same (i.e., when one compares the results on a dry weight basis). Of the water-soluble vitamins, it was surprising that no vitamin $B_{12}$ was detected. Folic acid was found only in the batter and jerky, perhaps originating from the dried plum puree. Biotin, on the other hand, was detected only in the final jerky product. A footnote in Table 3 includes the detection limits of the assay for each vitamin.

The mineral analysis of fresh emu meat, the formulated jerky batter and the final product is presented in Table 4. In total, 26 minerals were analysed. Data for each mineral in a sample (i.e., fresh meat, batter and jerky) are presented in units of μg/g sample on a wet weight basis or μg/g sample on a dry weight basis. Direct comparisons can only be made between data presented on a dry weight basis. The increase in the mineral content between fresh emu meat and the formulated batter (or jerky end product) is the result of mineral supplementation from the various additives. The best example of which is the increase in the sodium levels as a consequence of salt addition. Comparison of the mineral content of fresh emu meat with those of other red meat species indicates that there are no marked differences.

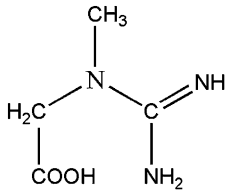
Creatine, $C_4H_9N_3O_2$, is present in muscular tissue of many vertebrates and is commercially isolated from

Table 4
Mineral analysis of fresh emu meat, the formulated jerky batter and the cooked end product[a]

| Mineral | Flesh detection limits, μg/g | Fresh Emu Meat | | Emu Batter | | Emu Jerky | |
|---|---|---|---|---|---|---|---|
| | | μg/g meat | μg/g d.m. | μg/g batter | μg/g d.m. | μg/g jerky | μg/g d.m. |
| Aluminium | 0.2 | 0.7 | 3.0 | 7.2 | 25 | 14 | 21 |
| Barium | 0.05 | n/d | n/d | 0.23 | 7.8 | 0.45 | 6.6 |
| Beryllium | 0.05 | n/d | n/d | n/d | n/d | n/d | n/d |
| Boron | 0.1 | 0.5 | 2.1 | 1.5 | 5.1 | 3.5 | 5.1 |
| Cadmium | 0.05 | n/d | n/d | n/d | n/d | n/d | n/d |
| Calcium | 1 | 50 | 210 | 120 | 410 | 280 | 410 |
| Chromium | 0.02 | 0.17 | 0.72 | 0.1 | 0.34 | 0.23 | 0.34 |
| Cobalt | 0.05 | 0.10 | 4.2 | n/d | n/d | n/d | n/d |
| Copper | 0.05 | 2.3 | 9.7 | 1.9 | 6.5 | 4.4 | 6.5 |
| Iodine | [b] | <0.3 | <0.3 | <1 | <1 | <3 | <3 |
| Iron | 0.05 | 50 | 211 | 45 | 150 | 110 | 160 |
| Lead | 0.05 | n/d | n/d | n/d | n/d | n/d | n/d |
| Magnesium | 1 | 250 | 1050 | 340 | 1160 | 800 | 1170 |
| Manganese | 0.05 | 0.30 | 1.3 | 0.84 | 2.9 | 1.8 | 2.6 |
| Molybdenum | 0.05 | n/d | n/d | n/d | n/d | n/d | n/d |
| Nickel | 0.02 | n/d | n/d | n/d | n/d | 0.16 | 0.23 |
| Phosphorus | 5 | 2300 | 9700 | 1900 | 6500 | 4700 | 6900 |
| Potassium | 5 | 3100 | 13,100 | 4000 | 13,600 | 8400 | 12,300 |
| Selenium | 0.05 | 1.1 | 4.6 | 0.84 | 2.9 | 1.9 | 2.8 |
| Silver | 0.05 | n/d | n/d | n/d | n/d | n/d | n/d |
| Sodium | 5 | 470 | 1980 | 8500 | 28,900 | 19,200 | 28,200 |
| Strontium | 0.05 | 0.06 | 0.3 | 1.7 | 5.8 | 3.9 | 5.7 |
| Titanium | 0.05 | n/d | n/d | 0.15 | 0.51 | 0.33 | 0.48 |
| Vanadium | 0.05 | n/d | n/d | n/d | n/d | n/d | n/d |
| Zinc | 0.1 | 36 | 150 | 27 | 92 | 71 | 100 |
| Zirconium | 0.1 | n/d | n/d | n/d | n/d | n/d | n/d |

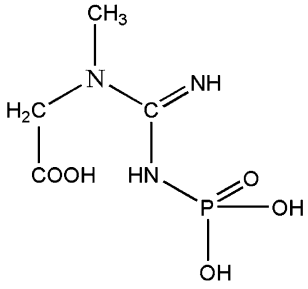
[a] n/d – not detected. Data are averages of duplicate determinations; a third assay was performed only if marked differences existed between the first two. Results are presented as μg/g sample in the actual state and μg/g d.m. (dry matter). The detection limits for a flesh sample matrix by the TJA-ICAP-61E trace analyser are given in column 2. Mean residual moisture contents in lyophilised emu samples for fresh meat, batter and jerky were 2.3, 8.0 and 12.1%, respectively; these percentages were factored in when determining μg/g d.m.

[b] Each sample had a unique matrix and produced different levels of background in the neutron activation analysis. Data presented in the table reflect the detection limits for $^{128}I$; they are the lowest achievable levels of detection for these samples.



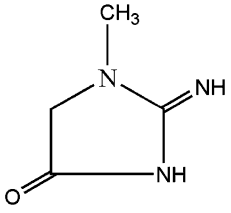
Creatine

*N*-(Aminoiminomethyl)-*N*-methylglycine



Phosphocreatine

*N*-[Imino(phosphonoamino)-methyl]-*N*-methylglycine



Creatinine

2-Amino-1-methyl-2-imidazolin-4-one

Fig. 1. Chemical structures for creatine, phosphocreatine and creatinine.

meat extracts. Although small amounts occur in the blood, it is not found in the urine of man. Rather, the greater part of creatine in muscle is combined with phosphoric acid as phosphocreatine. This is synthesised by the liver and kidneys via the transfer of the guanidine moiety of arginine to glycine, which is then methylated to give creatine (Merck Index, 1983). Creatinine, $C_4H_7N_3O$, is the end product of creatine catabolism. It is a constituent of the urine with a daily output of about 25 mg per kg of body weight. It is also found together with creatine in muscle tissues and blood. Fig. 1 depicts the chemical structure of these three compounds.

Accurate determination of both creatine and creatinine requires the resolution of these two compounds from the unretained peak and each other to be maximised. HPLC chromatograms (not shown) revealed that the standards purchased from Sigma–Aldrich had good peak symmetry and were well resolved when a mixture was injected onto the column, based on the method described in Section 2. Retention times for creatine, creatinine and phosphocreatine were 2.34, 2.86 and 25.52 min, respectively, using the separation conditions described. Investigation of peak area versus concentration of standards demonstrated a linear relationship when up to 100 μg/ml of each standard were injected onto the $C_{18}$ column. Based on nine data points (i.e., for concentrations varying between 1 and 100 μg/ml), linear correlation coefficients for creatine, creatinine and phosphocreatine were $r^2 = 0.9998$, 0.9995 and 0.9997, respectively. Separation of creatine, creatinine and phosphocreatine was equally good in muscle extracts as with standards, although only trace quantities of phosphocreatine were detected in fresh meat samples. Peak purity appeared good with no obvious evidence of co-elution from interfering compounds. The contents of creatine, creatinine and phosphocreatine in the fresh meat, formulated jerky batter and final cooked product from emu and beef are presented in Table 5. Results from triplicate determinations are presented as mg compound/100 g sample or mg compound/g dry matter. Only direct comparisons of the effects of processing can be made for data presented on a dry weight basis, whereas data for the effect of species can be compared using either basis.

Trace quantities of phosphocreatine were detected in the samples analysed, but not in all cases; this is not surprising as phosphocreatine would be expected to be present in the muscle tissue of live animals, but depleted once the muscle tissue had passed through rigor mortis and been converted to meat. At this later point, the majority of ATP deposits in muscle tissue, and its precursors, would be consumed. The detection of trace quantities of phosphocreatine in fresh meats may be used as an indicator of meat quality, thereby indicating a high-quality starting material. No traces of phosphocreatine were detected in the jerky product implying that it was broken down to possibly creatine or creatinine during thermal processing. Creatine levels were significantly ($P < 0.01$) greater than those of its catabolised product, creatinine. This suggests both emu and beef are good sources of creatine and that value-added meat products derived therefrom can be considered as functional foods.

When comparing creatine and creatinine contents on a dry matter basis in fresh emu meat and beef to those reported for their batter and jerky counterparts, significant ($P < 0.01$) differences were evident. As a result of thermal processing, creatine levels in emu meat preparations decreased by 22% while creatinine levels increased by ca. 390%. Most of the creatine lost, however, was not converted to creatinine; the summed content of creatine

Table 5
Creatine, creatinine and phosphocreatine analysis in fresh meat, the formulated jerky batter and cooked end product from emu and beef[a]

| Analyte | Fresh Meat | | Batter | | Jerky | |
|---|---|---|---|---|---|---|
| | mg/100 g sample[b] | mg/g dry matter | mg/100 g sample[b] | mg/g dry matter | mg/100 g sample[b] | mg/g dry matter |
| *Emu* | | | | | | |
| Creatine | 695 ± 46 | 29.31 ± 1.93[a] | 661 ± 8.3 | 22.47 ± 0.28[b] | 1553 ± 37 | 22.81 ± 0.55[b] |
| Creatinine | 5.64 ± 2.9 | 0.238 ± 0.015[b] | 5.59 ± 0.27 | 0.190 ± 0.009[c] | 79.7 ± 2.5 | 1.17 ± 0.037[a] |
| Phosphocreatine | tr | tr | tr | n/d | n/d | n/d |
| *Beef* | | | | | | |
| Creatine | 786 ± 51 | 30.37 ± 1.98[a] | 749 ± 7.0 | 24.55 ± 0.23[b] | 1518 ± 34 | 21.66 ± 0.48[c] |
| Creatinine | 23.3 ± 0.16 | 0.901 ± 0.006[b] | 20.2 ± 0.95 | 0.662 ± 0.031[c] | 123 ± 5.1 | 1.75 ± 0.051[a] |
| Phosphocreatine | tr | tr | n/d | n/d | n/d | n/d |

[a] Average residual moisture contents in freeze dried samples for fresh meat, batter and jerky from emu and beef were 2.3%, 8.0%, 12.1% and 2.6%, 11.6%, 11.8%, respectively. These percentages were factored in when determining mg contents/g dry matter. Results are means ± standard deviation of triplicate determinations. Only statistical analysis of data for creatine and creatinine, as presented on a dry matter basis, in each row is shown; least-squares means without the same letter (a,b,c) in each row differ ($P < 0.01$). Statistical comparison of creatine and creatinine contents between species is reported in the discussion. tr – trace amounts were detected; n/d – not detected.

[b] Values reported were calculated based on the mean values (mg/g dry matter) and moisture content.

and creatinine in the jerky had decreased by 18.8% from that in the fresh meat. Creatinine levels in beef were significantly ($P < 0.01$) greater than those in emu meat for all meat samples analysed. Purchas, Rutherfurd, Pearce, Vather, and Wilkinson (2004) reported on the creatine and creatinine levels in fresh and cooked beef *semitendinosus* muscle, which were assayed spectrophotometrically using an enzyme-based system. Creatine levels in fresh beef were reported as being 15 times less than those determined by the HPLC assay in the present study. It was also noted that creatine concentrations in the *semitendinosus* muscle decreased to 65% and 55% of the uncooked levels when thermal processed in a clam cooker to 60 and 80 °C, respectively. These authors noted, as did we, that the increase in the amount of creatinine in the cooked product did not fully account for the decrease in creatine levels.

The creatine level in fresh ground beef was slightly greater than that in emu meat, but this was not significant ($P > 0.01$) when analysing the data on a dry weight basis. On a wet or fresh meat basis, however, the differences were significant ($P < 0.01$); the compositional analysis, as presented in Table 2, revealed a significantly ($P < 0.05$) greater protein content and lesser moisture content in beef than in emu meat. After thermal processing the reverse was evident: slightly higher creatine levels were detected in the emu jerky than its beef counterpart, and these were significant ($P < 0.01$) when analysing the data on a dry weight basis. This is further reflected when the data is presented on the basis in which the product is provided to the consumer (i.e., mg of creatine/100 g jerky product), but from a statistical point of view the difference is not significant ($P > 0.01$). Nevertheless, this demonstrates a potential for this emu meat snack to be considered as a functional food for athletes looking for performance enhancement, and who are interested in consuming greater qualities of creatine from a natural food source.

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