# Sensory profiling of Egyptian goose (*Alopochen aegyptiacus*) meat

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## ARTICLE INFO

## ABSTRACT

No sensory profile information is available for Egyptian goose (*Alopochen aegyptiacus*) meat. The aim of this study was to conduct descriptive analysis in order to establish the sensory attributes of the breast portion of this species. Meat from guineafowl, Pekin duck, ostrich and broiler chicken were used as reference species. Egyptian goose meat had a very intense game aroma, game flavour and metallic aftertaste, mainly attributable to the muscle's high percentage of polyunsaturated fatty acids and Fe. Egyptian goose meat was also low in tenderness and high residue; this may be due to the high level of physical exercise endured by the breast muscle. Egyptian goose meat proved to be similar to ostrich meat regarding appearance (dark, red colour) and low tenderness, but differed from guineafowl and broiler chicken, the latter two meat types illustrated a higher degree of juiciness and tenderness. These results of Egyptian goose meat can now be used for further sensory studies as it is important to also establish the influence of extrinsic factors such as season and gender on the meat quality of this waterfowl species.

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## 1. Introduction

Globally, unusual animal species have been increasingly utilised as valuable sources of meat (Hoffman & Cawthorn, 2012; Hoffman & Wiklund, 2006). Irrespective of its contribution to human nutrition, the consumption thereof is becoming popular amongst modern day consumers. These unconventional meat sources include a wide variety of wild bird species, especially those that are either widespread or considered to be agricultural pests. However, the significance of these meat sources has been overlooked particularly in rural Southern Africa.

The Egyptian goose, a waterfowl species, is native to Africa south of the Sahara and the Nile Valley. In South Africa Egyptian geese are found in regions with inland water, along the coastline and in close proximity to croplands that they utilize for foraging (Viljoen, 2005). Egyptian geese are renowned for flying great distances. This species is also one of the leading gamebirds hunted in South Africa (Viljoen, 2005). The research by Mangnall and Crowe (2001, 2002) and Viljoen (2005) stresses the fact that population numbers have increased considerably and are still rising, especially in the Western Cape, South Africa. Consequently, farmers suffer financial losses due to damage on croplands. This situation could, however, be beneficial to farmers as wingshooting of this gamebird could provide farmers with an additional income if the meat is sufficiently utilized (Mangnall & Crowe, 2001).

Another common gamebird is the guineafowl (*Numida meleagris*). Guineafowl is considered to be the most abundant gamebirds in South Africa (Little & Crowe, 2011; Viljoen, 2005) and is also well known for being used in traditional cooking. Contrary to gamebirds, domestic birds such as ostrich, Pekin duck and broiler chicken are mainly farmed with for meat production. Scientific-based knowledge regarding the quality of gamebird meat is limited and it is therefore important to gain insight into the full sensory profile thereof. Especially since the gamebird industry in South Africa is becoming more viable. (Geldenhuys, Hoffman, & Muller, 2013a). There are a limited number of studies in which the sensory characteristics of meat from different species are compared (Rodbotten, Kubberod, Lea, & Ueland, 2004). Shahidi (1998) describes that several of the flavour volatiles, which occur in meat from different species, are in fact similar; however, the quantity thereof varies from species to species. Sensory reference standards could therefore be valuable tools when characterizing the sensory profile of a product such as Egyptian goose meat. Reference standards may be food products, chemicals or other substances and are used to communicate the concept of product attributes, thus ensuring that sensory panellists have the same understanding of the nature of a sensory attribute (Drake & Civille, 2002). Ostrich and Egyptian geese are similar with regard to the appearance of the meat; both having dark, red meat. Pekin ducks and Egyptian geese are both waterfowl species; however, the former is a domestic bird while the latter is a gamebird. Broiler chicken meat is regarded as having the least variation in terms of quality and is therefore considered to be a good reference standard when conducting sensory analysis of meat. This is due to the genetic selection and controlled environment under which domesticated animals such as broiler chickens are reared, resulting in a decrease in the intrinsic variation of the sensory attributes.

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The diet of Egyptian geese is mainly forage-based, consisting of growing crops, green plants, aquatic vegetation, invertebrates and insects (Viljoen, 2005). Guineafowl forage on bulbs and stems of plants, grass seeds, harvested grains, maize, as well as insects (Little & Crowe, 2011). Domestic species such as Pekin duck, ostrich and broiler chicken usually receive a standard commercial feed.

The physical and chemical characteristics of meat influence the sensory profile thereof, and it is widely regarded that the fatty acid composition of the diet can have a major influence on the flavour of meat (Calkins & Hodgen, 2007; Hornstein & Crowe, 1960, 1963; Mottram, 1998; Wood et al., 2003). In addition, the presence of certain minerals such as iron could also have an effect on the flavour of meat (Yancey et al., 2006). For instance, high iron content in meat has been linked to a metallic/livery flavour. Furthermore, when comparing game and domestic birds, the extent of physical exercise the different species are subjected to will have a direct influence on the sensory quality of the meat, mainly due to the difference in muscle constituents of active and inactive animals (Lawrie & Ledward, 2006). By investigating all the influential factors, i.e. chemical and physical, it is possible to conduct regression analysis to determine which of the latter intrinsic chemical and physical attributes predict specific sensory attributes of Egyptian goose meat. This will provide the necessary insight to understand the factors driving the sensory quality of meat.

In view of this, the objective of this study was to fingerprint and describe the sensory profile of Egyptian goose meat in comparison to other well-established species which are consumed on a regular basis in South Africa. The sensory, physical and proximate characteristics, together with the fatty acids and minerals, were determined, where after multivariate analyses were conducted to determine the drivers of sensory meat quality, as well as to quantify the potential of Egyptian goose meat for the meat industry.

## 2. Materials and methods

### 2.1. Experimental layout, sampling and slaughtering

The experimental layout is indicated in Table 1. The design consisted of six meat treatments which included the breast portion of Egyptian geese, guineafowl, Pekin duck and broiler chicken together with ostrich fan fillet (*Musculus iliofibularis*) and ostrich moon steak (*Musculus femorotibialis*). There were six samples per treatment. The different species and muscles were selected based on the fact that this is a descriptive study and that the samples should be representative of each species. As such, the extrinsic (diet etc.) and intrinsic (muscle differences) factors that may be influential are recognized and accepted as being characteristic of each sample.

The gamebirds Egyptian geese (*Alopochen egyptiacus*) and guineafowl (*N. meleagris*) were harvested during August 2010 on Mariendahl Agricultural Experimental Farm, Western Cape, South Africa (−33° 51′ 1.9074″; 18° 49′ 21.1476″). A double barrelled shotgun was used during the wingshooting activities (ethical clearance reference number: 10NP_HOF01). The geese and guineafowl were collected in the field and placed in a refrigerator (4 °C) over-night (±12 h) where after the slaughtering procedures were carried out manually as described by

**Table 1**
Sample set and experimental units.

| Meat treatments | Cuts used | Number of birds analysed |
|---|---|---|
| Egyptian goose | Breast | 6 |
| Guineafowl | Breast | 6 |
| Pekin duck | Breast | 6 |
| Ostrich | Fan fillet | 6 |
| Ostrich | Moon steak | 6 |
| Broiler chicken | Breast | 6 |

Geldenhuys, Hoffman, and Muller (2013b). The broiler chicken carcasses were slaughtered according to the acceptable standard slaughtering methods used for commercial chickens (Department of Agriculture, Forestry and Fisheries (DAFF) [DAFF], 2006). The breasts (M. pectoralis) were removed from the respective bird carcasses and each meat sample was individually vacuum-packed in a polystyrene bag and frozen at −18 °C for approximately 6 weeks. The Pekin duck breasts (*M. pectoralis*), ostrich fan fillets (*M. iliofibularis*) and moon steaks (*M. femorotibialis*) were sourced from commercial producers and also frozen at −18 °C for approximately 6 weeks. Sensory analysis was performed on the right breast (M. pectoralis) of the carcass, while the physical measurements were performed on the left breast. The two portions used for the analyses were treated as an entity and cooked together. Two strips were removed down the centre of the cooked ostrich fan fillet (*M. iliofibularis*) and moon steak (*M. femorotibialis*) samples, one of which was used for the sensory analysis and the other for the instrumental measurements.

Four reference standards were also prepared and used during the training phase of descriptive sensory analysis (Corollaro et al., 2013). The reference standards included commercial free range chicken, beef sirloin, beef rump, as well as the longissimus dorsi muscle of locally harvested blesbok (*Damaliscus pygargus phillipsi* — a free ranging wild ungulate). The reference samples enabled the panellists to calibrate their sensory perception during the training sessions, thereby allowing them to recognize and score all of the attributes tested in the respective meat samples.

### 2.2. Sample preparation

Sensory analysis was conducted on the six meat treatments (six different muscles/species) with six replications per treatment. The samples were randomly selected for each of the six replications. The vacuum-packed, frozen meat samples were thawed for 36 h in a refrigerator (4 °C) prior to each of the pre-determined sensory analysis sessions. The two breast meat samples of each bird were treated as one entity and placed together inside in an oven bag (Glad®), while one ostrich fan fillet and ostrich moon steak sample were placed in separate oven bags, respectively. No salt (NaCl) or any other seasoning was added to any of the meat treatments throughout the sensory analyses. The oven bags and meat samples were then placed on stainless steel grids which were fitted on an oven roasting pan. Thermocouple probes attached to a handheld digital temperature monitor (Hanna Instruments, South Africa) were placed in the centre of each of the meat samples (AMSA, 1995). The prepared samples were then placed in two conventional ovens (Defy, Model 835), pre-heated to 160 °C (AMSA, 1995). The ovens were connected to a computerized monitoring system responsible for regulation of the temperature (Viljoen, Muller, De Swardt, Sadie, & Vosloo, 2001). The meat samples were removed from the oven when a core temperature of 75 °C was reached (AMSA, 1995). The samples were cooled for 15 min where after they were cut into 1 cm × 1 cm cubes, individually wrapped in aluminium foil and placed into glass ramekins coded with randomized three-digit codes. The coded ramekins, each containing two wrapped meat cubes, were then placed in a preheated industrial oven (Hobart, France) at 100 °C for 10 min after which they were removed and immediately served to the sensory panel for analysis.

### 2.3. Descriptive sensory analysis

Descriptive sensory analysis (DSA) was performed on the six meat treatments (six different muscles/species). A panel of eight judges, based upon previous experience with sensory analysis of meat, was selected. The panellists were trained according to the guidelines for sensory analysis of meat by the American Meat Science Association (AMSA, 1995) and the generic descriptive sensory analysis technique as described by Lawless and Heymann (2010).

The panel undertook six training sessions and during each of these training sessions the panellists received 1 cm × 1 cm cubes of meat from the four reference standards, as well as the six meat treatments. Reference standards were chosen to illustrate the respective aroma and flavour attributes associated with Egyptian geese, as well as the other five treatments. Finally, the panel decided on 13 sensory attributes: game, chicken, ostrich and beef aroma and flavour, as well as metallic flavour, initial and sustained juiciness, tenderness (evaluated on first bite) and residue. The definitions for each of the attributes are described in Table 2.

The test re-test method was used for DSA. The panellists received the six treatments in a complete randomized order, while seated in individual tasting booths fitted with the software programme Compusense® five (Compusense, Guelph, Canada). The samples were analysed for the respective sensory attributes using an unstructured line scale anchored to zero (indicating "low intensity") and 100 (indicating "high intensity") (AMSA, 1995). The sensory analysis sessions took place inside a temperature-controlled (21 °C) and light-controlled (artificial daylight) room (AMSA, 1995). In order to cleanse and refresh their palates between samples, the panellists received distilled water (21 °C), apple quarters and water biscuits (Carr, UK).

## 2.4. Physical measurements

### 2.4.1. pH

The pH of the six meat samples for each of the six replications was measured after thawing the meat for 36 h, immediately after removal from the packaging and before the start of the cooking process of every DSA session. The pH was measured by means of a Crison pH 25 handheld portable pH metre (Lasec (Pty) Ltd, South Africa) with an automatic temperature adjuster calibrated before each session with the standard buffers (pH 4.0 and pH 7.0) provided by the manufacturer.

### 2.4.2. Drip and cooking loss

Following removal of the muscles from the carcasses, the mass was recorded before being vacuum-packed and frozen (−18 °C) for approximately 6 weeks. Before each of the DSA sessions, the meat was thawed in a freezer at 4 °C for 36 h where after the meat was removed from the packaging, blotted dry with blotting paper and weighed (Radwag PS 750/C/2, Lasec SA, Cape Town, South Africa). This procedure was followed for each of the six replications. The drip loss of each sample was calculated as a percentage of the original mass of the meat sample before it was frozen.

The cooking loss of the meat samples was determined according to the method described by AMSA (1995). The difference in the weight of each of the uncooked and cooked samples was calculated as the percentage of cooking loss.

### 2.4.3. Colour

Instrumental colour measurements were taken at three randomly selected positions on the inside of a strip of cooked meat removed from the centre of each sample. The colour was recorded using a Colour guide 45°/0° colorimeter (Catalogue no: 6805; BYK-Gardner, USA) to establish the L*, a* and b* values with L* indicating lightness, a* the red–green range and b* the blue–yellow range. The hue angle ($h_{ab}$) (°) and chroma value ($C^*$) were also calculated using the a* and b* values as indicated by Honikel (1998).

### 2.4.4. Water holding capacity

The water holding capacity (WHC) was determined according to the method described by Trout (1988). A 0.5 g cooked meat sample was used using Lasec filter paper (grade 292, 90 mm diameter, part no. FLAS3205090) and a standard pressure of 588 N for 60 s. Using Image J Software (Version 1.41, 2009, http://rsbweb.nih.gov/ij/) the ratio between the outer (liquid) and inner (meat) purge areas was calculated to indicate the water holding capacity of each meat sample.

### 2.4.5. Shear force

The Warner Bratzler shear force test (WBSF), as described by Honikel (1998), was used to measure the instrumental shear force of the cooked meat samples. Each of the six treatments (six replications per treatment) was analysed for instrumental tenderness. Two adjacent 1 × 1 cm meat strips were cut parallel to the muscle fibre direction from the centre of the cooked meat samples, wrapped in aluminium foil and placed in the refrigerator (4 °C) for 24 h. The respective meat strips were then cut to obtain a total of six rectangular cubes with a length of 2 cm per cube. An Instron Universal Testing Machine (Instron UTM, Model 2519-107), attached to a Warner–Bratzler fitting, was used to determine the force necessary to shear the cooked rectangular meat cubes perpendicular to the muscle fibre direction. The WB fitting was a 1 mm thick triangular (V-notch) blade with a semi-circular cutting edge (radius of 0.508 mm). The UTM was operated with a 2 kN compression load cell. The shear test was performed at a speed of 200 mm/min. The shear force value of each of the samples was recorded in Newton (N). For statistical analyses, the mean of the six readings was used.

## 2.5. Chemical data

The chemical data (proximate, fatty acid and mineral composition) used in the multivariate analyses were obtained from Geldenhuys et al. (2013b). This was possible as the data collected within this study and that of Geldenhuys et al. (2013b) were from the exact same samples.

**Table 2**
Definition and scale of each attribute used for the descriptive sensory analysis.

| Sensory attribute | Description | Scale |
|---|---|---|
| Game aroma[a] | Aroma associated with game meat as soon as the aluminium foil is removed | 0 = extremely bland 100 = extremely intense |
| Chicken aroma[a] | Aroma associated with chicken as soon as the aluminium foil is removed | 0 = extremely bland 100 = extremely intense |
| Ostrich aroma[a] | Aroma associated with ostrich as soon as the aluminium foil is removed | 0 = extremely bland 100 = extremely intense |
| Beef aroma[a] | Aroma associated with beef as soon as the aluminium foil is removed | 0 = extremely bland 100 = extremely intense |
| Game flavor[a] | Flavour associated with game meat prior to swallowing | 0 = extremely bland 100 = extremely intense |
| Chicken flavor[a] | Flavour associated with chicken prior to swallowing | 0 = extremely bland 100 = extremely intense |
| Ostrich flavor[a] | Flavour associated with ostrich prior to swallowing | 0 = extremely bland 100 = extremely intense |
| Beef flavor[a] | Flavour associated with beef prior to swallowing | 0 = extremely bland 100 = extremely intense |
| Metallic flavor[a] | Flavour associated with metal/liver prior to swallowing | 0 = extremely bland 100 = extremely intense |
| Initial juiciness | The amount of fluid exuded from the cut surface when pressed between the thumb and forefinger | 0 = extremely dry 100 = extremely juicy |
| Sustained juiciness | The level of juiciness perceived after the first 5 chews using the molar teeth | 0 = extremely dry 100 = extremely juicy |
| First bite | The impression of tenderness perceived after the first 5 chews using the molar teeth | 0 = extremely tough 100 = extremely tender |
| Residue | The amount of residue left inside the mouth after the first 10 chews | 0 = none 100 = abundant |

[a] Aroma and flavour were analysed orthonasally and retronasally, respectively.

## 2.6. Statistical analysis

The study consisted of a randomized block design with six meat treatments and six replications per treatment. The collected sensory data were pre-processed for further application in multivariate analyses using the following statistical techniques: PanelCheck Software (Version 1.3.2, www.panelcheck.com) was used to monitor DSA panel performance. The sensory, physical and chemical data were also subjected to test–retest analysis of variance (ANOVA) using SAS® software (Statistical Analysis System 2006, Version 9.2, SAS Institute Inc., Cary, NC, USA) to test for the reliability of the panel. The Shapiro–Wilk test was performed to test for non-normality of residuals (Shapiro & Wilk, 1965). In the event of significant non-normality (P ≤ 0.05), outliers were identified and residuals greater than 3 were removed. Correlation coefficients were calculated for the sensory, physical and chemical data by means of the Pearson's correlation coefficient (r) (Snedecor & Cochran, 1980). Principal component analysis (PCA), using the correlation matrix, was performed and used in conjunction with discriminant analysis (DA) in order to indicate and clarify the relationships between the sensory, physical and chemical data (Næs, Brockhoff, & Tomic, 2010). The latter multivariate analyses were conducted using XLStat software (Version 2012, Addinsoft, New York, USA).

## 3. Results and discussion

### 3.1. Aroma and flavour

The mean scores for the respective aroma and flavour attributes are illustrated in Fig. 1. It is clear that the aroma and flavour profile of Egyptian goose meat was very distinct compared to the other treatments. The trained panel found Egyptian goose meat to have a more (P ≤ 0.05) intense game aroma (41.9), game flavour (48.4) and metallic flavour (28.2) compared to the other treatments. PCA plots are used in sensory analysis to demonstrate the relationships between different sensory attributes, as well as their association with other chemical or physical characteristics. The PCA bi-plot (Fig. 2) provides insight into the sensory attribute associations when comparing the different species. Although the PCA bi-plot only describes 51% of the variation, this is still high when it is taken into account that there are numerous extrinsic (and intrinsic) factors that could influence the sensory profile such as diet and age. The sensory attributes illustrated in the top left quadrant of the 1st principal component (PC1/F1) associate with Egyptian goose meat. This offers further evidence that the sensory profile of Egyptian goose meat was predominantly governed by game-like attributes, and the metallic flavour. According to Fig. 2 there is a reasonably strong correlation between game flavour and intramuscular fat (IMF%) (r = 0.601; P = 0.0001). Generally IMF is regarded as an essential driver of meat flavour (Melton, 1990). Studies by Hoffman, Mostert, Kidd, and Laubscher (2009) and Tshabalala, Strydom, Webb, and de Kock (2003) showed significant correlations between the amount of IMF present and meat flavour intensity. These findings are in agreement with our study as the high IMF content of Egyptian goose meat (Geldenhuys et al., 2013b) seemed to contribute to the reasonably intense game flavour.

According to Swanson and Penfield (1991) increased levels of PUFA in meat from game animals are also responsible for the distinct game characteristics. According to Geldenhuys et al. (2013b) the Egyptian goose meat samples used in this study illustrated high levels of PUFA. As indicated in Fig. 2, both game aroma and game flavour were highly correlated with omega 3 fatty acids (n-3) with values of 0.800 (P < 0.0001) and 0.701 (P < 0.0001). However, the correlation between the game characteristics and total polyunsaturated fatty acid (PUFA) content was low, and not significant.

In a study comparing the sensory attributes of 15 different species, Rodbotten et al. (2004) states that the flavour of game animals can be influenced by diet. In monogastric animals, such as gamebirds and
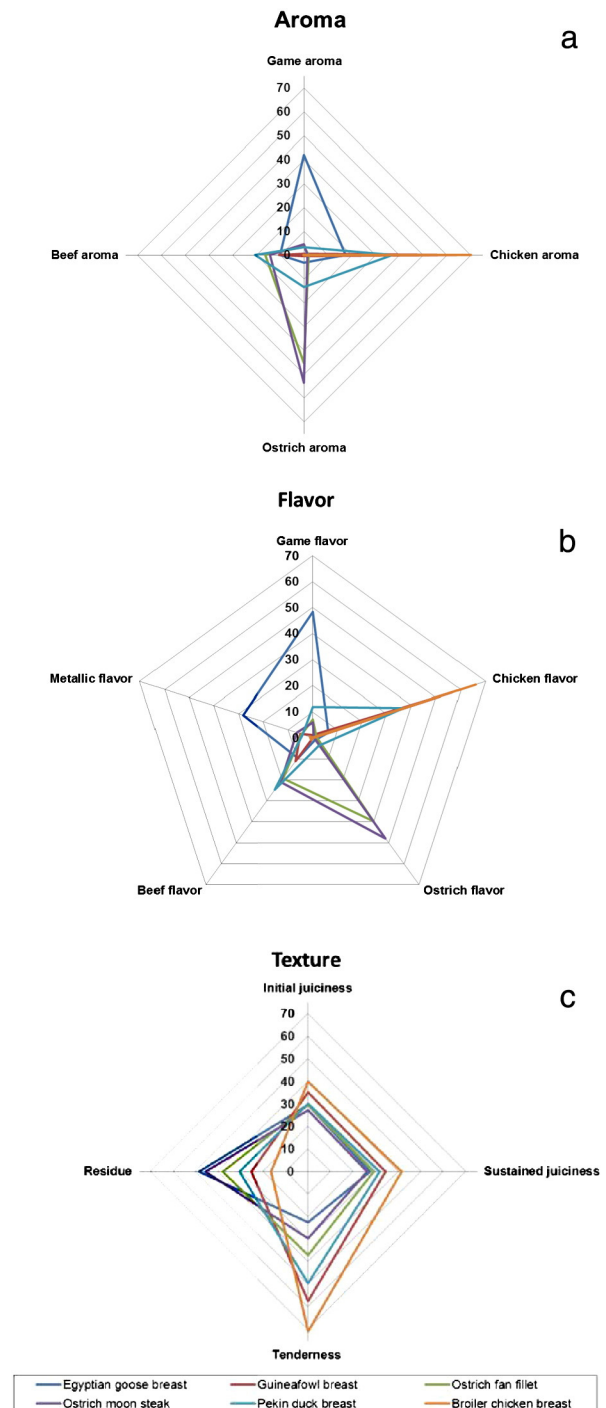
Fig. 1. Spider plots illustrating the aroma (a), flavour (b) and texture (c) attributes derived from the six meat treatments. Unstructured line scale ranged from 0 = low intensity to 100 = high intensity.

poultry, diet is a key factor. The dietary lipids in the feed is directly linked to the fatty acid composition of the intramuscular lipids (MacRae, O'Reilly, & Morgan, 2005; Wood & Enser, 1997). This applies particularly to essential fatty acids which cannot be synthesized (Wood & Enser, 1997). The food supply of Egyptian geese is variable, but mainly forage-based (Viljoen, 2005). During the grain harvesting season they forage on crops such as wheat and barley (Maclean, 1988; Viljoen, 2005). The geese used in this study were, however, not harvested during the grain season and thus predominately consumed grasses, young green crops and aquatic vegetation. According to the DA plot (Fig. 3a), indicating the classification of the different meat samples
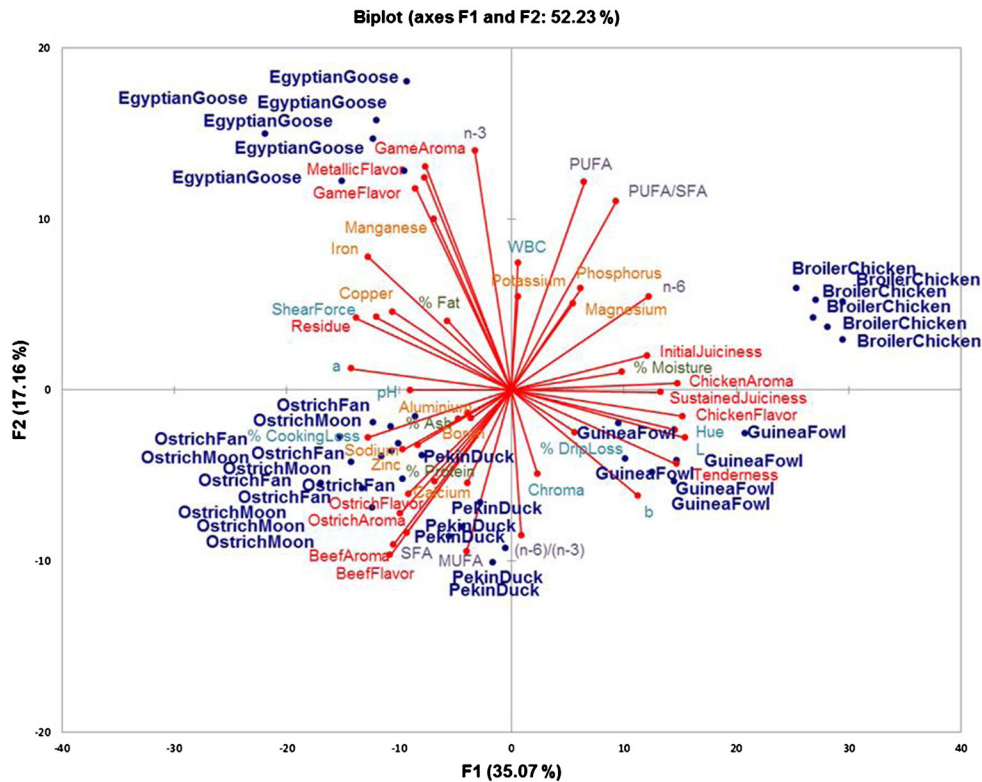
**Fig. 2.** PCA bi-plot of sensory attributes, physical attributes, proximate composition, mineral composition and total fatty acids of the six meat treatments.

based on the individual fatty acids (Fig. 3b), it is evident that the fatty acid composition of the respective species is quite diverse. The diet of Egyptian geese is of a more unsaturated nature, since grass- or forage-based diets are regarded as high in linolenic acid (18:3) (Enser et al., 1998; Manner, Maxwell, & Williams, 1984; Ward, Wittenberg, Froebe, Przybylski, & Malcolmson, 2003). Another important aspect to consider is the abundance of specific individual fatty acids. In Fig. 3b moderate to strong correlations are illustrated between the game aroma and flavour attributes and some of the individual fatty acids. See Table 3 for significant correlations between specific PUFAs and game aroma and flavour. α-Linolenic acid (C18:3n-3) had the strongest correlation with game aroma and flavour, respectively. Although Yancey et al. (2006) suggest that specific fatty acids seem to result in game-like attributes, limited information could be found to substantiate the link between individual fatty acids and specific sensory notes. This is an area of research that requires further investigation. Free iron (Fe) in meat acts as an oxidative catalyst and during cooking the concentration thereof increases as the Fe containing proteins (myoglobin and haemoglobin) denature (Campo et al., 2003). High levels of polyunsaturated fatty acids are particularly susceptible to oxidation (Campo et al., 2003). With the increased Fe levels of Egyptian goose meat (Geldenhuys et al., 2013b) having a possible pro-oxidant effect, lipid oxidation might contribute to the intense game-like aroma and flavour. However, Yancey et al. (2006) suggest that game-like or livery flavours do not seem to be related to lipid oxidation.

It is interesting to note that there is such a major difference between the sensory profiles of the two gamebird species, i.e. Egyptian goose and guineafowl. The mean sensory scores (Fig. 1) for game aroma (0.62) and game flavour (1.01) of guineafowl meat were extremely low and barely detectable (P ≤ 0.05) compared to that of Egyptian goose meat. The guineafowl meat compared well with broiler chicken in that it was high in chicken aroma (64.1) and chicken flavour (56.6). This phenomenon is also clearly visible on the PCA plot (Fig. 2) where there were moderate, negative correlations (P ≤ 0.05) between the game and chicken sensory attributes. The very low game aroma or game

flavour scores for guineafowl may be explained by the fact that the range of fatty acids found in guineafowl meat is different to that of Egyptian goose meat. This could be related to the difference in the diet in terms of linoleic and linolenic acid contents, where grain-based diets are high in linoleic acid and grass or forage-based diets are high in linolenic acid (Enser et al., 1998 Manner et al., 1984; Ward et al., 2003). Guineafowl feed on bulbs and stems of plants, grass seeds, harvested grains and maize which may clarify the similarity between the sensory profiles of guineafowl and broiler chicken. Diet is thus also the key factor when comparing the sensory profile of Egyptian goose meat with that of the other domestic fowl species.

It is evident from the PCA plot (Fig. 2) that Egyptian goose meat is also associated with a strong metallic flavour. This sensory attribute definitely contributes to the unique sensory profile of this species. Very strong correlations were noted for metallic flavour, game aroma (r = 0.928; P = < 0.0001) and game flavour (r = 0.943; P < 0.0001), respectively. The metallic flavour could be explained by the reasonably strong correlation (r = 0.793; P < 0.0001) with iron (Fe) content. Geldenhuys et al. (2013b) reported a very high level of Fe (7.46 mg/100 g) in Egyptian goose meat and the metallic flavour may thus be ascribed to the presence of Fe. In literature, there seems to be an association between metallic flavour and a liver-like flavour in meat. Miller (2001) found that a metallic flavour is often connected to a liver flavour in beef and Mendell, Buchanan-Smith, and Campbell (1998) reported a correlation between liver flavour and a metallic aftertaste. Rodbotten et al. (2004) define metallic flavour as the flavour of ferrosulphate, whereas a liver flavour is associated with animal liver. It is possible that, in this study, metallic flavour could have been perceived as a combination of the two. Wild animals tend to have a more intense liver flavour than farmed animals (Rodbotten et al., 2004). Yancey et al. (2006) established that an increase in the total Fe content (myoglobin) resulted in a more intense liver flavour in beef. The fact that the geese were not bled after being shot might also have caused an increase in the intensity of the metallic flavour due to the presence of haemoglobin (blood) in
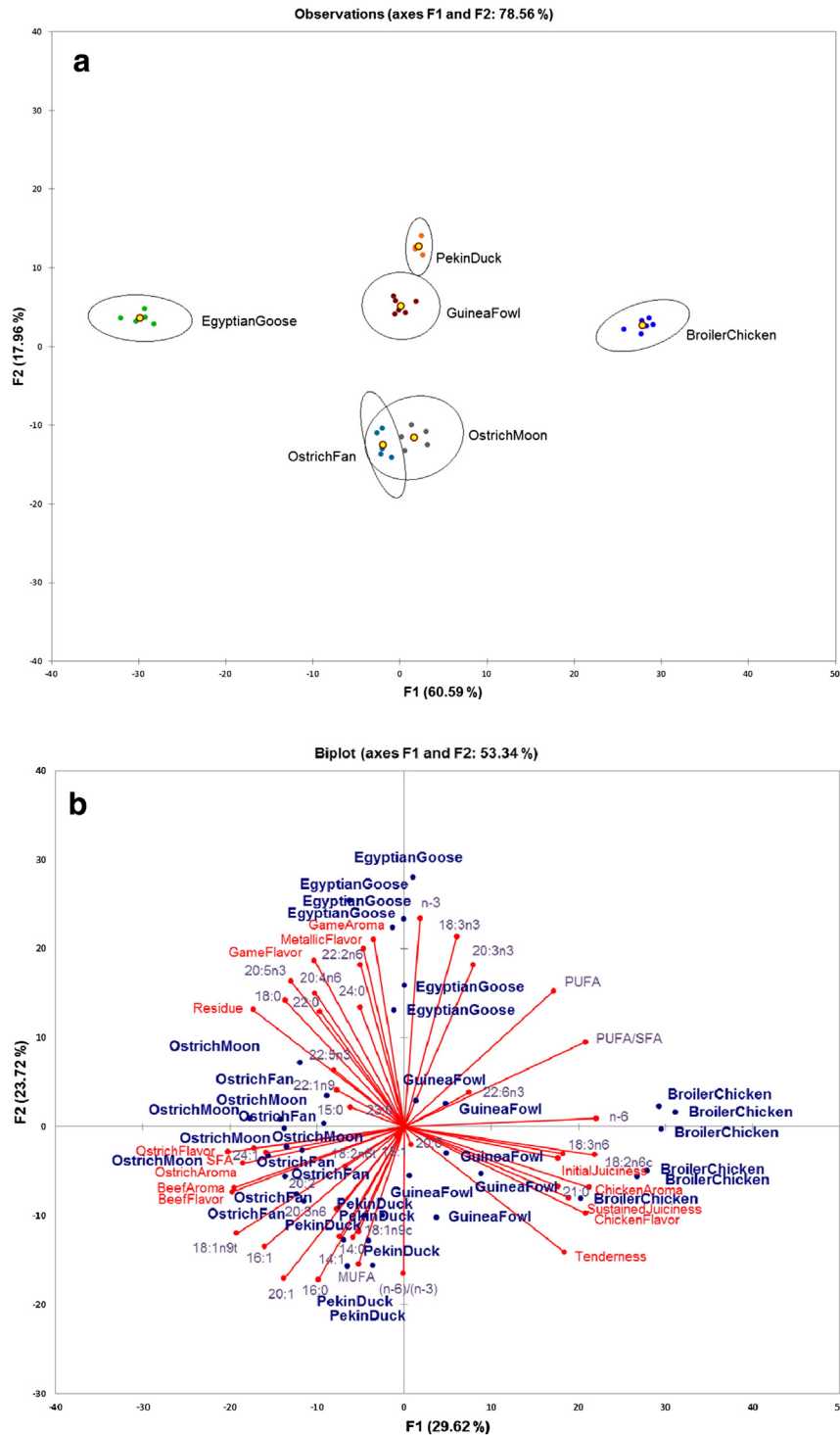
**Fig. 3.** a. DA plot illustrating the classification of treatments based on the specific fatty acids. b. PCA bi-plot indicating the means for each individual fatty acid, as well as the sensory attributes of the six respective meat treatments.

the muscle. Yancey et al. (2006), however, found no significant correlation in terms of haemoglobin content and a liver-like flavour. Furthermore; the studies of Calkins and Hodgen (2007) and Yancey et al. (2006) revealed that the presence of long chain unsaturated fatty acids in the meat can also be responsible for the development of a liver-like flavour. Mendell et al. (1998) reports a significant correlation between metallic aroma and 18:3 fatty acids in forage fed beef and speculated that dietary fatty acids (18:1 and 18:3) are responsible for the higher metallic aroma found. In our study this relates back to the fact that relatively strong correlations were found between metallic flavour

and the long chain PUFA listed in Table 3 and indicated in Fig. 3b. Of these PUFA, α-linolenic acid (C18:3n-3) (r = 0.788, P < 0.0001) showed the highest correlation with metallic flavour.

An aspect that warrants further investigation is the effect of ageing on the flavour and aroma of Egyptian goose meat. This is particularly pertinent as there is a strong probability that most consumers would age the meat because of the low tenderness of the breast muscle (Fig. 1, Fig. 2 and Table 4). Strong associations with any of the other aroma and flavour attributes were absent, proving the dominance of the game-like and metallic sensory attributes in Egyptian goose meat.

**Table 3**
Significant correlations between the game attributes and individual fatty acids.

| Fatty acids | | Game aroma | | Game flavour | | Metallic flavour | |
|---|---|---|---|---|---|---|---|
| | | r[a] | P-value | r[a] | P-value | r[a] | P-value |
| α-Linolenic acid | 18:3 n-3 | 0.838 | <0.0001 | 0.766 | <0.0001 | 0.788 | <0.0001 |
| Arachidonic acid | 20:4 n-6 | 0.600 | 0.0001 | 0.560 | 0.000 | 0.590 | 0.000 |
| Eicosatrienoic acid | 20:3 n-3 | 0.445 | 0.007 | – | – | 0.388 | 0.019 |
| Eicosapentaenoic acid (EPA) | 20:5 n-3 | 0.434 | 0.008 | 0.377 | 0.024 | 0.431 | 0.009 |
| Docosadienoic acid | 22:2 n-6 | 0.660 | <0.0001 | 0.575 | 0.000 | 0.606 | <0.0001 |

[a] r (Pearson correlation coefficient).

The aroma and flavour of Egyptian goose meat are thus quite unique when compared to the other fowl species.

### 3.2. Juiciness

Initial juiciness in meat is defined as the moisture released during mastication, whereas the stimulation of saliva secretion due to the presence of intramuscular fat is defined as sustained juiciness (Dryden & Maechello, 1970; Lawrie & Ledward, 2006). Egyptian goose meat received significantly lower sensory mean scores for initial and sustained juiciness (Fig. 1) compared to the broiler chicken and guineafowl samples. This is also illustrated in the PCA plot (Fig. 2) where broiler chicken and guineafowl associate with both forms of juiciness. It is also evident from Fig. 2 that there is a moderate correlation between percentage moisture and initial (r = 0.618; P < 0.0001) and sustained juiciness (r = 0.583; P = 0.0002), respectively. The juiciness is therefore a reflection of the moisture content (%) of the meat. As a result of the cooking process, Egyptian goose meat had a greater loss of moisture than guineafowl and broiler chicken (Table 4), this may explain the lower juiciness. This higher cooking loss is inconsistent with literature as muscle with a high ultimate pH generally produces meat with a relatively low cooking loss (Lawrie & Ledward, 2006). However, it could be argued that the lower drip loss due to the high $pH_u$ (r = −0.377; P = 0.024) may have resulted in an increased amount of moisture available for release during cooking. This theory may explain the moderate correlation (Fig. 2) of a high pH with cooking loss (r = 0.450; P = 0.006). Thomas, Gondoza, Hoffman, Oosthuizen, and Naude (2004) also reported that the percentage cooking loss and drip loss showed an inverse trend and a high muscle pH usually results in less drip loss. Another indication of the juiciness of the meat is the WHC as this reflects the amount of fluid present in the meat after the cooking process. Fig. 2 illustrates a low, but significant correlation (r = 0.370; P = 0.027) between the percentage moisture and the WHC of the meat. The initial juiciness of meat is thus positively correlated to the water holding capacity which in turn is determined by the $pH_u$ of the muscle (Offer & Trinick, 1983).

Generally IMF contributes to sustained juiciness, but in this study, no significant correlation was observed between these two attributes (Fig. 2). The absence of a significant correlation between IMF and sustained juiciness may be related to the effect of cooking on the IMF (%) determination. The cooking process causes moisture loss which results in a significant increase in the IMF (%) in meat from the raw to the cooked state. In our study the proximate analysis was performed after completion of the cooking process, and in this instance meat with a higher cooking loss will naturally have a higher intramuscular fat content (Alfaia et al., 2010). The low tenderness of Egyptian goose meat (Fig. 1) could also have had a concealing effect on the perception of sustained juiciness due to the elevated fat content. Hoffman, Kroucamp, and Manley (2007), in a study on Springbok (*Antidorcas marsupialis*) meat quality, found that with an increase in the shear force values (decrease in tenderness) the sustained juiciness decreased. It could thus be expected that with a decrease in the tenderness, the meat will become lower in juiciness due to impeded water release from the meat (Tshabalala et al., 2003).

### 3.3. Tenderness

Egyptian goose meat proved to have the lowest tenderness compared to the other treatments as indicated by the very low mean sensory tenderness (22.7) and residue (48.2) values (Fig. 1), as well as the shear force mean value of 48.7 N (Table 4). Fig. 2 also illustrates that Egyptian goose meat associated with a high shear force and high residue, respectively. It is perhaps of note that although Egyptian goose meat had the highest mean shear force value, it did not differ (P > 0.05) from the ostrich moon steak and fan fillet.

According to Lewis, Rakes, Brown, and Noland (1989) muscles with a high level of physical activity pre-slaughter will result in less tender meat because of an increased intramuscular collagen content. Egyptian geese are gamebirds and are known for flying long distances compared to the other domestic fowl in this study. Therefore the breast muscle (pectoralis), primarily used for flying (Biewener, 2011), has a higher level of activity resulting in less tender meat.

An important correlation illustrated by the PCA plot (Fig. 2) is that of shear force and pH (r = 0.427; P = 0.009). The low tenderness could also be related to the higher pH (5.95) of Egyptian goose meat (Table 4). Egyptian geese endure continuous physical exercise and were shot as they were flying back to the roosting sites from the areas

**Table 4**
The average values (±SD) of the physical measurements from the six meat treatments.

| | Species | | | | | | LSD |
|---|---|---|---|---|---|---|---|
| | Egyptian goose | Guineafowl | Ostrich fan | Ostrich moon | Pekin duck | Broiler chicken | P = 0.05 |
| % Drip loss | 7.93[b] ± 3.66 | 10.59[a] ± 2.29 | 5.14[c] ± 0.67 | 8.41[ab] ± 1.42 | 10.51[a] ± 0.57 | 8.98[ab] ± 2.06 | 2.38 |
| % Cooking loss | 29.99[b] ± 4.91 | 22.89[c] ± 2.15 | 35.21[a] ± 2.90 | 35.78[a] ± 3.81 | 28.65[b] ± 2.54 | 22.94[c] ± 3.12 | 3.55 |
| pH | 5.95[ab] ± 0.11 | 5.70[c] ± 0.09 | 6.06[a] ± 0.12 | 5.94[ab] ± 0.08 | 6.02[a] ± 0.06 | 5.85[b] ± 0.12 | 0.12 |
| L* | 40.92[d] ± 3.34 | 68.17[b] ± 1.61 | 49.47[c] ± 0.97 | 51.76[c] ± 1.43 | 51.86[c] ± 2.72 | 78.02[a] ± 2.23 | 2.50 |
| a* | 9.82[a] ± 2.08 | 4.57[c] ± 0.65 | 9.13[a] ± 2.09 | 9.04[a] ± 1.59 | 7.30[b] ± 1.51 | 1.93[d] ± 0.64 | 1.71 |
| b* | 14.11[e] ± 0.61 | 18.45[a] ± 0.83 | 14.86[d] ± 0.68 | 15.89[c] ± 0.22 | 15.91[c] ± 0.46 | 17.36[b] ± 0.96 | 0.56 |
| Hue | 55.41[d] ± 6.53 | 76.38[b] ± 2.54 | 59.16[d] ± 6.22 | 60.49[cd] ± 4.71 | 65.51[c] ± 4.35 | 83.68[a] ± 1.96 | 5.11 |
| Chroma | 17.28[b] ± 0.92 | 19.56[a] ± 1.42 | 17.79[b] ± 1.28 | 18.33[ab] ± 0.65 | 17.54[b] ± 0.87 | 17.48[b] ± 0.99 | 1.24 |
| WBC | 3.83[a] ± 0.66 | 3.77[ab] ± 0.38 | 3.37[ab] ± 0.27 | 3.34[b] ± 0.47 | 2.68[c] ± 0.25 | 3.39[ab] ± 0.33 | 0.47 |
| Shear force (N) | 48.76[a] ± 13.65 | 25.72[b] ± 5.34 | 42.38[a] ± 12.23 | 41.71[a] ± 11.94 | 26.20[b] ± 4.62 | 18.10[b] ± 3.98 | 8.83 |

SD (standard deviation); LSD (least significant difference); WBC (water binding capacity); [a-e] means in rows with different superscripts are significantly different at P ≤ 0.05.

where they were foraging. They may thus have covered a long distance. This exercise ante mortem causes the $pH_u$ of the breast muscle to be relatively high as there is very few energy reserves left for lactic acid production (Lawrie & Ledward, 2006). The rate of pH fall and $pH_u$ has a considerable effect on shear force and sensory tenderness of meat (Sales & Mellett, 1996). According to Purchas (1990) there is a decrease in tenderness as the $pH_u$ increases from 5.5 to 6.2. Yu and Lee (1986) also concluded that between pH 5.8 and 6.3 the tenderness is at its lowest as this is not the optimal functioning pH for the proteolytic enzyme system, i.e. the calpains and cathepsins.

There also seems to be a trend in terms of cooking loss (%) and sensory tenderness, with a moderate to strong negative correlation ($r = -0.695$; $P < 0.0001$) existing between these two attributes (Fig. 2). Also, an increase in shear force is positively correlated to a high percentage cooking loss ($r = 0.648$; $P < 0.0001$). Egyptian goose meat and the ostrich treatments had significantly higher cooking losses (%) compared to the other treatments (Table 4) and were considered to be the least tender treatments by the sensory panel. In several studies, similar results were found (Hoffman, Muller, Cloete, & Brand, 2008; Hoffman et al., 2007; Silva, Patarata, & Martins, 1999) and a possible reason for this decreased tenderness could be the diluting effect of the bound moisture (Thomas et al., 2004).

### 3.4. Instrumental colour

In general game meat is considered to have a darker red colour when compared to domestic animals (Hoffman, 2000). The colour of Egyptian goose meat resembles that of ostrich and other ruminant game species which is evident from the strong association of these species and the a* value (red colour) in the PCA plot (Fig. 2). The mean a* value (Table 4) is low for game species in general, but this value reflects that of cooked and not raw meat where the a* value is usually substantially higher. The dark colour of game meat is most likely the result of the higher level of physical activity in game species (Hoffman, 2000). The level and type of activity that a muscle is subjected to directly determine the fibre composition. Kiessling (1977) reported that the breast muscle of geese consists of approximately 80% red fibres and Baeza et al. (2000) found that the M. pectoralis of mule ducks consist of 88% type IIa fibres and 12% type IIb fibres. Lawrie and Ledward (2006) state that there is an amplification of the myoglobin content in the muscle during regular exercise, mainly to enhance its oxygen carrying capacity, therefore the dark red colour. In our study, the gamebird species were more active than the domestic birds. In Fig. 2 the high myoglobin content relates to the higher a* value (red colour) of Egyptian goose meat and there are negative correlations with the hue angle (less red colour) and the L* value (lightness). The association of Egyptian goose meat with a dark red colour is verified by the mean scores in Table 4. This species indicated a mean score of 9.82 for a*, which was not significantly different from that of ostrich proving the similarity in terms of colour between the two. Furthermore, the L* value of Egyptian goose meat (40.92) was significantly lower than the other meat treatments, especially broiler chicken (78.02), indicating a much darker meat colour.

In Fig. 2 there is a moderate correlation ($r = 0.434$; $P = 0.008$) between high pH and a high a* value (red colour). The PCA also illustrates a moderate negative correlation ($r = -0.534$; $P = 0.001$) between pH and L* value (lightness). These correlations verify the fact that pH may partly be responsible for the dark, red colour of Egyptian goose meat. Red (type I and IIa) muscles with a high level of exercise have a higher ultimate pH ($pH_u$). The Egyptian geese used for this study were all shot while in flight, the breast muscles thus also experienced a certain amount of ante mortem stress. Although the meat is not classified as DFD (pH < 6.0), the tendency towards this condition could be a contributing factor to the darker colour. There is a greater depletion of muscle glycogen, ante mortem, which is associated with stress and causes a higher $pH_u$ (Lawrie & Ledward, 2006). Consequently, water is bound tightly, the structure of the muscle is firmer, scattering of light is low

and the muscle surface appears to be darker (Warris, 2000). Therefore an inverse correlation between pH and lightness exists which relates to a darker coloured meat.

Where ostrich meat was very similar in appearance to Egyptian goose meat, it was entirely the opposite with guineafowl and broiler chicken. The association of guineafowl and broiler chicken with L*, b* and hue values were expected (Fig. 2). These associations are confirmed by the significantly different mean values (Fig. 1) for the colour variables. Compared to the other treatments, broiler chicken and guineafowl both had significantly higher L* and b* mean values and significantly lower a* values. Guineafowl was more yellow (higher b*) and broiler chicken lighter (higher L*) in appearance. The difference in the colour of these two birds compared to the other species, can be attributed to the type of fibres present in the breast muscle. Both guineafowl and broiler chicken are birds that do not use their wing muscles very often. Broiler chickens never fly, whereas guineafowl will, on occasion fly short distances. Kiessling (1977) established that the guineafowl breast muscle consists mainly of fast twitch, type IIb, glycolytic, white fibres with only 17% red fibres present. This is typical for gallinaceous birds to rapidly take off and fly short distances.

## 4. Conclusions

This study illustrated that the aroma and flavour attributes of Egyptian goose meat are very distinct when compared to the other species used in this study. The sensory profile of Egyptian goose meat has a very strong game aroma and game flavour, but also a distinctive metallic aftertaste. The presence of a substantial amount of Fe in the meat was responsible for the intense metallic flavour, while the high PUFA content could have been involved in producing intense game aroma and flavour notes. Egyptian goose meat is low in tenderness (high shear force), which is a result of the high level of physical activity endured by the breast muscle during flying. The low moisture content and high cooking loss explains the low initial juiciness thereof and regardless of the high fat content, Egyptian goose meat tends to be low in sustained juiciness.

This research essentially categorizes the sensory profile of Egyptian goose meat in relation to that of other well-known fowl species consumed in South Africa. This allows for the potential incorporation of the meat as a product on the South African meat market. With an initial sensory profile in place, it is now possible to do further sensory research in order to determine the effect of factors such as gender and grain season (diet) on the meat quality of Egyptian geese.

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## References

Alfaia, C. M. M., Alves, S. P., Lopes, A. F., Fernandes, M. J. E., Costa, A. S. H., Fontes, C. M. G. A., et al. (2010). Effect of cooking methods on fatty acids, conjugated isomers of linoleic acid and nutritional quality of beef intramuscular fat. Meat Science, 84, 769–777.

AMSA (1995). Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. Chicago, USA: National Livestock and Meat Board.

Baeza, E., Salichon, M. R., Marche, G., Wacrenier, N., Dominguez, B., & Culioli, J. (2000). Effects of age and sex on the structural, chemical and technological characteristics of mule duck meat. British Poultry Science, 41, 300–307.

Biewener, A. A. (2011). Muscle function in avian flight: Achieving power and control. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *366*, 1496.

Calkins, C., & Hodgen, J. (2007). A fresh look at meat flavor. *Meat Science*, *77*, 63–80.

Campo, M., Nute, G., Wood, J., Elmore, S., Mottram, D., & Enser, M. (2003). Modelling the effect of fatty acids in odour development of cooked meat in vitro: Part I — Sensory perception. *Meat Science*, *63*, 367–375.

Corollaro, M. L., Endrizzi, I., Bertolini, A., Aprea, E., Dematte, M. L., Costa, F., et al. (2013). Sensory profiling of apple: Methodological aspects, cultivar characterisation and post harvest changes. *Postharvest Biology and Technology*, *77*, 111–120.

Department of Agriculture, Forestry and Fisheries (DAFF) (2006). *Meat Safety Act (Act no. 20 of 2000, R153/2006)*. South African Government Gazette, 28520, 20–22.

Drake, M.A., & Civille, G. V. (2002). Flavour lexicons. *Comprehensive Reviews in Food Science and Food Safety*, *2*, 33–40.

Dryden, F., & Maechello, J. (1970). Influence of total lipid and fatty acid composition upon the palatability of three bovine muscles. *Journal of Animal Science*, *31*, 36.

Enser, M., Hallett, K. G., Hewitt, B., Fursey, A. J., Wood, J.D., & Harrington, G. (1998). Fatty acid content and composition of UK beef and lamb muscle in relation to production system and implications for human nutrition. *Meat Science*, *49*, 329–341.

Geldenhuys, G., Hoffman, L. C., & Muller, M. (2013a). Gamebirds: A sustainable food source in Africa? *Journal of Food Security*, *5*, 235–249.

Geldenhuys, G., Hoffman, L. C., & Muller, M. (2013b). Aspects of the nutritional value of cooked Egyptian goose (*Alopochen aegyptiacus*) meat compared with other well-known fowl species. *Poultry Science*, *92*, 3283–3291.

Hoffman, L. C. (2000). Meat quality attributes of night-cropped Impala (*Aepyceros melampus*). *South African Journal of Animal Science*, *30*, 133.

Hoffman, L. C., & Cawthorn, D.M. (2012). What is the role and contribution of meat from wildlife in providing high quality protein for consumption? *Animal Frontiers*, *2*, 40–53.

Hoffman, L., Kroucamp, M., & Manley, M. (2007). Meat quality characteristics of springbok (*Antidorcas marsupialis*). 4: Sensory meat evaluation as influenced by age, gender and production region. *Meat Science*, *76*, 774–778.

Hoffman, L., Mostert, A., Kidd, M., & Laubscher, L. (2009). Meat quality of kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*): Carcass yield, physical quality and chemical composition of kudu and impala longissimus dorsi muscle as affected by gender and age. *Meat Science*, *83*, 788–795.

Hoffman, L., Muller, M., Cloete, S., & Brand, M. (2008). Physical and sensory meat quality of South African black ostriches (*Struthio camelus var. domesticus*), Zimbabwean blue ostriches (*Struthio camelus australis*) and their hybrid. *Meat Science*, *79*, 365–374.

Hoffman, L. C., & Wiklund, E. (2006). Game and venison – Meat for the modern consumer. *Meat Science*, *74*, 197–208.

Honikel, K. O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science*, *49*, 447–457.

Hornstein, I., & Crowe, P. F. (1960). Meat flavor chemistry, flavor studies on beef and pork. *Journal of Agricultural and Food Chemistry*, *8*, 494–498.

Hornstein, I., & Crowe, P. (1963). Food flavors and odors, meat flavor: Lamb. *Journal of Agricultural and Food Chemistry*, *11*, 147–149.

Kiessling, K. H. (1977). Muscle structure and function in the goose, quail, pheasant, guinea hen, and chicken. *Comparative Biochemistry and Physiology Part B: Comparative Biochemistry*, *57*, 287–292.

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: Principles and practices* (2nd ed.). New York, USA: Springer.

Lawrie, R. A., & Ledward, D. A. (2006). *Lawrie's meat science* (7th ed.). Cambridge, UK: Woodhead Publishing.

Lewis, P., Rakes, L., Brown, C., & Noland, P. (1989). Effect of exercise and pre-slaughter stress on pork muscle characteristics. *Meat Science*, *26*, 121–129.

Little, R., & Crowe, T. (2011). *Gamebirds of Southern Africa* (2nd ed.). Cape Town: Struik Nature.

Maclean, G. L. (1988). The Egyptian goose (*Alopochen aegyptiacus*). *Eastern Cape Game Management Association*, *7*, 30–39.

MacRae, J., O'Reilly, L., & Morgan, P. (2005). Desirable characteristics of animal products from a human health perspective. *Livestock Production Science*, *94*, 95–103.

Mangnall, M., & Crowe, T. (2001). Managing Egyptian geese on the croplands of the Agulhas Plain, Western Cape, South Africa. *South African Journal of Wildlife Research*, *31*, 25–34.

Mangnall, M. J., & Crowe, T. M. (2002). Population dynamics and the physical and financial impacts to cereal crops of the Egyptian goose (*Alopochen aegyptiacus*) on the Agulhas Plain, Western Cape, South Africa. *Agriculture, Ecosystems & Environment*, *90*, 231–246.

Manner, W., Maxwell, R. J., & Williams, J. E. (1984). Effects of dietary regimen and tissue site on bovine fatty acid profiles. *Journal of Animal Science*, *59*, 109.

Melton, S. L. (1990). Effects of feeds on flavor of red meat: A review. *Journal of Animal Science*, *68*, 4421.

Mendell, I. B., Buchanan-Smith, J. G., & Campbell, C. P. (1998). Effects of forage vs grain feeding on carcass characteristics, fatty acid composition, and beef quality in Limousin-cross steers when time on feed is controlled. *Journal of Animal Science*, *76*, 2619–2630.

Miller, R. K. (2001). *Beef flavor: A white paper.* Centennial, Colorado, USA: National Cattlemens' Beef Association.

Mottram, D. S. (1998). Flavour formation in meat and meat products: A review. *Food Chemistry*, *62*, 415–424.

Næs, T., Brockhoff, P. B., & Tomic, O. (2010). *Statistics for sensory and consumer science*. West Sussex, UK: John Wiley & Sons.

Offer, G., & Trinick, J. (1983). On the mechanism of water holding in meat: The swelling and shrinking of myofibrils. *Meat Science*, *8*, 245–281.

Purchas, R. (1990). An assessment of the role of pH differences in determining the relative tenderness of meat from bulls and steers. *Meat Science*, *27*, 129–140.

Rodbotten, M., Kubberod, E., Lea, P., & Ueland, O. (2004). A sensory map of the meat universe. Sensory profile of meat from 15 species. *Meat Science*, *68*, 137–144.

Sales, J., & Mellett, F. (1996). Post-mortem pH decline in different ostrich muscles. *Meat Science*, *42*, 235–238.

Shahidi, F. (1998). Flavor of muscle foods — An overview. In F. Shahidi (Ed.), *Flavor of meat, meat products and seafoods* (2nd ed.). London, UK: Blackie Academic and Professional.

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

Silva, J., Patarata, L., & Martins, C. (1999). Influence of ultimate pH on bovine meat tenderness during ageing. *Meat Science*, *52*, 453–459.

Snedecor, G. W., & Cochran, W. G. (1980). *Statistical methods* (7th ed.). Ames, USA: The Iowa State University Press.

Swanson, R. B., & Penfield, M. P. (1991). Reindeer meat: Relationship among dietary fat, flavor and acceptability. *Agroborealis*, *23*, 15–19.

Thomas, A.R., Gondoza, H., Hoffman, L. C., Oosthuizen, V., & Naude, R. J. (2004). The roles of the proteasome, and cathepsins B, L, H and D, in ostrich meat tenderisation. *Meat Science*, *67*, 113–120.

Trout, G. R. (1988). Techniques for measuring water-binding capacity in muscle foods — A review of methodology. *Meat Science*, *23*, 235–252.

Tshabalala, P., Strydom, P., Webb, E., & de Kock, H. (2003). Meat quality of designated South African indigenous goat and sheep breeds. *Meat Science*, *65*, 563–570.

Viljoen, P. J. (2005). *AGRED's gamebirds of South Africa, field identification and management.* Houghton, Johannesburg, South Africa: African Gamebird Research Education and Developement Trust.

Viljoen, M., Muller, M., De Swardt, J., Sadie, A., & Vosloo, M. (2001). Computerized electronic temperature control system for thermal efficiency during baking in food research. *International Journal of Consumer Studies*, *25*, 30–42.

Ward, A., Wittenberg, K., Froebe, H., Przybylski, R., & Malcolmson, L. (2003). Fresh forage and solin supplementation on conjugated linoleic acid levels in plasma and milk. *Journal of Dairy Science*, *86*, 1742–1750.

Warris, P. D. (2000). *Meat Science: An introductory text.* Wallingford, UK: CABI Publishing.

Wood, J., & Enser, M. (1997). Factors influencing fatty acids in meat and the role of antioxidants in improving meat quality. *British Journal of Nutrition*, *78*, 49.

Wood, J.D., Richardson, R. I., Nute, G. R., Fisher, A. V., Campo, M. M., Kasapidou, E., et al. (2003). Effects of fatty acids on meat quality: A review. *Meat Science*, *66*, 21–32.

Yancey, E., Grobbel, J., Dikeman, M., Smith, J., Hachmeister, K., Chambers, E., IV, et al. (2006). Effects of total iron, myoglobin, hemoglobin, and lipid oxidation of uncooked muscles on livery flavor development and volatiles of cooked beef steaks. *Meat Science*, *73*, 680–686.

Yu, L., & Lee, Y. (1986). Effects of postmortem pH and temperature muscle structure and meat tenderness. *Journal of Food Science*, *51*, 774–780.