The manipulation of ostrich meat quality, composition and shelf life

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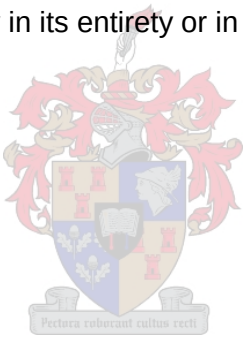
I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.



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ABSTRACT

Two experiments were conducted in order to manipulate the physical and chemical properties and shelf life of ostrich meat.

Experiment 1: **The effect of dietary fish oil rich in *n*-3 fatty acids on the organoleptic, fatty acid and physicochemical characteristics of ostrich meat**.

The diet of four ostrich groups (15 birds per group), approximately 3 months of age (*ca.* 41 kg live weight) grazing a predominantly oats pasture, was supplemented with a diet containing 6.7% fish oil. The birds received a supplement of either 0 (diet 1), 800 (diet 2), 1600 (diet 3) or 2400 g (diet 4) DM/day resulting in the consumption of 0 (diet 1), 14.5 (diet 2), 29 (diet 3) and 43.5 (diet 4) g fish oil per day. The ostriches were slaughtered at 10 months of age (*ca.* 70 kg live weight).

An increase in the amount of fish oil consumed was found to have had statistically no significant effect on the sensory characteristics of the *M. iliofibularis*, although there was a tendency towards an increase in 'fishiness', for both aroma and flavour. However, increased concentrations of fish oil had a significant effect on the aroma and flavour of the abdominal fat pads. The muscle pH_f and muscle lightness (L*) reflected a significant reduction with increased fish oil levels. The increased feed intake, on the other hand, had no effect on the chemical composition (moisture, protein, fat and ash content) of the meat. The fatty acid profile of both fat and meat was affected by the consumption of fish oil. The SFA concentration increased, while the PUFA concentration decreased, with an increase in feed intake. The MUFA concentration remained constant for all four groups.

Experiment 2: **The effect of dietary vitamin E and the type of packaging on the sensory quality, physicochemical composition and shelf life of ostrich meat.**

Two groups of ostriches (35 birds per group; *ca.* 3 months old) were fed diets containing either 40 mg/kg feed vitamin E (control) or 150 mg/kg feed Vitamin E for nine months. The birds were slaughtered at 12 months of age.

The effect of different the levels of vitamin E and heat shrink treatment of vacuum packaging material on the shelf life of refrigerated (0°C) ostrich *M. flexor cruris lateralis,* was evaluated over 81 days. Vitamin E and heat shrink treatments were found to have had no significant effect on the sensory characteristics; off-meat aroma, sourness, juiciness and mealiness. Rancidity was found to be slightly more pronounced (although

not statistical significant) in the vitamin E and heat shrink groups than in the feed control and vacuum-packed groups. A significant decrease in the organoleptic quality of the meat, over a 40 day shelf life period, was observed. The pH and muscle tenderness showed a significant reduction with increased storage time. The purge loss in the package increased over time with no change in muscle drip loss. The colour, conjugated dienoic acid and fatty acid content showed no significant changes over time or with regards to treatment. The total viable counts and coliform numbers in the muscle increased over time, with the coliforms being slightly suppressed by the inclusion of vitamin E in the diet. A microbiological safe shelf life of 40 days at 0°C was obtained.

UITTREKSEL

Twee eksperimente is uitgevoer om die fisiese en chemiese eienskappe, asook die rakleeftyd van volstruisvleis, te manipuleer.

Eksperiment 1: **Die effek van visolie, ryk aan *n*-3 vetsure, op die organoleptiese, vetsuur- en fisies-chemiese eienskappe van volstruisvleis.**
Die dieet van vier groepe volstruise (15 voëls per groep), ongeveer 3 maande oud (*ca.* 41 kg lewende massa) wat 'n hawer weiding bewei het, is aangevul met 'n byvoedingsmengsel wat 6.7% visolie bevat en in toenemende hoeveelhede vir die groepe volstruise gevoer is. Die voëls het 'n aanvulling van 0 (dieet 1), 800 (dieet 2), 1600 (dieet 3) of 2400 g (dieet 4) DM/dag ontvang wat gelei het tot 'n inname van 0 (dieet 1), 14.5 (dieet 2), 29 (dieet 3) en 43.5 (dieet 4) g visolie per dag. Die volstruise is op 'n ouderdom van 10 maande geslag (*ca.* 70 kg lewende massa).

'n Toename in die hoeveelheid visolie ingeneem, het geen statisties betekenisvolle effek op die sensoriese eienskappe van die *M. ilifibularis* gehad nie, alhoewel daar 'n tendens was vir 'n toename tot 'n 'visagtige' aroma en smaak. 'n Toename in die konsentrasie visolie het egter 'n betekenisvolle effek op die 'visagtige' aroma en smaak van die abdominale vet neerslae gehad. Die spier pH_f en spier ligtheid (L*) het 'n betekenisvolle afname met toename in voer inname getoon. Die verhoogde olie inname het egter geen effek op die chemiese samestelling (vog-, proteïen-, vet- en asinhoud) van die vleis gehad nie. Die vetsuurprofiel van beide die abdominale vet neerslae en die vleis is deur die inname van visolie verander. Die versadigde vetsuurkonsentrasie het verhoog terwyl die poli-onversadigde vetsuurkonsentrasie verlaag het met 'n toename in rantsoenvlakke. Die mono-onversadigde vetsuurkonsentrasie het egter konstant gebly vir al vier groepe.

Eksperiment 2: **Die effek van vitamien E en die tipe verpakking op die sensoriese kwaliteit, fisies-chemiese samestelling en rakleeftyd van volstruisvleis**.
Twee groepe volstruise (35 voëls per groep, ongeveer 3 maande oud) het voere oor 'n tydperk van nege maande ontvang wat 40 mg vitamien E/kg voer (kontrole) of 150 mg vitamien E/kg voer bevat het. Die voëls is op 12 maande ouderdom geslag.

Die effek van die verskillende vlakke van vitamien E en hitte-behandeling van die verpakkings materiaal op die rakleeftyd van verkoelde (0°C) volstruis *M. flexor cruris*

lateralis, is oor 81 dae geëvalueer. Vitamien E en die hitte-behandeling het geen betekenisvolle effek op die organoleptiese eienskappe (af-vleis aroma, suurheid, sappigheid en melerigheid) gehad nie. Galsterigheid was ‘n bietjie meer gedefinieerd (anie-betekenisvol) in die vitamien E en hitte behandelde groepe as in die rantsoen kontrole en vakuum verpakte vleis. ‘n Betekenisvolle afname is waargeneem in die organoleptiese kwaliteit van die vleis oor ‘n 40 dae rakleeftyd periode. Die pH en taaiheid van die spier het betekenisvol afgeneem met ‘n toename in bergingsperiode. Die drup verlies tydens verpakking het ook oor tyd toegeneem, terwyl geen verandering in die analitiese drup verlies van die spier verkry is nie. Die kleur, gekonjugeerde dieensuur en vetsuursamestelling het geen verandering oor tyd of ten opsigte van behandeling getoon nie. Die Totale Lewendig Seltelling en coliforme het toegeneem oor tyd, terwyl die coliforme deur die byvoeging van vitamien E tot ‘n mate onderdruk is. ‘n Mikrobiologies veilige rakleeftyd van 40 dae is verkry.

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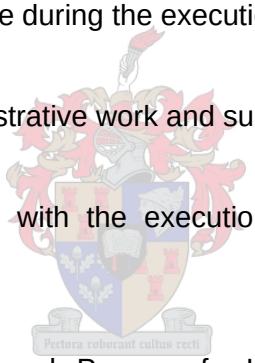

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TABLE OF CONTENTS

LIST OF ABBRIVIATIONS

MUFA	Mono-unsaturated fatty acids
pH_f	Final pH
PUFA	Poly-unsaturated fatty acids
SFA	Saturated fatty acids
VitaE	Vitamin E diet

The common or systematic names of fatty acids and their associated shorthand notations

Common or systematic name	Shorthand notation
Capric acid	C10:0
Lauric acid	C12:0
Myristic acid	C14:0
Pentadecylic acid	C15:0
Palmitic acid	C16:0
Palmitoleic acid	C16:1*n*-7
Heptadecanoic acid	C17:0
Stearic acid	C18:0
Oleic acid	C18:1*n*-9
Linoleic acid	C18:2*n*-6
α-Linolenic acid	C18:3*n*-3
γ-Linolenic acid	C18:3*n*-6
Eicosanoic acid	C20:0
Gondoic acid	C20:1
Arachidonic acid	C20:4*n*-6
Eicosapentaenoic acid	C20:5*n*-3
Behenic acid	C22:0
Docosadienoic acid	C22:2*n*-6
Docosatetraenoic acid	C22:4*n*-6
Docosapentaenoic acid	C22:5n-3
Docosahexaenoic acid	C22:6*n*-3
Lignoceric acid	C24:0
Nervonic acid	C24:1

NOTE

The language and style used in this thesis are in accordance with the requirements of the scientific journal, *Meat Science*. This dissertation represents a compilation of manuscripts where each chapter is an individual entity and some repetition between the chapters has therefore, been unavoidable.

Results from this study have been presented at the following Congresses/Symposia and Journals:

1. Joubert, M., Hoffman, L.C., Muller, M., Brand, T.S. & Manley, M. (2002). Ostrich meat, fish oil: your taste buds will tell it all. In: Proc. Grassland Society of South Africa/South African Society of Animal Science Joint Congress, Christiana, South Africa.
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INTRODUCTION

Commercial ostrich farming was initiated in the late 1800's, with feathers as the primary product (Smith, 1963). Towards 1913, ostrich feathers were as economically pronounced as gold, diamonds and wool, being one of South Africa's most important export products. Shortly after this period, the entire feather market, and thus the ostrich industry, collapsed with the outbreak of the First World War. However, following the Second World War, ostrich farming started to bloom once again. At this stage, leather became an all-important export product. Ostrich meat became a competitive marketing product, when the first ostrich abattoir in South Africa opened in 1967 (Marks, Stadelman, Linton, Schmieder & Adams, 1998). The export of ostrich meat was only started in 1977, when the first batch of meat was exported to Switzerland (Lambrechts & Swart, 1998). Ostrich farming remained within the South African borders untill 1986, but has since become an ever-expanding industry internationally. Today, the ostrich industry relies upon three products: feathers, meat and leather, of which the ostrich meat industry was responsible for 27% of the income in 2001 (Van Zyl, 2001).

The main problem with the ostrich industry to date, is the fact that the ostrich has always been considered as a single-commodity animal (Huchzermeyer, 1998). Firstly it was kept solely for its feathers. Changes in the fashion industry led to the 'discovery' of the ostrich leather and it was promoted as the all-important commodity. The feathers were still traded, but only reflected a small percentage of the overall revenue. When a demand for the meat arose, it was also marketed, even though this was somewhat reluctantly (Huchzermeyer, 1998). A change in fashion, coupled with an overproduction of mainly poor-quality leather, deflated the international leather market. The breeder market collapsed after having reached saturation. The outbreak of Bovine Spongiform Encephalopathy (BSE) and Foot and Mouth disease in large parts of Europe during the year 2000, led to an increased demand for an alternative safe meat source other than beef (Van Zyl, 2001).

Ostrich meat is an ideal substitute for other meat types, due to its colour, aroma, favourable fatty acid profile and low intra-muscular fat content (Lambrechts & Swart, 1998; Sales, 1994). It is also lower in calories and rivals the other meat types with regards to taste, texture and tenderness. Regarding meat production, only the two legs, as well as the neck and the gizzard are of economic importance (Van Zyl, 2001). A live ostrich of 90 kg provides approximately 25 kg of meat, only half of which can be used for exports (Van Zyl, 2001). The ostrich is therefore not a very cost-effective meat source, although the role of ostrich meat in the market-place is significant and cannot be ignored.

The production of ostrich meat in South Africa is still perceived to be uneconomical, due to the high feed conversion ratio of 12,8 for an ostrich between the weight of 60 to 110 kg, and the low meat yield of the ostrich (*ca.* 28%) (Van Zyl, 2001). The inclusion of a high energy feed, such as fish oil, may decrease the feed conversion ratio. Oil is an essential component of the diet of the young ostrich, due to its preventative effect on respiratory diseases (Brand, Joubert, Hoffman, Van der Merwe & Young, 2002).

Fish oil is rich in long chain omega-3 (*n*-3) fatty acids, especially the essential fatty acids docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA) and linolenic acid (Pike, 1999). With some intensively reared animals, diets have become unbalanced in terms of fat composition, especially with regards to polyunsaturated fatty acids (PUFA) (Pike, 1999). The *n*-6 fatty acids had increased, while the *n*-3 fatty acids decreased. By supplementing the ostrich feed with fish oil, rich in *n*-3 fatty acids, a possible enrichment of *n*-3 fatty acids may also be achieved. A ratio of *n*-6:*n*-3 fatty acids of 5:1 is regarded as optimal for good health (Pike, 1999). The lipids in the fish oil improve disease resistance by both moderating the immune reaction to the disease challenges, as well as improving specific immunity (Pike, 1999). The lipids also improve bone formation in birds and enhance growth.

Fish oil may increase the PUFA content of the meat, which will result in a product that is highly susceptible to oxidation. Oxidation is responsible for colour changes as well as the development of rancid flavours and aroma. Vitamin E, an anti-oxidant, may reduce oxidation due to the inclusion of oil in the diet and prolong its shelf life (Halliwell, 1987).

Fish oil may be responsible for changes in the quality and flavour of the meat. Most of the flavour is stored within the fat, which forms a layer in the abdominal cavity of ostriches and is not intra-muscular as with broilers (Sales, 1994). With poultry, up to 2% of fish oil can be incorporated into the diet in the presence of adequate levels of vitamin E, without adversely affecting flavour (Pike, 1999). It is thus important to understand the effect of dietary fish oil on ostrich meat flavour and fat flavour, when fish oil is used as a supplementary feed ingredient.

The ostrich is a production animal with little accumulated knowledge known about any aspect of it, especially as pertaining to meat quality and the manipulation thereof. Pre-harvest management, as well as post-mortem storage, can influence the quality of meat. The inclusion of unrefined dietary fish oil, a relative cheap energy source rich PUFA, may change the fatty acid profile positively, whilst changing the organoleptic properties of the meat negatively and may also lead to oxidation. At this stage, plant oils are used as energy source in a wide range of ostrich diets, while normal diets for slaughter ostriches contain 2.5-3% ether extractable oils (Personal Communication, T.S. Brand, Elsenburg Agricultural Research Centre, Private Bag X1, Elsenburg, 7607).

The inclusion of dietary vitamin E, a well-known anti-oxidant, may reduce oxidation of the meat that is caused by the inclusion of oil in the diets. Vacuum packaging and its heat shrink treatment, also enhances the shelf life of the meat by slowing down oxidation and microbiological spoilage (Pollok *et al.,* 1997). The purpose of this study was twofold:

1) To investigate the effect of dietary fish oil and fish meal on the composition and organoleptic properties of ostrich meat.
2) To investigate the effect of dietary vitamin E, together with the heat shrinking of packaging material versus normal vacuum-packed meat on specifically the microbiological and oxidative shelf life of ostrich meat.

In order to reach these goals, knowledge about the lipid composition of ostrich meat is required, as well as an understanding of the way it may influence the organoleptic properties. It is also important to understand the effect of dietary fish oil, vitamin E and the packaging method on the quality of meat.

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LITERATURE REVIEW

2.1 INTRODUCTION

There is relatively little accumulated knowledge about any aspect of the ostrich as a production animal compared to other traditionally farmed species, especially with regards to meat quality and the manipulation of the composition and the shelf life of the meat. To produce a product that has to compete with other well-known products with established markets, it is important to know and understand the product in order to be able to utilise it to its full potential. Knowledge surrounding the actual chemical and physical composition, as well as the organoleptic properties of the meat, is essential in order to understand the effect of various factors such as dietary fish oil, vitamin E and packaging on the manipulation of the meat's composition and shelf life.

2.2 CHEMICAL COMPOSITION OF OSTRICH MEAT

Ostrich meat has traditionally been marketed as lean meat with a high protein content compared to beef, chicken and pork (Table 1).

Table 1

Mean ranges of the chemical composition of ostrich meat from different sub-species and muscle types.

Component	Content (%)*
Moisture (%)	65.8-77.7
Protein (%)	20.5-22
Fat (%)	0.27-3.1
Ash (%)	1.0-1.25

*References: Harris *et al*. (1993); Horbañczuk *et al.,* (1998); Paleari *et al*. (1998); Sales (1996); Sales & Hayes (1996)

2.2.1 Fat

Ostrich meat has an exceptionally low intramuscular fat content (Table 1), in comparison to other meat types (Sales, 1999), because the main fat deposition takes place in the abdominal cavity of the ostrich carcass. The low overall fat content of ostrich meat makes it a highly sought-after meat product. However, the consumer also evaluates

the eating quality of the meat, where juiciness plays an important role. The absence of fat causes a loss of sustained juiciness during chewing, largely due to the stimulatory effect of fat on the secretion of saliva (Lawrie, 1985) and leaves the consumer with the notion of a dry product.

There are, however, differences between sub-species (Horbañczuk *et al.,* 1998) and the different muscle types (Sales, 1994) as pertaining to the fat content. Horbañczuk *et al.* (1998) noted that the ostrich sub-species of Blue Necks has a higher fat content than the Red Necks for both the *M. gastrocnemius* and the *M. iliofibularis*. Sales (1994) found that the variation in fat content for the different muscle types varies between 0.27% for the *M. gastrocnemius pars interna* and 0.82% for the *M. flexor cruris lateralis*.

2.2.2 Fatty Acids

Ostrich meat is reported to be higher in poly-unsaturated fatty acids (PUFA) than beef, broilers or turkey (Sales, 1996; Paleari *et al.,* 1998). However, the concentration of fatty acids differs between sub-species, muscles within a given species and between fractions within a single muscle (Lawrie, 1985, Sales, 1994). The meat of older animals contains more fat than that of younger animals (Lawrie, 1985) and thus contains a higher percentage of saturated fatty acids (SFA) and less PUFA (Cameron & Enser, 1991). Table 2 indicates the ranges for the fatty acid values of ostrich meat. Age, species and muscle differences are incorporated into the table. These result in a large variation in the proportions of the fatty acids as seen in Table 2.

Hoffman & Fisher (2001) noted differences in the fatty acid content within birds of different ages, but it must be remembered that the majority of commercial birds are slaughtered with a body weight of *ca.* 90 kg (10-14 months of age).

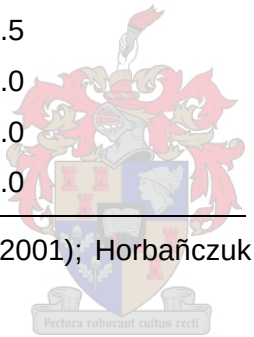
The large variation in data found by the various authors is partly due to the different methods used for extraction, esterification and column attributes. However, some tendencies were noted for all of the data. Oleic acid (C18:1) was found to be present in the highest concentration, followed by palmitic acid (C16:0) and then linoleic acid (C18:2*n*-6). Information is limited with regards to the effect of the diet on the fatty acid composition of ostrich meat.

Table 2

Mean fatty acid ranges for ostrich meat from different ages, species and muscles.

Fatty acids	Contents (g/100 g)*
Saturated:	
C16:0	18.5-26.5
C18:0	11.0-16.5
Mono-unsaturated	
C16:1	3.0-5.5
C18:1	27.0-34.0
C20:1	0.2-1.2
Poly-unsaturated	
C18:2*n*-6	5.0-18.5
C18:3*n*-3	0.4-6.5
C20:3*n*-6	0.4-1.0
C20:4*n*-6	0.9-8.5
C20:5*n*-3	0.4-2.0
C22:5*n*-3	0.3-1.0
C22:6*n*-3	0.5-2.0

*References: Hoffman & Fisher (2001); Horbañczuk (1998); Paleari *et al*. (1998); Sales (1994; 1998)



2.2.3 Moisture, Proteins and Ash content

Paleari *et al.* (1998) and Sales & Hayes (1996) reported higher moisture content values for ostrich meat than for beef, chicken and turkey. Table 1 gives a summary of all of the data obtained by various researchers for the moisture, protein and ash content in ostrich meat from different species and muscle types. Sales (1996) found very slight variation in the moisture content of the different muscles (75.1-77.7%), while Harris *et al.* (1993) found that the moisture content varies between 65.8% and 68.5%, which is about 9% lower than those values noted by Sales (1996).

Protein, composed of amino acids, plays an important role in the growth, maintenance and general functioning of the body, as well as maintaining immunity (Maynard & Loosli, 1969). According to Paleari *et al.* (1998) ostrich meat is slightly higher in protein content, when compared with beef and turkey, though Sales & Hayes (1996) found that beef has a higher protein content than ostrich meat in their comparative study.

The protein content between the different muscle types does not differ. Sales (1996) found 1% difference while Harris *et al.* (1993) found 2% differences, with values being approximately 3% higher than those of Sales (1996). No data could be found for different sub-species.

Sales & Hayes (1996) noted that the ash content of ostrich meat is higher than both beef and chicken. Paleari *et al.* (1998) found that the ash content of beef is higher than that of ostrich meat. Between the different muscle types, slight but significant differences were noted by Sales (1996), with slightly higher variation reported by Harris *et al.* (1993).

2.3 ORGANOLEPTIC AND PHYSICAL PROPERTIES OF OSTRICH MEAT

Meat quality is determined by the consumer, according to a combination of characteristics that define the level of acceptability (Kramer & Twigg, 1962). These include: sensory evaluation regarding the visual appearance when meat is bought; flavour when meat is cooked; and juiciness, taste and tenderness which are evaluated over the short chewing period (Smith, Carpenter, King, & Hoke, 1970).

2.3.1 Tenderness

Jones, Robertson & Brereton (1994) found that ostrich meat, evaluated by means of sensory evaluation, to be more tender than beef. Paleari *et al.* (1998) also found that ostrich meat is more tender than beef and similar to turkey (Table 3). However, Dunster & Scudamore-Smith (1992) found no differences between the species.

Tenderness usually refers to the ease of shearing or cutting during mastication, as well as to the amount of residue remaining in the mouth after chewing (Gillespie, 1960; Forrest, Aberle, Hedrick, Judge & Merkel, 1975). The tenderness of meat depends, among other factors, on the amount and state of three types of protein: the connective tissue (collagen, elastin, reticulin and mucopolysaccharides of the matrix); myofibrils (actin, myosin and tropomyosin); and sarcpolasm (sarcoplasmic proteins and sarcoplasmic reticulum) (Bailey, 1972). Other factors that play a role in tenderness are: the interfibre water content; the extent of the contraction of actin; myosin; and the tropomyosin components of the myofibrils (Currie & Wolfe, 1980).

Table 3

Mean ± standard deviation of colour parameters in raw and cooked meat and tenderness (shear force) in ostrich, turkey and bovine meat (Paleari *et al.,* 1998).

	Ostrich (n=20)	Turkey (n=13)	Bovine (n=10)
Colour parameters:			
Raw meat			
L*	36.74±3.6	46.43±2.8	33.74±2.9
a*	22.84±2.8	19.30±3.2	21.77±3.1
b*	6.57±5.0	3.43±2.0	4.80±1.6
Tenderness			
Shear force (kg/mm^2)	0.027±0.01	0.021±0.01	0.071±0.02

Van Jaarsveld, Naudé & Oelofsen (1997a) suggest that Ca^{2+}-dependent protease (CDP) and lysosomal enzymes are the best candidates in bringing about an increase in tenderness during post-mortem storage. CDP was found to be the major causative factor that produces changes in the myofibrillar proteins during storage. These changes, however, did not lead to any tenderisation of the ostrich muscles that were studied. Cathepsins B, B+L and D were also found to be very stable during storage (2-4°C, 12 days) and may play a role in the tenderisation of meat (Van Jaarsveld, Naudé & Oelofsen, 1997b).

However, data from a study conducted by Sales, Mellett & Heydenrych (1996) suggests that the tenderisation of ostrich meat during post mortem ageing result from proteolysis, which is governed by the action of calpains. Factors such as the rate of glycolysis, ultimate pH and the rate of temperature decline affect meat tenderness due to their influence on the proteolytic systems involved. Marks *et al. (*1998) found that ageing had very little effect regarding tenderness values that were obtained for various muscle types. The *M. iliofibularis* showed slight changes over the period of one week, while the *M. flexor cruris lateralis* did not tenderise at all in this study. Sales *et al*. (1996) also found a tenderisation effect in the *M. iliofibularis,* where the changes were more prominent than noted by Marks *et al*. (1998).

2.3.2 Colour

Colour is frequently defined mathematically by the CIE or Hunter formulas where L* measures the brightness and where a* and b* define the red to green and yellow to blue

axis respectively. Colour is usually the first quality attribute of meat detected by the consumer. The red meat colour is mainly the result of the presence of myoglobin, which accounts for approximately three fourths of the pigment in red meat (Lawrie, 1985). The remainder is the result of haemoglobin (Charley & Weaver, 1998; Levie, 1979). Meat colour is also dependant on external factors such as species, breed, sex, age, nutritional status and exercise (Lawrie, 1985).

Ostrich meat is dark red in colour (Table 3) and, when cooked, is similar in appearance to cooked beef. It is often referred to as 'the other red meat' (Marks *et al,* 1998). Ostrich muscles range from slightly dark red to slightly cherry red, in comparison with the slightly cherry red to moderately cherry red colour of beef (Morris *et al*., 1995; Paleari *et al.,* 1998). The dark colour of ostrich meat, sometimes classified as dark firm and dry (DFD) (Sales, 1999), can be partly explained by its high pH_f (Lawrie, 1985). Pigment content also contributes to the dark colour of ostrich meat. Naudé *et al*. (1979) reported the pigment content of ostrich meat as 104-153 mg Fe/g, compared with 69 mg Fe/g in beef muscle from animals of comparable age.

2.1.3 pH

A striking characteristic of ostrich meat is the relatively high hydrogen ion concentration measured 24 h (pH_f) after the animal is bled. In comparison to beef, ostrich meat can be classified as an intermediate meat type, ranging anything between normal (pH_f=5.5) and extremely dark, firm and dry (DFD, pH_f>6.2) meat types (Sales, 1999). Living muscles have a pH of approximately 7.2, but when the animal dies, glycogen is broken down by anaerobic glycolysis, thus producing lactic acid, which causes a drop in pH (Lawrie, 1985). Normally glycolysis takes place slowly and proceeds to a pH_f of approximately 5.5 after 24 h. If glycolysis takes place very quickly, such meat has a pH_f below 5.5, a light appearance and poor water-holding properties. Conversely, if a slow, slight drop in pH occurs over a period of time, the meat will have a dark colour, high water-holding capacity (WHC) and a limited shelf life. This dark, firm and dry (DFD) condition is associated with the depletion of glycogen in the muscles and it is common in animals that are stressed before slaughter (Hofmann, 1988).

Post mortem glycolysis, as described by the decline in muscle pH, has been investigated in several ostrich muscles (Sales & Mellett, 1996). Whilst the *M. gastrocnemius pars interna, M. femorotibialis medius, M. iliotibialis* l*atereralis* and *M. iliofemoralis* showed the typical pattern of descending pH decline, the *M. ambiens* and *M. iliofibularis* showed a very rapid decline in pH until 2 h post mortem, whereafter the pH again increased.

2.2.4 Water-holding capacity (WHC)

The WHC describes the ability of meat to retain water in the midst of the presence of external forces, such as cutting, mincing and heating. Pre-cooking appearance, cooking ability, juiciness during chewing, tenderness, texture, drip on freezing and the total amount of saleable meat are all influenced by the WHC of the meat (Trout, 1988; Wierbicki, Kunkle & Deatherage, 1957), while the pH and tempo of pH decline influences the WHC of meat (Swatland, 1995). The higher the pH_f, the stronger the WHC and the lower the moisture loss. When a carcass is cut, a red aqueous solution of proteins, known as drip or purge, oozes from the cut surfaces over a period of days, which decreases the value of the meat. The purge loss is a combination of water and water-soluble proteins such as sarcoplasmic protein.

The WHC of the meat is related to the juiciness, as measured by a sensory panel (Penfield & Campbell, 1998). Juiciness is associated with two phases. The first is the impression of wetness during the first few chews and is produced by the release of meat juices. The second is the impression of sustained juiciness, which is affected by the presence of fat. The latter stimulates the secretion of saliva and thus improves juiciness (Lawrie, 1985; Bratzler, 1971). Contradicting this is the fact that consumers prefer leaner meat (Tarrant, 1992).

2.2.5 Flavour and Aroma

Ostrich meat is found to have a fishy, creeky, grassfed beef odour (Otremba, Dikeman & Boyle, 1999). Paleari, Cosico & Beretta (1995) found a characteristic after-taste present in ostrich meat, which is seldom observed in beef. The panel used also considered ostrich meat to be bland. The sensory panel used by Harris *et al.* (1993) also found ostrich meat to have an after-taste and found that it tends to be bland. However, this blandness, may result from the high pH_f and low fat content (Lawrie, 1985) that is characteristic of ostrich meat. This is possibly because the swollen structure, a result of the higher pH, interferes with the access to the palate of the flavour substances involved. Fat and fat-soluble precursors are also important components responsible for the different flavours of the different species of meat (Chang & Peterson, 1977).

Flavour is a complex sensation. It consists of odour and taste and is influenced by texture, pH and temperature (Lawrie, 1985). The most important reactions producing meaty flavours include the pyrolysis of peptides and amino acids, the degradation of sugars, the oxidation, dehydration and decarboxylation of lipids, the degradation of

thiamine and ribonucleotides and reactions involving sugars, amino acids, fats, H_2S and NH_3.

Another important biochemical factor that influences flavour, arises during the 'ageing' or 'conditioning' of meat when it is held for some time after the ultimate pH has been reached. During this period the meat becomes tender and the flavour develops (Lawrie, 1985). However, a gradual loss in flavour occurs due to storage, even under frozen conditions. Undesirable odours and taste may develop during storage as a result of microbial growth, chemical deterioration (on the surface) or tainting by extraneous agents (Peterson, Simone, Lilyblade & Martin, 1959).

Another factor that plays a role in flavour, is age. The dark muscles of older broilers have a more intense flavour than the dark muscle of younger birds (Peterson *et al*., 1959). However, no data could be sourced on the age effect of meat from ostriches raised in the same environment but slaughtered at different ages.

2.4 FISH OIL

Unrefined fish oil is a relative cheap source of energy for animals (Brand, Brand, Nel & Van Schalkwyk, 2000). It is a food product rich in long chain *n*-3 fatty acids, especially the essential fatty acids docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) (Table 4) (Hulan, Ackman, Ratnayake & Proudfoot, 1989; Leskanich, Mathews, Warkup, Noble & Hazzledine, 1997; Pike, 1999). It improves disease resistance by moderating the immune reaction to disease challenges and improving specific immunity. In birds, it is found to improve bone formation, enhance growth and can help with the prevention of respiratory diseases (Brand, Joubert, Hoffman, Van der Merwe & Young, 2002). In ostriches, respiratory disease is a great problem and the risk must be reduced as far as possible. The inclusion of oil in the diet is one way to lower the risk thereof.

However, due to the high levels of MUFA and PUFA in fish oil (Table 4), the latter can be rapidly oxidised to lipid peroxides. It has been reported that plasma and tissue levels of lipid peroxidases increase in animals fed with fish oil (Hu, Frandel, Leibovitz & Pappel, 1989; Kobatake, Hirahara, Innami, & Nishide, 1989; Leibovitz, Hu & Tappel, 1990). Lipid peroxidation is considered to be a pivotal mechanism of cell membrane destruction and cell damage and has been suggested to be associated with the initiation and progression of atherosclereosis (Steinberg, Parthasarathy, Carew, Khoo & Witztum, 1989). Antioxidants and anti-oxidative enzymes protect cells and tissues from oxidative injury (Halliwell, 2000).

Table 4

Fatty acid composition (%) of fish oil (Herstad *et al*., 2000)

Fatty acids	Fish oil
Saturated:	
16:0	15.6
18:0	2.0
Mono-unsaturated	
16:1*n*-7	7.9
18:1*n*-9	13.5
Poly-unsaturated	
18:2*n*-6	1.2
18:3*n*-3	0.8
20:5*n*-3	16.1
22:5*n*-3	2.6
22:6*n*-3	11.8

Fat or lipid oxidation is one of the primary causes of loss in the quality of meat and meat products during storage (Reindl & Stan, 1982). Oxidative rancidity begins shortly after death, and involves the formation of a complex mixture of aldehydes, ketones and alcohols from the breakdown of lipid hydroperoxides (Reindl & Stan, 1982). The flavour and odour of this mixture is unacceptable to consumers. Oxidation of unsaturated fatty acids also adversely affects the colour, texture, nutritive value and safety of meat (Addis, 1986). Vitamin E, a highly effective anti-oxidant, is known to reduce the peroxidative damage caused by fish oil-related lipid peroxidation and therefore fish oil supplementation is usually combined with vitamin E as an anti-oxidant.

It is well known that incorporating fish oils at relatively low levels (10-30 mg/kg diet) can lead to off-flavours and odours (Sheard *et al.,* 2000). Øverland, Tangbøl, Haug, & Sundstøl (1996) found unacceptably high off-flavour and odours emanating in pork, when the animals were fed 1-3 % fish oil. These negative organoleptic attributes were associated with muscle EPA levels of 1.5 to 3.8 g/100g and DHA levels of 1.8 to 2.9 g/100g fatty acids.

It was found that fish oil supplementation significantly reduces atheroma as well as increases glutathione reductase and glutathione peroxidase activities including blood glutathione levels. It was also found that it increases plasma lipid peroxide levels in rabbits (Hsua, Leea & Chen, 2001). Glutathione peroxidase and glutathione reductase are two preventive antioxidants present in healthy tissue that form part of a well-

developed and essentially endogenously controlled defence system. Vitamin E supplementation of a fish oil diet enhances the beneficial effects of the latter, by increasing glutathione reductase activity and decreasing peroxide levels. A high fat and cholesterol diet attenuates blood glutathione levels and plasma antioxidant enzyme activities, which may account for some of its atherogenic properties. Consumption of fish oil enhances anti-oxidative defences against the oxidative stress imposed by hypercholesterolemia and vitamin E further enhances these beneficial effects (Hsua *et al*., 2001).

2.5 MANIPULATION OF MEAT QUALITY AND SHELF LIFE THROUGH THE DIET OF THE ANIMAL

For many years now, researchers have been searching for ways in which to improve meat products in order to be more competitive with the other available meat products. The most general means is by manipulation of the meat through pre-harvest processes for eg. breeding, slaughtering processes and most importantly, through the diet. The main purpose of the manipulation of meat is to improve its quality and shelf life. This normally results in a product with improved nutritional value and higher consumer acceptance.

It is possible to successfully manipulate some of the major properties of meat, such as the PUFA profile, oxidation status, colour, flavour, microbiological safety, pH, tenderness, as well as the drip, purge and cooking loss (Lawrie, 1985). When changing a single property, more than one of the other properties are also frequently changed, which makes the manipulation of meat quality a very complex procedure.

Lipids are needed in the animal diet for the provision of metabolic energy and the production of polar lipids (Reed, 1980). Of all of the nutrients, lipids are the greatest source of energy with 39.2 kJ/g, in contrast with 23.4 kJ/g and 17.2 kJ/g for protein and carbohydrates respectively (Merwyn & Leat, 1983). Lipids are also responsible for the essential fatty acids that are required in the body. They serve as carrier molecules for fat-soluble vitamins and other components, as well as playing an important role in the texture and formation of flavour components in the meat (Coetzee, 2000).

Fats are mainly composed of triglycerides (99%), but also contain a considerable amount of phospholipids, which is a component of the cell membrane (Lawrie, 1985). Meat products that are low in intra-muscular fat, such as veal and ostrich meat, have a very high percentage of phospholipids. Phospholipids are a rich source of PUFA. In pigs, an increase in the intra-muscular fat concentration resulted in an increase in the occurrence of SFA and MUFA, as well as a decrease in the concentration of PUFA (Cameron, & Enser, 1991). The high degree of association between the fatty acids

reveals that when the intra-muscular fat concentration increases, there is a dilution of PUFA by the MUFA and SFA. This dilution is due to the difference in fatty acid composition of the muscle phospholipids and the neutral lipids. The content and composition of phospholipids is relatively constant and consists mainly of PUFA. On the other hand, the neutral lipids in the muscle contain mainly SFA and MUFA (Hughes, 1995).

The diets of humans and intensively reared animals, have generally become unbalanced in terms of fat composition, especially with regards to PUFA (Pike, 1999). The *n*-6 fatty acids have increased, while the *n*-3 fatty acids have decreased. By supplementing the diet with fish oil that is rich in *n*-3 PUFA, the balance can be restored (Hulan *et al*., 1989). A ratio of *n*-6:*n*-3 fatty acids of 5:1 is regarded as optimal for good health for the human (Pike, 1999).

The manipulation of the fatty acid composition of meat through the diet has been successfully performed in monogastric animals (broilers and pigs) and to a lesser extent in ruminants (beef and lamb). Differences in species exist between the monogastric and ruminants for altering tissue fatty acid composition. In poultry and swine, tissue fatty acid composition reflects the fatty acid composition of the diet (Leskanich & Noble, 1997; Mandell, Buchanan-Smith, & Holub, 1998; Miller, Leong & Smith, 1969). In contrast, tissue fatty acid composition in ruminants is influenced by the ability of ruminal micro-organisms to hydrolyse and then to hydrogenate unsaturated fatty acids found in the diet. Swart, Mackie & Hayes (1993) noted that volatile fatty acid production in ostriches is similar to those reported for ruminants.

The increase of *n*-3 PUFA levels (dietary fish meal) in the diet will cause an increase in the accumulation of *n*-3 PUFA's in broilers and pork, particularly EPA, DPA and DHA, at the expense of decreasing levels of *n*-6 PUFA (Leskanich & Noble, 1997). This will lead to a very slight increase in the total fatty acids content, with 3 or more double bonds (the most unstable fatty acids) (Sheard *et al.,* 2000). The reduction of *n*-6 PUFA content when fed a diet rich in C18:3 is presumably a result of the fact that C18:2, the precursor for the *n*-6 PUFA, does not compete as well for the enzyme systems involved in chain elongation and desaturation when C18:3 is present at high levels (Enser, 1995).

The fatty acid composition can, however, only be manipulated to a limited extent (Irie & Sakimoto, 1992). A plateau is reached where the feeding of additional fatty acid rich feed will have no impact. This plateau is reached more rapidly with the feeding of low concentrations of fatty acids than with high concentrations. It is therefore optimal to feed a product rich in *n*-3 fatty acids over a short period of time, in high concentrations (Irie & Sakimoto, 1992). The *n*-3 PUFA concentration increases linearly, with an increase in the amount of fish oil fed to the animal. However, with an increase in the concentration of oil

in the diet, the level of oxidation will also increase (Irie & Sakimoto, 1992). The rate and extent of lipid oxidation are dependent on a number of factors, the most important being the level of PUFA's present in the particular muscle system (Allen & Foegeding, 1981; Cannon *et al.,* 1995; Sheard *et al.,* 2000). Earlier studies concluded that triacylglycerols and phospholipids are important in the development of rancidity in chicken (Igene, Pearson, Dugan & Price, 1980) and fish (Tichivangana & Morrissey, 1982). It is now generally accepted that the phospholipids present in the subcellular membranes (microsomes, mitochondria), rather than the triacylglycerols, are responsible for the initial development of oxidised flavours in raw and cooked meat products during storage (Gray & Pearson, 1987). The phospholipid fraction is highly unsaturated and contains fatty acids with more than two double-bonds. It is therefore not surprising that the phospholipid fraction contributes approximately 90% of the thiobarbituric-acid-reactive substances (TBARS) in chicken fat (Pikul, Leszczynski & Kummerow, 1984).

Oxidation is one of the major processes that is responsible for losses in quality of meat during storage (Pearson, Gray, Wolzak & Horenstein, 1983). As oxidation advances, a continuous decrease in unsaturated fatty acids, particularly linoleic acid, can usually be observed (Crapiste, Brevedan & Carelli*,* 1999). Linoleic and palmitic acids are generally used as indicators of the extent to which fat deteriorates as palmitic acid is more stable regarding oxidation than linoleic acid (Tan, Che Man, Jinap & Yusoff*,* 2001). Oxidation may also be manifested as off-odours and flavours (a warmed-over flavour), detected by sensory panels. It could possibly also manifest as increased peroxide values or oxidative compounds such as malonaldehyde.

The feeding of animals can also have an effect on the myoglobin status of the meat (Lawrie, 1985). A diet rich in PUFA may enhance oxidation, while the inclusion of anti-oxidants may slow oxidation. However, in his study of pigs, Leskanich *et al.* (1997) found that a diet rich in PUFA does not have significant differences with regards to any of the colour parameters. The effect of an anti-oxidant such as vitamin E on meat colour, is significant in animals with a high mioglobin content (for example, beef and lamb) (Chan *et al*., 1996; Giudere, Derry, Buckley, Lynch & Morrissey, 1997).

The intense red colour of fresh meat results from the very high myoglobin pigment content present. The most important form of myoglobin present in fresh meat is the oxymyoglobin, the component responsible for the bright red colour of fresh meat (Lawrie, 1985). A high final pH (pH_f), vacuum packaging and oxidation however, leads to the formation of the unacceptable dark purplish red myoglobin compounds (Jones *et al*., 1994; Lawrie, 1985*)*. At a high pH, the water in the muscle will still be associated with the fibres, which will be tightly packed together, presenting a barrier to diffusion. As a result

of these factors, the layer of bright red oxymyoglobin becomes very thin and metmyoglobin will predominate.

The pH of meat is a very important parameter, since its influence is so widespread. Either directly or indirectly, it influences colour, WHC, juiciness, aroma and flavour and microbial shelf life (Lawrie, 1985). An energy rich diet can increase available glycogen post mortem and therefore decrease the pH_f. Undesirable aspects of DFD (high pH_f) meat, of which ostrich meat is an example, include less acceptable flavour, dark colour, sticky texture, high WHC (low moisture loss) and greater susceptibility to microbiological growth during storage (Bailey, 1986).

The major physiological conditions that might influence quality compared to that of the normal animal are the availability of muscle glycogen, then rate of glycolysis, availability of ATP residues, and pH_f during chilling and freezing and their influence on tenderness, flavour and water binding (Bailey, 1986). The high pH_f will put a restriction on the shelf life of ostrich meat. Meat with a pH_f of near 6.0 is considered to have a very short shelf life, because of possible microbiological spoilage and undesirable odours. Even in evacuated gas-impermeable packs, bacteria will produce H_2S that leads to the formation of green sulphmyoglobin and thus undesirable discoloration. The storage of meat at low temperatures for 10-14 days will, however, increase the tenderness of meat (Lawrie, 1985). The toughening effect during the beginning of rigor mortis is gradually reversed during an increase in the time post rigor (Davey & Winger, 1988). Proteolysis of myofibrillar proteins, including lysosomal as well as non-lysosomal proteins, appears to be a major contributor to meat tenderisation during *post mortem* storage (Dutson & Lawrie, 1974).

A high pH_f leads to short shelf life due to the meat's susceptibility to microbial growth at a high pH. Microbial growth will also induce a lowered pH over time due to lactic acid production from lactic acid bacteria (Otremba *et al.,* 1999). Considering ostrich meat, Otremba *et al.* (1999) found on ostrich meat that aerobic plate counts stayed below 6 log CFU/cm^2 for 21 days, but reached 7.2 log /CFU/cm^2 after 28 days. Lactic acid bacteria on the other hand stayed below 4 log/CFUcm^2 for the duration of a 28 days study. Drip loss increased with time and peaked at 14 days. Off-odours increased over time, reaching unacceptable levels at 21 days. However, Otremba *et al.* (1999) suggest that previously frozen vacuum-packed ostrich meat, should be used within 10 days, due to a decline in consumer acceptability after 14 days. Lawrie (1985) noted that odours produced by microbes growing on meat surfaces are not so objectable as those due to the metabolic products of anaerobes, which tend to be sour rather than putrid.

A study conducted by the International Food Institute of Queensland (IFIQ, Dunster & Scudamore-Smith, 1992), found substantially low initial counts for lactobacillus,

coliforms and total counts on ostrich meat. They also noted that Lactobacilli do not make a significant contribution to the microbial flora, while coliforms do. However, in vacuum packaged beef, the lower pH (5.6) and anaerobic conditions tend to favour Lactobacilli. The IFIQ also found that chilled ostrich meat has a microbiological shelf life of 6 weeks.

The manipulation of the composition of meat holds a number of advantages for man, especially with regards to health. A product low in intramuscular fat content can be obtained, although the essential fatty acids are still present. Secondly, it plays a very important role in the organoleptic properties of meat, such as juiciness, aroma, flavour (López-Ferrer, Baucells, Barroeta & Grashorn, 1999) and colour (Leskanich *et al*., 1997). In general, saturated and mono-unsaturated fatty acids are correlated positively with eating quality, while PUFA's correlate negatively, with the exception of linolenic acid, which shows a positive correlation with juiciness.

2.6 THE EFFECT OF THE PACKAGING METHOD AND VITAMIN E ON THE SHELF LIFE OF MEAT

Vacuum packaging is the most common method recognised by meat processors and retailers in improving the shelf life and safety of meat. However, vacuum packaging leads to a less acceptable dark, purplish colour, due to the exclusion of oxygen (Pollok *et al*., 1997). This colour change is temporary and re-exposure to oxygen will restore the normal red colour of meat due to the conversion of myoglobin to oxymyoglobin. Ostrich meat, a product high in PUFA and with a high final pH (Sales, 1994), is very susceptible to oxidation, which will result in browning and the development of warmed-over and rancid flavours, as well as rapid growth of spoilage bacteria (Pollock *et al*., 1997). The benefits of vacuum packaging can be further enhanced by the heat treatment thereof.

Heat shrinking improves the appearance of the treated pack and has some operational as well as functional benefits over normal vacuum packaging (Pollock *et al*., 1997). Perhaps the most important benefits are associated with product handling: heat shrinking eliminates some excess plastic that enhances purge loss. As a packaging film shrinks in response to heat treatment, it becomes more closely applied to the meat surface. During this process the majority of void spaces into which purge could move during prolonged chilled storage are eliminated. The resulting decrease of the packaging material, helps to reduce the leaker rate and to improve its appearance (Bell, Moorhead & Broda, 2001). Furthermore, as the packaging film shrinks, its thickness increases as does its strength and oxygen barrier properties, helping to reduce the entry of atmospheric oxygen into vacuum packs during storage. The adverse effect of such oxygen entry on chilled meat storage life, has been well-established (Newton & Rigg, 1979). However, in

the particular case of clostridial blown pack spoilage, that reduction in oxygen entry could create in-pack conditions that are more conducive to clostridial growth.

Meat colour and lipid stability are major factors limiting the quality and acceptability of meat and meat products (Arnold *et al*., 1992). Oxidative rancidity begins shortly after death and results in the production of free radicals, which may lead to the oxidation of meat pigments and to the generation of rancid odours and flavours. It also involves the formation of a complex mixture of aldehydes, ketones and alcohols from the breakdown of lipid hydroperoxides (Reindl & Stan, 1982). There is a range of factors that contribute to the oxidation occurring in meat and meat products. These factors include the state and content of pro-oxidants (iron, myoglobin); the levels of antioxidants present in muscle (α-tocopherol and enzymes such as glutathione peroxidase, superoxide dismutase and catalase) as well as the composition and amount of muscle lipids and the storage conditions of meat and meat products (D'Souza & Mullan, 2001; Tichivangana & Morrissey, 1985). The oxidative stability of the muscle depends upon the balance between anti-oxidants, such as α-tocopherol, as well as some carotenoids and pro-oxidants including the concentration of PUFA and free iron in the muscle (Kanner, 1992).

The antioxidant substances are of two types: firstly, preventive antioxidants, which form a well-developed and essentially endogenously-controlled defence system such as the selenium-containing glutathione peroxidase and secondly, the chain-breaking anti-oxidants such as vitamin E (α-tocopherol) (Hoffman-La Roche, 1992). The glutathione peroxidase destroys hydrogen peroxide and peroxides generated in the aqueous phase by dismutation of the superoxide ion by superoxide dismutase. On the other hand, α-tocopherol, which constitutes the second line of defence in biological systems, is the major lipid-soluble anti-oxidant, breaking the chain of lipid peroxidation in cell membranes and preventing the formation of lipid hydroperoxides (Halliwell, 1987). It can also scavenge the superoxide ion, the hydroxyl radical and other free radicals generated during the reaction of hyrogen peroxide with metmyoglobin (Hoffmann-La Roche, 1991).

Faustman *et al.,* (1989) noted that a minimum muscle tissue α-tocopherol concentration level of 0.30-0.35 mg per 100 g meat is necessary in order to extend the shelf life of beef. The effect of vitamin E has been widely studied in pork and broilers (Table 5). Research has shown that meat from pigs, receiving an excess vitamin E supplement as part of their feed, have significantly lower lipid oxidation levels (Cannon *et al*., 1995) and that a combination of vitamin E supplementation, certain cooking conditions and vacuum packaging was extremely successful in inhibiting lipid oxidation.

Vitamin E appears to have several different, but related, functions (Hoffman-La Roche, 1992). One of the most important functions, is its role as an inter- and intra-

cellular antioxidant as seen in Table 5. In this capacity, vitamin E prevents the oxidation of unsaturated lipid materials within the cell (Cannon *et al*., 1995; Halliwell, 1987). If lipid hydroperoxides are allowed to form in the absence of adequate tocopherols, direct cell tissue damage can result. The more active the cell, such as those of skeletal and involuntary muscles, the greater the inflow of lipids for energy supply and the greater the risk of tissue damage if vitamin E is limiting.

Yang, Lanari, Brewster & Tume (2002) found in their study on beef that the vitamin E content of the meat did not change with the ageing of the meat. Oxidation was not influenced by vitamin E in pasture fed animals, but it had a significant effect in grain fed animals, although the vitamin E levels of the meat from both the pasture and grain fed animals was the same, *ca.* 4.5 μg/g tissue.

Table 5

The influence of vitamin E supplementation on pork and poultry meat quality traits.

Meat product	Feed vitamin E (mg/kg feed)	Reduced lipid oxidation[a] (%)	Improved colour[b] (%)	Reference
Fresh pork:				
Steaks	200	73	106	Lanari, Schaefer
	100	76	NS	& Scheller (1995)
	200	77	44	Monahan *et al*.
	100	68	33	(1992)
	200	80	43	Asghar *et al*. (1991)
Fresh poultry:				
Chicken breast meat	120	92		Marusich, Ritter, Ogrinz, Keating, Mirtrovic, & Bunnell (1975)
	100	84		Lin, Asghar,
	100	69		Buckley, Booren, & Flegal (1989)
	100	55		Jensen, Skibsted,
	500	55		Jakobsen & Bertelsen (1995)

[a]decrease in TBARS numbers in supplemented group relative to control group

[b]increae in a-vaues (red colour) in supplemented group relative to control group.

2.7 CONCLUSION

Ostrich meat has an exceptionally low intramuscular fat content relative to other species (Sales, 1994). However, the absence of fat in ostrich meat could cause a loss of sustained juiciness during chewing and might thus give the impression of a dry sensation in the mouth. The percentage of individual fatty acids differs significantly between ostrich muscles and variations are even found within the muscles, but the percentage SFA and PUFA are relatively constant between different muscles. Ostrich meat also has a higher PUFA content than beef, turkey or broilers (Sales,1996; Paleari *et al*., 1998)

The possibility exists that dietary effects could manipulate the fatty acid content of ostrich meat. With fish oil being used in the industry for preventative medicinal purposes in ostrich diets, two questions can be asked. Firstly, will the flavour and odour of ostrich meat change, as has been noted in chicken meat? Secondly, will the fatty acid profile change with increasing consumption of fish oil by the birds?

Ostrich meat tends to have a high pH_f that causes it to frequently be defined as DFD meat. This high pH_f also leads to a shortened shelf life, due to the higher susceptibility of DFD meat to microbiological spoilage.

The purpose of this study was to see if dietary fish oil leads to fishiness regarding the organoleptic attributes of ostrich meat, as found in other meat species. Furthermore, is it possible to change the fatty acid content of ostrich meat through the inclusion of fish oil in the diet? Vitamin E is postulated to have a significant effect on the shelf life of meat, but will this also be true with ostrich meat, especially when used together with vacuum and heat shrink packaging and what is the shelf life of ostrich meat microbiologically?

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THE EFFECT OF DIETARY FISH OIL RICH IN *n*-3 FATTY ACIDS ON THE ORGANOLEPTIC, FATTY ACID AND PHYSICOCHEMICAL CHARACTERISTICS OF OSTRICH MEAT.

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ABSTRACT

The effect of different levels of unrefined fish oil in the diet on ostrich *M. iliofibularis* was evaluated in a completely randomised experimental design, where a supplementary energy rich feed, containing 6.7% fish oil, was fed at four different levels over a 7 month period. An increase in the amount of fish oil consumed was found to have had no significant effect on the sensory characteristics of ostrich meat, although there was a tendency towards an increase in fishiness, for both aroma and flavour. Increased concentrations of fish oil, however, did have a significant effect on the aroma and flavour of the abdominal fat pads. The muscle pH_f and muscle lightness (L*) revealed a significant reduction, with increased energy intake. However, the increased energy intake had no effect on the chemical composition (protein, fat, ash and moisture content) of the meat. The fatty acid profile of both fat and meat was altered as a result of the consumption of fish oil. The SFA concentration increased, while the PUFA concentration decreased with increasing dietary levels. The MUFA concentration remained constant for all four groups.

Keywords: Ostrich, Fish oil, Fatty acids, Sensory evaluation

1. INTRODUCTION

Consumers are becoming increasingly aware of the nutritional quality and health effects of the foods that they consume. The lipid composition, specifically with regards to animal products, has been a primary area of consumer concern. This is due to an increased awareness regarding the link between both the amount and composition of the fat in the human diet and the development of coronary heart disease, as well as certain forms of cancer (Pike, 1999). Most studies involving dietary modification with a view to altering lipid composition of meat products have focused primarily on the manipulation of the total fat content, in order to manipulate specific lipids in the product. Examples of

these would be decreased saturated fatty acids (SFA) or enrichment of foods with fatty acids, such as omega-3 (*n*-3) fatty acids (Hargis & Van Elswyk, 1993). Food sources of *n*-3 fatty acids include fatty fish, rich in eicosapentaenoic acid (EPA, C20:5*n*-3) and decosahexaenoic acid (DHA, C22:6*n*-3), and a small variety of plant and seed oils abundant in α-linolenic acid (C18:3*n*-3).

Various studies have been conducted on the inclusion of fish oil or fish meal in the diet of broilers (Herstad *et al.,* 2000; Hulan, Ackman, Ratnayake & Proudfoot*,* 1988), pigs (Leskanich, Matthews & Warkup*,* 1996; Øverland, Taugbøl, Haug & Sundstøl*,* 1996) and beef (Choi, Enser, Wood & Scollan*,* 2000; Mandell, Buchanan-Smith, & Holub, 1998) in order to try and manipulate the lipid composition of the meat. In all mentioned cases, fish oil was found to have had a positive effect on the fatty acid profile, but a negative effect on the sensory quality of the meat when included in concentrations that were too high for the respective animals.

Oils are also commonly added to ostrich diets as an economic means of producing energy-rich formulations. Of all the different types of oil, unrefined fish oil is by far the cheapest, but is not used due to the unknown effect that it may have on the organoleptic properties of the meat. In this study, four supplementary feed levels, with a fish oil concentration of 6.7%, were fed to different groups of ostriches when grazing a predominantly oat pasture. The influence of the dietary level on various sensory attributes, fatty acids and the physical and chemical properties of ostrich meat were examined.

2. MATERIALS AND METHODS

2.1 Birds and diet

Four groups of ostriches (15 birds per group) of approximately 3 months of age (*ca.* 41 kg live weight) were used in this investigation. The experiment was conducted at the Outeniqua Experimental farm of the Elsenburg Agricultural Research Centre near George, in the Southern Cape area of South Africa. The four ostrich groups received increasing amounts of supplementary feed (Tables 1 & 2) that contained 6.7% unrefined fish oil and 30.7% fish meal for a period of seven months. During this period the birds were maintained on predominantly oat pastures. The treatment groups were rotated

Table 1

Ingredient composition of the supplementary feed supplied to ostriches grazing oat pastures.

Ingredients	Content
Maize meal (%)	38.1
Fish meal (%)	30.2
Soybean oilcake (%)	15.8
Fish oil (%)	6.7
Feed lime (%)	5.8
Salt (%)	1.7
Synthetic methionine (%)	1.5
Mineral and vitamin Premix* (%)	0.2
Vitamin A (IU)	12 000
Vitamin D3 (IU)	3 000
Vitamin E (mg)	40
Vitamin K3 stab (mg)	3
Vitamin B1 (mg)	3
Vitamin B2 (mg)	8
Vitamin B6 (mg)	6
Vitamin B12 (mg)	0.10
Niacin (mg)	80
Pantothenic Acid (mg)	12
Folic Acid (mg)	2
Biotin (mg)	0.20
Choline (mg)	600
Magnesium (mg)	50
Manganese (mg)	120
Iron (mg)	25
Zinc (mg)	80
Copper (mg)	8
Cobalt (mg)	0.10
Iodine (mg)	1
Selenium (1%) (mg)	0.30

*values for different vitamins and minerals noted per kg feed

frequently to cancel any potential paddock effects.Diet 1 (D1), the control, did not include any supplementary feed. The total oil content treatments are summarised in Table 2.

The birds were slaughtered at approximately 10 months of age (*ca.* 70 kg live weight). They were slaughtered and dressed according to standard South African techniques at a European Union approved abattoir (HACCP and British Retail Consortium accredited).

Strips of fat were removed from the abdominal cavity of the ostriches and immediately frozen at a temperature of –18°C. The pH and temperature (handheld Crison pH/mV-506 pH meter equipped with a glass electrode) of the *M. iliofibularis* was taken 45 min after exsanguination. Thereafter, the whole, intact carcasses were cooled at *ca.* 4°C for 24 h in a cooling chamber before deboning. The pH and temperature was taken repeatedly (6 readings) after exsanguination over the next 18 hours, until deboning. The *M. iliofibularis* from both the right and left hand side of the carcass, was removed, trimmed and vacuum-packed. The *M. iliofibularis* of the right leg was kept chilled at *ca.* 4°C for the duration of the sensory evaluation. The *M. iliofibularis* of the left leg was kept at 4°C, until the completion of the physical analysis and the mincing that followed (within three days after deboning). The samples were then frozen at *ca.* -20°C, for further chemical analysis.

Table 2

Oil content of different supplementary diets as fed to different experimental groups of ostriches.

Groups	Fish oil (g/d)	Oil from fish meal (g/d)	Total oil consumed per day (g/d)	Equivalent* oil in a complete feed (%)
D1 (0%)	0	0	0	0
D2 (0.6%)	10	4.5	14.5	0.6
D3 (1.2%)	20	9.0	29.0	1.2
D4 (1.8%)	30	13.5	43.5	1.8

*Based on the intake of 2 400g DM/feed/day

2.2 Preparation of meat for sensory analysis

For sensory evaluation, a meat slice of 12 mm thickness, which was cut cross sectional to the muscle fibres, was taken from the middle of the *M. iliofibularis*. Each sample was placed on an aluminium foil coated metal rack in an oven bag. A thermocouple was inserted in the centre of the sample and the meat was roasted in a preheated oven at 180°C, to an internal temperature of 73°C. Thereafter, the sample was cut into *ca.* 1x1x1 cm samples, folded in aluminium foil, placed in a preheated glass ramekin and presented to the panel members.

The fat strips from the different groups were thawed for an hour, placed into individually marked oven bags and then roasted for 10 minutes in a preheated oven at 180°C. The fat was cut into smaller portions, folded in aluminium foil, placed in preheated glass ramekins and presented to the panel members.

Five randomly chosen muscles and fat strips from each of the four groups were used for the five repetitions of the evaluation. Every sample was marked with a different, randomly chosen, three-digit code number. The order of the samples was randomised for each session and each panellist (AMSA, 1978).

2.3 Sensory evaluation

The panel consisted of 5 individuals (experienced in the sensory evaluation of meat) that were trained during three sessions, according to AMSA (1978). Two broilers, fed 15% and 30% fish meal respectively, were used as reference standards in order to familiarise the panel with a fishy aroma and flavour. The panellists were also introduced to the four groups of ostrich meat and fat. A questionnaire was compiled during the first training session, refined and tested during the second training session.

A 0-100 mm unstructured line scale was used to determine the difference between meat samples. This scale depicted the attributes, aroma, flavour and tenderness as well as juiciness with regards to chewing and pressing between fingers (Table 3). For the fat samples, the same type of scale was used, although only the attributes aroma and flavour were evaluated.

Four days after slaughtering, the meat and fat were evaluated during five sessions, over a period of three days. Each sample was tested individually, for all attributes. The panellists were all seated in white individual booths, in order to reduce distraction. They were asked to evaluate the samples in the order presented and to refresh their mouths between each sample, by means of distilled water and Carr's Table Water Biscuits and for the fat samples, also with a slice of apple. They cleaned their hands with a damp cloth between each sample, and with a new cloth for each set of samples. Their hands were dried with a disposable paper towel.

In determining aroma, samples were smelled immediately after opening the aluminium foil. The meat samples were then placed in the mouth and evaluated (Table 3), after which they were either swallowed or expectorated into the containers provided. The flavour of the fat was evaluated by tasting the fat from the finger after touching each sample with a different finger.

Table 3

Definitions of terms used on a scale from 0-100 mm in the sensory analysis of ostrich meat.

Attribute	Attribute definitions

Aroma*	Smell that you get immediately after removing the foil with regards to fishiness. Meat: (none to slightly fishy aroma) Fat: (none to prominent fishy aroma)
Flavour*	Combination of taste and swallowing with regards to fishiness. Meat: (none to minimal fish flavour) Fat: (none to prominent fishy flavour)
Juiciness – touch[#]	Amount of juice that remained on fingers after pressing meat between two fingers. Meat: (dry to slightly juicy)
Juiciness – mouth[#]	Degree/amount of moisture within the sample, released after chewing three times. Meat: (dry to juicy)
Tenderness[#]	Force required for compressing the sample of meat between molar teeth after chewing 10 times. Meat: (tough to tender)

* Higher values indicate a stronger fishy attribute.

[#] Higher values indicate a more positive attribute.

2.4 Physical analysis

Meat slices of *ca.* 12 mm thick were cut cross sectional to the muscle fibre for the determination of cooking loss, drip loss and colour, respectively, on the fresh muscle (4°C, 48 h post mortem). The colour of the fresh meat was evaluated after a blooming period of 30 min, by using a hand-held Gardner Colorimeter in order to determine CIELab L*, a* and b* values, indicating brightness, the red-green range and the blue-yellow range, respectively. The hue [$Hue=\tan^{-1}(b^*/a^*)$] and chroma {$Chroma=[(a^*)^2+(b^*)^2]^{1/2}$} were also calculated. For the drip loss determination, meat samples with a known weight were placed in netting and suspended in an inflated bag. After a storage period of 24 h at *ca.* 4°C, the samples were weighed again and drip loss was expressed as a percentage of the initial weight of the sample (Honikel, 1998). For cooking loss determination, the freshly cut (12 mm thick) and weighed sample (initial weight), was placed in a water-bath at *ca.* 75°C. After one hour the samples were removed from the water-bath and cooled in cold water. The meat was removed from the packaging material, blotted dry and weighed (Honikel, 1998). Cooking loss was expressed as a percentage of the initial sample weight.

The shear force measurements of the cooked meat samples (same samples as used for cooking loss determination) were obtained with a WBS attachment, fitted to an Instron Universal Testing Machine (Model 4444). These readings were taken within 24 h of cooking. Three randomly sampled cylindrical cores were cut from the centre of each meat sample, using a 12.7 mm diameter bore. Maximum Warner Braztler Shear (WBS) values (N) required to shear these cores of cooked muscle, perpendicular to the muscle fibre longitudinal axis (at a crosshead speed of 200 mm/min), were recorded for each sample and the mean was calculated for each muscle. A larger value indicated greater shear force and therefore, tougher meat.

2.5 Chemical analyses

The chemical composition of the *M. iliofibularis* was determined according to AOAC standard techniques (AOAC, 1995). The analyses included moisture (105°C, 24 h), protein (N x 6.25) and ash (550°C, 5 h) determinations. Total lipid content was determined according to the method (using chloroform/methanol 2:1 as solvent) of Lee, Trevino & Chaiyawat (1996).

The fatty acid profiles of the *M. iliofibularis*, abdominal fat pads, fish oil and the diet were determined. The fatty acid extraction was performed according to Folch, Lees & Sloane-Stanley (1957), while the methylation process was performed according to the method described by Butte (1983). The gas chromatograph used was a Hewlett Packard 5890 series II, equipped with a flame ionisation detector and a Supelcowax 10 fused glass capillary column (30 m X 0.53 mm id. with nitrogen as a carrier gas at a flow rate of 2 ml/min). The oven temperature increased from 120°C (held for 3 min) at a rate of 3°C/min to 225°C (held for 10 min) and then to 245°C again at a rate of 3°C/min, where it was maintained until all peaks were eluted. A 1 μl sample was injected at a split ratio of 1:50 with an inlet temperature of 230ºC.

2.6 Statistical analysis

Analysis of variance was performed on the variables of the sensory analysis, using the general linear models (GLM) procedure of SAS (1990). The sensory analysis consisted of four treatment (diet) combinations, each replicated five times by five panel members, in a completely randomised design. An effect with a probability smaller than 0.05 % ($P<0.05$) was considered to be significant.

The effect of the feed on the physical and chemical properties (except for pH) of the meat was evaluated by analyses of variance, using the Anova Linear Models procedure of

SAS Enterprise Guide (SAS, 1990). The least significant difference was calculated at a 5% significance level to compare the treatment means for significant effects.

It was assumed that pH decline would follow a pattern over time. The effect of fish oil supplementation on pH changes over a period of time was modelled by way of using cubic splines (Gilmour, Dullis, Welham & Thompson, 1999). The fixed linear and random non-linear components of the spline were interacted with the diet, in order to detect differences in trends over time. The analysis was complicated by the fact that the same carcass was sampled repeatedly. This complication was accounted for by the inclusion of the random effect of carcass, in the model of analysis. This effect was found to be very small and not significant (P>0.05). It was thus assumed that the covariance arising from the sequential sampling of the same carcass was sufficiently small to allow analysis of variance procedures.

3. RESULTS AND DISCUSSION

3.1 Sensory evaluation

The aroma and flavour of the meat from the different groups of ostriches showed no significant difference (P>0.05), although there was a tendency for a higher fishy attribute with increasing dietary fish oil or fish meal intake (Table 4) (aroma: y= 0.047X+11,54 R^2=0.0044; flavour: y=0.124X+5.30 R^2=0.029)). Otremba, Dikeman & Boyle (1999) described the typical aroma of cooked ostrich meat as similar to a “fishy”, “creaky”, “grass-fed beef” odour, although it is not clear whether their birds had received either fish oil or fish meal in their diets. The slight fishiness that was detected in the aroma and flavour of the meat for all dietary groups (Table 4) could be a result of the natural fishy aroma of ostrich meat and/or the inclusion of fish oil in the diet of the ostriches. The aroma and flavour mean values for the fat as perceived by the panel, showed that fishiness increased significantly (P<0.05) with an increase in the amount of fish oil in the diet (Table 5).

Table 4

Mean values of sensory evaluation as obtained from a 100 mm unstructured line scale for ostrich meat from birds consuming increasing levels of fish oil.

Attribute	Dietary groups				LSD (P=0.05)
	D1 (0)	D2 (0.6)	D3 (1.2)	D4 (1.8)	
Aroma*	9.79	13.32	12.20	13.67	9.74
Flavour*	4.92	7.21	9.38	7.59	5.51

Tenderness[#]	60.12	56.76	61.24	61.00	11.76
Juiciness-touch[#]	44.24 [ab]	53.56 [a]	39.04 [b]	50.75 [ab]	13.78
Juiciness-mouth[#]	45.16	53.24	44.96	50.79	14.14

a-b Values in the same row with different superscripts differ significantly (P<0.05)

* Higher values indicate a stronger fishy attribute.

[#] Higher values indicate a more positive attribute.

Meat from the four different treatments did not differ significantly (P>0.05) in tenderness (Table 4). The mean tenderness value was, however, lower for D1 and D2 than for D3 and D4. These tenderness values indicate that panel members used the upper part of the scale (all values above 50), indicating that the meat was perceived as tender and not tough. This was verified by the results (Table 9) obtained from the physical analyses of the meat, by means of a Warner-Bratzler shear force apparatus, where also no significant difference was found between the meat samples. It thus seems that the inclusion of fish oil in the diet of ostriches does not have any effect on the tenderness of meat. This correlates with the results found by Mandell *et al.* (1998), who studied the effect of fish meal on beef. However, Leskanich *et al.* (1996) found by means of sensory analysis of pork, an increase in tenderness with the inclusion of fish oil in the diet.

The meat from the four different groups differs significantly (Table 4) with regards to juiciness (-touch), as perceived through the pressing of the meat between the fingers. The significant difference obtained is due to the samples of D3 that revealed exceptionally low values. The reason for this is however, not clear. Juiciness as perceived through chewing, however, showed no significant difference between samples from the different treatments (Table 4).

Table 5

Mean values of sensory evaluation as obtained from a 100 mm unstructured line scale for ostrich fat from birds consuming increasing levels of fish oil.

Attribute	Dietary groups				LSD (P=0.05)
	D1 (0)	D2 (0.6)	D3 (1.2)	D4 (1.8)	
Aroma*	21.32 [c]	47.48 [b]	62.56 [ab]	65.80 [a]	17.448
Flavour*	22.00 [c]	37.12 [bc]	52.08 [ab]	65.60 [a]	17.457

a-c Values in the same row with different superscripts differ significantly (P<0.05)

* Higher values indicate stronger fishy attribute.

3.2 Fatty acids

The fatty acids with the highest concentration found in ostrich meat are oleic acid (C18:1*n*-9) and palmitic acid (C16:0), followed by linoleic acid (C18:2*n*-6) and stearic acid (C18:0) (Table 6). For the fat samples, these fatty acids were C16:0, followed by C18:1*n*-9 and C18:2*n*-6 (Table 7). However, Sales (1994) found in his study higher values for C18:1*n*-9 (28.33 mg/g) than those found for the control samples of this study. In this investigation, the saturated fatty acids (SFA) was approximately 40% in the muscle and 50% in the fat pads. The SFA, especially the fatty acids C16:0 and C14:0, also increased with an increase in fish oil consumption.

Differences exist between monogastrics and ruminants for altering tissue fatty acid composition. In poultry and swine, tissue fatty acid composition reflects the fatty acid composition of the diet (e.g. Mandell *et al.,* 1998). In contrast, tissue fatty acid composition in ruminants is influenced by the ability of ruminal micro-organisms to hydrolyse and then hydrogenate the unsaturated fatty acids found in the diet. The results from this study suggest that ostriches metabolise fatty acids in the same way as ruminants. Swart, Mackie & Hayes (1993) also noted that volatile fatty acid production in ostriches is similar to those reported for ruminants.

The C16:0 fatty acid in fish oil is present in very high concentrations, together with C16:1*n*-7, C18:1*n*-9 and C22:6*n*-3 (Table 6). For the total mono-unsaturated fatty acids (MUFA) in the muscle, no change in fatty acid concentration was observed. However, C16:1*n*-7 increased proportionally in both the fat and meat, with an increase in the fish oil contents of the diet. C18:1*n*-9, on the other hand, decreased significantly in the meat. As expected, the poly-unsaturated fatty acids (PUFA) were more concentrated in the meat than in the fat (Tables 6 & 7). A decrease in the total concentration of PUFA's was detected with the increase in the amount of fish oil in the diet, which is primarily due to the decrease in *n*-6 PUFA's, which include C18:2*n*-6, C18:3*n*-6 and C20:4*n-6*. The *n*-3 fatty acids, C20:5*n*-3 and specifially C22:6*n*-3, reflected an increase with an increase in fish oil concentration.

It is well known that incorporating fish oils at relatively low levels (10-30 mg/kg diet), in especially monogastric animal diets, can result in off-flavours and odours in the meat (Sheard *et al.,* 2000). Øverland *et al.* (1996) found unacceptably high off-flavour and odours at 10-30 g fish oil/kg feed in pork, associated with muscle EPA levels of 1.5 to 3.8 g/100g and DHA levels of 1.8 to 2.9 g/100g fatty acids. This was, however, not found in this study. In the fat samples, a fishy aroma was detected in all four samples, with EPA levels that vary from to 0.11 to 0.3 g/100g and DHA levels that vary between 0.2 to 1.53 g/100g fatty acids. In the meat samples, there were no fishy aroma detected at all. The

EPA values were between 1.21 and 4.80 and the DHA levels between 1.22 to 3.43 g/100g fatty acids. This would seem to indicate that EPA and DHA are not the only factors responsible for a fishy aroma in meat as postulated before.

The feeding of *n*-3 PUFA to animals with the purpose of improving the meat quality for human nutrition also increases the susceptibility of the meat to oxidation (Sheard *et al.,* 2000). Oxidation may manifest as off-odours and flavours, detected by sensory panels or chemically as increased peroxide values or secondary oxidative compounds (for example, malonaldehyde). As oxidation advances, a continuous decrease in unsaturated fatty acids, particularly oleic (C18:1), linoleic acid (18:2) and linolenic acid (18:3) can usually be observed (Crapiste, Brevedan & Carelli, 1999). The susceptibility and rate of oxidation of these fatty acids increase in relation to their degree of unsaturation (Gunstone, 1996). A significant decrease in the concentration of both C18:3*n*-3 and C18:3*n*-6 was detected in the meat, as well as the fat (Tables 6 & 7). The fat showed only a slight decrease in C18:2*n*-6, while the meat revealed a highly significant decrease. No change was found for C18:1*n*-9 in the meat sample, while a slight decrease in the fat samples was detected.

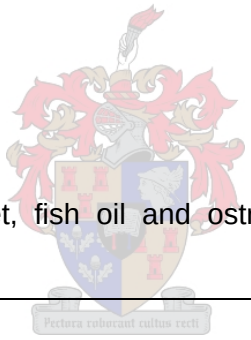


Table 6

The fatty acid profile of the diet, fish oil and ostrich meat (mean ± SE) consuming increasing levels of fish oil.

Fatty Acids (%)	Feed	Fish oil	Diets			
			D1 (0%) (n=11)	D2 (0.6%) (n=15)	D3 (1.2%) (n=12)	D4 (1.8%) (n=13)
SFA (Saturated Fatty Acids)						
C10:0	2.11	0.0	1.67±0.45	1.78±0.39	0.81±0.43	1.51±0.43
C12:0	1.82	0.9	0.00±0.03^{a}	0.04±0.03^{ab}	0.08±0.03^{ab}	0.09±0.03^{b}
C13:0			0.41±0.51	1.10±0.44	0.45±0.49	0.43±0.47
C14:0	0.0	0.0	0.75±0.20^{a}	0.97±0.17^{a}	1.67±0.19^{b}	2.62±0.19^{c}
C15:0	0.85	1.19	0.11±0.08	0.07±0.07	0.25±0.07	0.10±0.07
C16:0	34.98	37.18	21.73±1.07^{ab}	19.32±0.92^{a}	24.49±1.03^{b}	24.18±0.99^{b}
C17:0	0.0	0.0	0.97±0.17^{a}	0.83±0.14^{a}	0.80±0.16^{a}	0.16±0.16^{b}
C18:0	5.53	4.82	14.08±0.66^{ab}	15.19±0.57^{a}	13.36±0.63^{b}	13.19±0.61^{b}
Total SFA	45.3	44.1	39.73±0.77^{ab}	38.07±0.66^{b}	40.25±0.77^{a}	42.45±0.69^{c}
MUFA (Mono-unsaturated Fatty Acids)						
C15:1	0.0	0.0	0.12±0.07	0.03±0.06	0.19±0.07	0.11±0.07

C16:1*n*-7	13.79	25.5	3.51±0.42^{ab}	2.94±0.36^{a}	4.51±0.41^{b}	5.91±0.39^{c}
C17:1	5.53	0.0	0.71±0.34^{ab}	1.05±0.29^{a}	0.55±0.32^{ab}	0.10±0.31^{b}
C18:1*n*-9	13.86	17.11	21.15±0.78	20.37±0.67	21.62±0.75	21.95±0.72
C20:1	0.0	0.0	1.96±0.57^{a}	0.21±0.48^{b}	0.27±0.54^{b}	0.27±0.52^{b}
Total MUFA	33.2	42.6	27.27±1.13^{ab}	24.79±0.97^{b}	27.59±1.13^{ab}	27.92±1.00^{a}
PUFA (Poly-unsaturated Fatty Acids)						
C18:2*n*-6	1.52	2.61	18.06±0.84^{a}	18.03±0.72^{a}	14.52±0.86^{b}	14.38±0.78^{b}
C18:3*n*-3	0.0	1.15	5.76±0.36^{a}	3.08±0.31^{b}	3.82±0.35^{b}	3.45±0.33^{b}
C18:3*n*-6	0.0	1.59	0.59±0.16^{a}	0.09±0.13^{b}	0.02±0.15^{b}	0.00±0.14^{b}
C20:4*n*-6	0.0	0.0	6.15±0.77^{a}	8.91±0.66^{b}	7.16±0.74^{ab}	5.36±0.71^{a}
C20:5*n*-3	0.0	1.87	1.21±0.76^{a}	3.26±0.54^{b}	4.80±0.73^{b}	2.86±0.70^{b}
C22:6*n*-3	4.72	6.16	1.22±0.55^{a}	2.65±0.47^{ab}	2.16±0.52^{ab}	3.43±0.50^{b}
Total PUFA	6.24	13.4	32.99±1.22^{a}	37.16±1.05^{b}	32.20±1.22^{ac}	29.62±1.08^{c}

a-c: Values in the same row with different superscripts differ significantly (P<0.05)

Table 7

The fatty acid profile of feed, fish oil and ostrich fat (mean ± SE) consuming increasing levels of fish oil.

Fatty Acids (%)	Feed	Fish oil	Diets			
			D1 (0%) (n=11)	D2 (0.6%) (n=15)	D3 (1.2%) (n=12)	D4 (1.8%) (n=13)
SFA						
C10:0	2.11	0.0	0.14±0.07	0.04±0.06	0.03±0.07	0.15±0.07
C12:0	1.82	0.9	0.54±0.14^{a}	0.81±0.13^{ab}	0.57±0.14^{a}	1.02±0.14^{b}
C14:0	0.0	0.0	1.32±0.59^{a}	4.07±0.52^{b}	4.98±0.59^{b}	5.34±0.56^{b}
C15:0	0.85	1.19	1.13±0.07^{a}	1.15±0.06^{a}	0.93±0.07^{b}	1.05±0.07^{ab}
C16:0	34.98	37.18	32.50± 0.70	32.55± 0.63	33.47± 0.70	32.96± 0.68
C17:0	0.0	0.0	1.37±0.28^{a}	0.85±0.25^{ab}	0.90±0.28^{ab}	0.50±0.27^{b}
C18:0	5.53	4.82	9.71±0.44^{a}	9.44±0.39^{a}	6.93±0.44^{b}	6.95±0.42^{b}
C22:0	0.0	0.0	0.00±0.34^{a}	0.94±0.30^{b}	2.59±0.34^{c}	3.41±0.32^{c}
Total SFA	45.3	44.1	46.71±0.80^{a}	48.92±0.72^{b}	47.80±0.80^{ab}	47.96±0.77^{ab}
MUFA						
C15:1	0.0	0.0	0.59±0.05^{a}	0.38±0.04^{b}	0.34±0.05^{b}	0.43±0.05^{b}

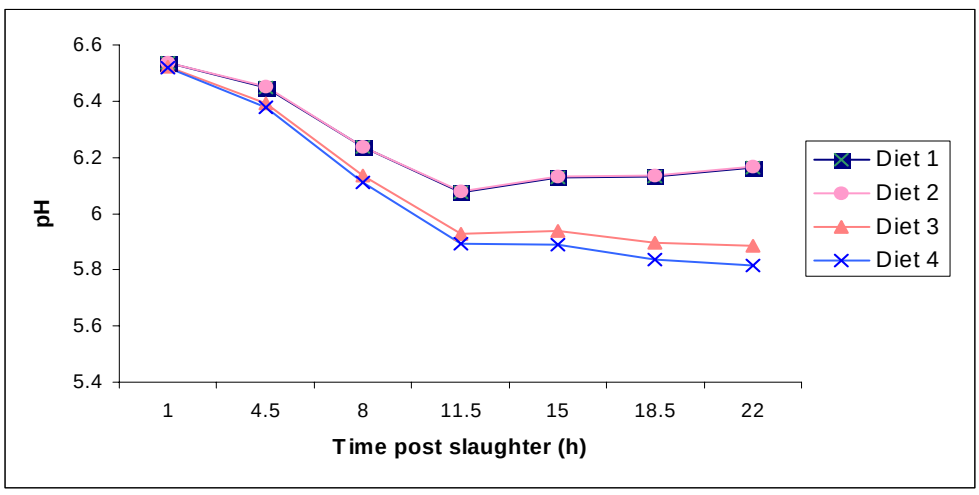
C16:1*n*-7	13.79	25.5	5.39±0.40^{a}	6.33±0.35^{a}	8.67±0.40^{b}	9.07±0.38^{b}
C17:1	5.53	0.0	0.88±0.17^{a}	0.38±0.16^{b}	0.33±0.17^{b}	0.28±0.17^{b}
C18:1*n*-9	13.86	17.11	22.77±0.68^{a}	20.72±0.61^{b}	20.41±0.68^{b}	19.38±0.65^{b}
C20:1	0.0	0.0	0.14±0.12^{ab}	0.42±0.10^{a}	0.09±0.12^{b}	0.29±0.11^{ab}
Total MUFA	33.2	42.6	29.77±0.87	28.23±0.78	29.84±0.87	29.44±0.84
PUFA						
C18:2*n*-6	1.52	2.61	10.80±0.59^{ab}	12.00±0.53^{a}	10.28±0.59^{b}	10.07±0.57^{b}
C18:3*n*-3	0.0	1.15	9.97±0.64^{a}	8.44±0.58^{ab}	7.56±0.64^{b}	6.59±0.62^{b}
C18:3*n*-6	0.0	1.59	0.36±0.07^{a}	0.23±0.06^{ab}	0.17±0.07^{ab}	0.16±0.07^{b}
C20:4*n*-6	0.0	0.0	1.95±0.54^{a}	0.37±0.48^{b}	0.23±0.54^{b}	0.56±0.52^{ab}
C20:5*n*-3	0.0	1.87	0.16±0.09	0.11±0.08	0.11±0.09	0.30±0.09
C22:6*n*-3	4.72	6.16	0.21±0.13^{a}	0.73±0.12^{b}	1.33±0.13^{c}	1.53±0.13^{c}
Total PUFA	6.24	13.4	23.52±0.91	22.86±0.82	22.28±0.91	22.61±0.88

a-c: Values in the same row with different superscripts differ significantly (P<0.05)

3.3 Physical and Chemical Analysis

Ostrich meat is generally classified as a dark, firm and dry (DFD) meat type due to its high final pH (pH_f) of around 6.0 (Sales & Mellet, 1996), which is seen as the distinguishing feature between normal and DFD meat. DFD is a condition found in meat with deficient glycogen levels (Newton & Gill, 1981). Significant differences were detected in the pH_f values (Figure 1) of the *M. iliofibularis,* between the different dietary groups. An increase in the amount of fish oil in the diet, led to a decrease in the pH_f values. This is an indication that the diet was a rich source of energy and that glycogen accumulated in the muscles of the dietary group consuming the larger amount of supplementary feed, to a greater extent than in the control group that had received no supplementary feed.

Figure 1. The changes in pH post mortem of ostrich *M. iliofibularis* of birds receiving diets



containing different fish oil levels, measured over a 24 h period.

The pH_f is one of the most important post-slaughtering factors influencing the colour of meat. A high pH_f, as found in ostrich muscles, results in a dark purplish-red colour (Lawrie, 1985). At such high pH values, the water in the muscle will still be associated with the fibres, which will be tightly packed together, presenting a barrier to diffusion. As a result of these factors, the layer of bright red oxymyoglobin becomes very small and metmyoglobin will predominate, resulting in the dark colour. Diet 3 & 4 had the lowest pH_f, but the highest L* values (Table 8) – a result consistent with the phenomenon of DFD and non-DFD meat. The latter has a lower pH_f and lighter colour (Lawrie, 1985). The b* values did not differ between the groups, while a significant difference could be detected for the a* values, due to a very low value obtained for the meat of D2. Leskanich, Mathews, Warkup, Noble, & Hazzledine (1997) found in their study on pork that there were no significant differences in any of the meat colour values between pigs receiving different diets with increasing levels of PUFA. The values obtained in this study, differ slightly from those of Hoffman & Fisher (2001) who found lower a* (5.48) and b* (3.51) values for 14 month old ostriches. However, the results for their L* values (29.42) are similar to those found in this study. The hue values did not change significantly, while the chroma values showed a difference, due to the low b* values obtained for D2. However, there is a tendency for the chroma values to decrease with an increase in fish oil consumption.

Table 8

Mean values for the physical properties of ostrich *M. ioliofibularis* of birds receiving different levels of fish oil in their diets.

Physical parameters	Diets			
	D1 (0.0) (n=11)	D2 (0.6) (n=15)	D3 (1.2) (n=12)	D4 (1.8) (n=13)
Colour *L	30.91±0.48[a]	30.04±0.44[a]	33.39±0.48[b]	33.07±0.46[b]
*a	14.45±0.32[a]	13.32±0.30[b]	13.89±0.32[ab]	13.78±0.31[ab]
*b	8.78±0.27	8.22±0.25	8.83±0.27	8.58±0.26
hue	30.83±0.92	31.612±0.74	32.42±0.84	31.95±0.80
chroma	17.19±0.37[a]	15.690±0.30[b]	16.47±0.33[ab]	16.26±0.32[ab]
Shear force (N)	107.97±5.27	95.14±4.88	102.19±5.27	96.47±5.06
Cooking loss	62.99±088[ab]	65.13±0.81[a]	62.91±0.88[ab]	62.58±0.84[b]

Drip loss	2.19±022	2.07±0.21	2.45±0.22	2.56±0.21

a-b: Values in the same row with different superscripts differ significantly (P<0.05)

No significant changes were detected for the cooking loss and drip loss (Table 8) with increasing fish oil intake. Swatland (1995) noted that the pH and tempo of pH decline have a significant effect on the water holding (WHC) capacity of meat. The higher the pH_f, the stronger the WHC and the lower the moisture loss that occurs. Higher drip and cooking losses were therefore expected for the samples from diets 3 and 4. Although not significant, diets 3 & 4 had higher drip losses. No dietary effect was detected for the cooking loss.

In Table 9, the proximate chemical compositions of the ostrich *M. iliofibularis* are depicted. There were no significant differences (P>0.05) detected in the chemical composition of the meat samples from the different dietary groups, although there was a tendency towards a higher intramuscular fat content with an increase in fish oil intake. Most of the excessive energy is deposited as fat in the abdominal fat pads of ostriches. The muscle however, also contains small amounts of fat, which is an indication that some fat is deposited in the meat in order to serve as an energy store.

Table 9. Mean values (%) for the chemical composition of ostrich *M. iliofibularis* from birds receiving different levels of fish oil in their diets.

Chemical parameters	Diets			
	D1 (0.0) (n=11)	D2 (0.6) (n=15)	D3 (1.2) (n=12)	D4 (1.8) (n=13)
Protein	21.65±0.33	21.40±0.30	21.66±0.33	21.54±0.32
Fat	1.95±0.10	2.05±0.09	2.05±0.10	2.12±0.09
Ash	1.20±0.07	1.18±0.06	1.22±0.07	1.31±0.07
Moisture	76.96±0.52	77.66±0.48	76.66±0.52	76.57±0.50

4. CONCLUSION

It was noted in this study that the maximum amount of fish oil (1.8%, 43.5 g/day) fed to the ostriches did not have a significant effect on the sensory quality of the meat, with regards to flavour and aroma. However, the increased fishy flavour and aroma trend that was observed, could cause one to postulate that increased levels of fish oil in the diet could result in the development of a fishy aroma and flavour. This warrants further research. On the other hand, higher concentrations of fish oil than those used in this

study, are not economically justifiable in South Africa, since 1.8% fish oil is the optimum amount to be used in a balanced diet.

The negative effect of the fish oil was detected clearly in the fat. This was an indication that most of the chemical components that are responsible for the fishy aroma and flavour accumulate in the fat to a greater extent than in the meat.

It was also noted that dietary fish oil had a positive effect on the fatty acid profile of the meat due to increased levels of *n*-3 PUFA's. However, the inclusion of fish oil also led to a general decrease in the amount of PUFA, as well as an increase in SFA with an increase in the amount of fish oil fed to the ostriches.

Future research on the subject may be focused on withdrawal times of fish oil containing diets before slaughtering to neutralize the effect of fish flavour in the meat.

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THE EFFECT OF DIETARY VITAMIN E AND THE TYPE OF PACKAGING ON THE SENSORY QUALITY, PHYSICOCHEMICAL COMPOSITION AND SHELF LIFE OF OSTRICH MEAT.

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ABSTRACT

The effect of different levels of Vitamin E and the heat shrink treatment of vacuum packaging material on a 81 day shelf life of refrigirated (0°C) ostrich *M. flexor cruris lateralis,* was evaluated in a completely randomised experimental design involving two groups of ostriches. Feed containing 3.75% more vitamin E for the Vit E group than in the control group, were fed to the ostriches over a 7 month period. Vitamin E and heat shrink treatments, were found to have no significant effect on the sensory characteristics: off-meat aroma, sourness, juiciness and mealiness. Rancidity was found to be slightly more pronounced (though not significantly) in the Vit E and heat shrink groups than in the control and vacuum-packed groups. A significant decrease in organoleptic quality of the meat over a 40 day shelf life period was observed. The pH and muscle tenderness showed a significant reduction with increased storage time. The purge loss (in the package) increased over time with no change in muscle drip loss. The muscle colour, conjugated dienoic acid and fatty acid content showed no significant changes over time, or with regards to treatment. The TVC and coliform numbers in the muscle increased over time with the coliforms being slightly suppressed by the inclusion of vitamin E in the diet. A microbiologically safe shelf life of 40 days at 0°C was obtained.

Keywords: Ostrich, Vitamin E, Heat shrink treatment, Vacuum packaging, Shelf life, Sensory evaluation, Microbiology

1. INTRODUCTION

Meat quality is determined by the consumer, according to a combination of characteristics that define the level of acceptability (Kramer & Twigg, 1962). These include sensory evaluation according to visual appearance when a consumer buys meat, as well as flavour, juiciness and tenderness when meat is cooked and consumed (Arnold *et al*., 1992; Smith, Carpenter, King & Hoke, 1970).

Meat quality is influenced by pre-harvest management as well as post-mortem storage. Proper meat storage is an essential factor in providing a high quality and safe product for the consumer. Vacuum packaging is the most common system that is used to improve the shelf life and safety of meat products. It is known that the exclusion of oxygen in vacuum packages decreases microbial activity and lipid oxidation in meat (Pollok *et al.,* 1997). Meat producing species such as ostriches, high in unsaturated fatty acids (Sales, 1998), are more susceptible to oxidation, which potentially increases the possibility of warmed-over and rancid flavours and browning development. In addition to this, meats with a higher post mortem final pH (pH_f), favour increasingly more rapid growth of spoilage bacteria (Newton & Gill, 1981).

Fat or lipid oxidation is one of the primary causes of quality deterioration in meat and meat products during storage (Pearson, Gray, Wolzak & Horenstein, 1983). Oxidative rancidity begins shortly after death and involves the formation of a complex mixture of aldehydes, ketones and alcohols from the breakdown of lipid hydro-peroxides (Reindl & Stan, 1982). There is a range of factors that contribute to the oxidation occurring in meat and meat products (D'Souza & Mullan, 2001). These factors include the state and content of pro-oxidants (iron and myoglobin), the levels of antioxidants present in muscle (α-tocopherol and enzymes such as glutathione peroxidase, superoxide dismutase and catalase), the composition and amount of muscle lipids as well as the storage conditions of meat and meat products. The oxidative stability of the muscle depends upon the balance between anti-oxidants, such as α-tocopherol and some carotenoids, and pro-oxidants including the concentration of poly-unsaturated fatty acids (PUFA) and free iron in the muscle (Kanner, 1992). Oxidation of unsaturated fatty acids also adversely affects the colour, texture, nutritive value, aroma flavour and safety of the meat (Addis, 1986). Ostrich meat is high in PUFA and is therefore very susceptible to oxidation (Sales, 1998). Dietary vitamin E supplementation, together with vacuum packaging, are perhaps the two best-known methods for reducing lipid oxidation within the cell in fresh meat and meat products (Cannon *et al*., 1995; Halliwell, 1987).

The heat treatment of vacuum-packed meat helps to reduce lipid oxidation (Pollock *et al.,* 1997). The addition of heat to the packaging film results in the shrinkage of the

packaging film and a consequent increase in package membrane thickness, which enhances the oxygen barrier properties of the packaging material. Heat shrinking also improves the appearance of the treated pack and eliminates excess plastic, which results in a reduced leaker rate (Pollock *et al.,* 1997). As a packaging film shrinks in response to heat treatment, it becomes more closely applied to the meat surface. This process causes an elimination of the void spaces into which leakage could take place during prolonged chilled storage. Consequently, heat shrinking of vacuum packs helps to minimise drip loss. Heat shrink treatment of vacuum-packed meat also improves the appearance of the meat as it becomes more closely applied to the meat surface (Pollock *et al.,* 1997).

The purpose of the study was to investigate the effect of dietary vitamin E supplementation and the heat treatment of the vacuum packaging material on the organoleptic properties and physicochemical quality of ostrich meat, following the refrigerated storage thereof. It is postulated that the treatments will have an effect on the oxidation, moisture loss and microbiological shelf life of the meat.

2. MATERIALS AND METHODS

2.1 Birds and diet

Two groups (35 each; *ca.* 3 months old) of ostriches were raised in feedlots at the Kromme Rhee Experimental Farm of the Elsenburg Research Centre in the Western Cape area, South Africa. The birds received a feed (Table 1) that contained either high (Vit E) or normal (control) levels of vitamin E. The control group received a diet containing 40 mg vitamin E/kg feed/day and 0.30 mg Selenium (1%)/kg feed/day (Table 2). The experimental group's Vit E diet (Table 2) contained 150 mg Vitamin E/kg feed/day, 0.10 mg Selenium/kg feed/day and 100 mg Sel-Plex 50 (0.2% selenium)/kg feed/day (Alltec Biotechnology, P.O. Box 7156, Stellenbosch, 7599), resulting in 0.3 mg Selenium/kg feed/day. The birds, at *ca.* 12 months of age, were slaughtered and dressed according to standard South African techniques (National Department of Agriculture, 2002) at an abattoir approved by the European Union (HACCP and British Retail Consortium accredited). The carcasses were cooled within *ca.* 45 min after exsanguination, in a cooling chamber at 4°C for 24 h before deboning.

Table 1

The composition of the feed fed at 2.11 kg/bird/day to ostriches in feedlots (*ca.* 30-95 kg).

Ingredients	Amount (kg/ton)
Lucerne	785
Maize meal	150
Soybean oilcake	25
Molasses	20
Mono Calcium Phosphate	7.5
Salt	4.0
Feed lime	3.6
Synthetic Methionine	0.9
Premix (Table 2)	4.0

Table 2

Composition of premix used in supplementary feed of the different groups of ostriches.

Ingredients (Composition per unit of premix)	Units	Control diet	Diet supplemented with vitamin E
Vitamin A	IU	12 000 000	12 000 000
Vitamin D3	IU	3 000 000	3 000 000
Vitamin E	mg	40 000	150 000
Vitamin K3 stab	mg	3 000	3 000
Vitamin B1	mg	3 000	3 000
Vitamin B2	mg	8 000	8 000
Vitamin B6	mg	6 000	6 000
Vitamin B12	mg	100	100
Niacin	mg	80 000	80 000
Pantothenic Acid	mg	12 000	12 000
Folic Acid	mg	2 000	2 000
Biotin	mg	200	200
Choline	mg	600 000	600 000
Magnesium	mg	50 000	50 000
Manganese	mg	120 000	120 000
Iron	mg	25 000	25 000
Zinc	mg	80 000	80 000
Copper	mg	8 000	8 000
Cobalt	mg	100	100
Iodine	mg	1 000	1 000
Unit size	kg	4	4

2.2 Shelf life

After a 24 h chilling period, the *M. flexor cruris lateralis* (also known as triangle steak, long fillet, outside strip or flat filet) from both the right and left leg was removed, trimmed, demembraned and vacuum-packed. The packaging of the right *M. flexor cruris lateralis* was also heat shrinked for 12 s at 70 – 75°C. The plastic bags used for the vacuumed samples were 260 x 340 mm, while the shrink bags used, were 285 x 345 mm. The shrink bags had a permeability of 19 cc/m^2/24hr/bar for oxygen, while the permeability for the vacuum bags was 40 cc/m^2/24hr/bar. All samples were stored at 0°C and analyses were repeated every 13-14 days, over an 81 day period, in order to determine the shelf life of the meat. At the end of each shelf life period, each muscle sample was divided in half and one of the two samples was quick-frozen at –40°C (45 min). Thereafter, it was stored at –20°C for later sensory analysis. The second sample was used immediately for physical and chemical analyses.

2.3 Cooking procedure of sensory analysis

Only muscle samples from the first four shelf life periods (days 1, 14, 27 and 40) were used for the sensory analysis. All muscles were frozen, stored and defrosted using the same methods. The appropriate samples were removed from the freezer and placed in a refrigerator (4°C) for 24 h prior to cooking. When cooking, the muscle sample was placed on an aluminium foil coated metal rack, in an oven bag. A thermocouple was inserted in the centre of the sample and the meat was roasted at 180°C to an internal temperature of 73°C in a conventional electric Defy 835 oven, connected to a computerised-temperature control system (AMSA, 1978).

2.4 Sensory evaluation

Analytical sensory evaluation, performed by a trained panel of eight members, was completed according to the guidelines of the American Meat Science Association (AMSA, 1978). The samples were cut into *ca*. 1x1x1 cm cubes wraped in tin foil, prior to serving. The sensory analysis was performed directly after the cooking procedure was completed. The meat was evaluated in four sessions. Each session consisted of meat from a specific treatment (diet and package) and the four shelf life periods. The sample analysed first (period 1) always served as the control sample and was always analysed first for all subsequent measurements. Oxidised ostrich fat (heated for 3 days at 50°C) was used as reference standard in order to familiarise the panel with a rancid aroma and flavour. An

unstructured line scale (0-100 mm) was used for the qualification of the various attributes, where 0 was very low in the mentioned attribute and 100 was very high. The panellists were trained to evaluate the attributes of rancid aroma, off-meat aroma, mealiness, juiciness and sour flavour on a questionnaire compiled and refined by the panel during the training sessions. Meat from the different periods was randomly served to each panel member in heated Pyrex beakers coded with a three digit random code. Definitions, which were determined and described by the panel during the training session (Table 3), were used.

Table 3

Definitions of terms used on a scale from 0-100 mm in the sensory analysis of ostrich meat

Attribute	Definitions and scale
Off meat aroma	Any aroma that is not associated with fresh cooked ostrich meat (cooked ostrich meat aroma (0) to off meat aroma (100))
Rancid aroma	Aroma associated with rancid ostrich fat (no rancid aroma (0) to rancid aroma (100))
Sourness	Sour taste of meat sample (no sour flavour (0) to sour flavour (100))
Juiciness	Amount of fluid expressed on mastication of sample (juicy (0) to dry (100))
Mealiness	Disintegration of muscle fibres on mastication (no mealiness (0) to mealy (100))

2.5 Chemical and physical analyses

Purge is the fluid commonly lost by post-rigor lean tissue in vacuum and plastic overwrap packaging. Purge loss (%) was determined by comparing the weights of the dried muscle sample, after the required shelf life period, with that of the fresh sample.

Thereafter, samples of *ca.* 30 g, cut from the one end of the muscle sample, were used for microbial analyses. The analyses included total viable counts (TVC) and coliforms. Tests for *E. coli, Salmonella, Clostridium*, Lactic acid bacteria (LAB) and anaerobic plate counts were also conducted. The TVC and coliforms were enumerated with the Rapid Automated Bacterial Impedance Technique (RABIT). RAPID'E COLI 2 was used, in accordance to ISO 7251, to test for *E. coli*. LAB, anaerobic plate counts and *Salmonella* and *Clostridia* counts were done in accordance with ISO 52214, 4833 (modified), 6579 and SABS 761 respectively. An independent ISO 17 025 accredited (by the South African Accreditation Systems) microbiological laboratory, performed all analyses.

The internal pH was measured at each sampling period with the probe inserted in the centre of the meat sample, at a depth of *ca.* 1 cm, by using a handheld Crison pH/mV-506 pH meter equipped with a glass electrode. Meat slices of 15 mm thickness were cut cross sectionally to the muscle fibre for the determination of cooking loss, drip loss and colour (Honikel, 1998).

The fresh meat colour was evaluated after a 30 min blooming period by using a hand held Gardner Colorimeter determining the Hunter colour L, a and b values, which indicated the brightness, red-green range and blue-yellow range respectively.

The drip loss determinations were performed by placing the meat sample of a known weight in netting and suspending it in an inflated bag, where after it was stored at 4°C for 24 h. The sample was then dried with a paper towel and weighed again with the drip loss expressed as a percentage of the initial weight of the sample (Honikel, 1998). The total moisture loss was then calculated as the sum of the purge loss and the drip loss.

For cooking loss determination, the freshly cut and weighed sample was placed in a plastic bag in a water-bath at 75℃. After fifty minutes, the samples were removed from the water-bath, cooled in cold water, blotted dry and weighed (Honnikel, 1998). Cooking loss was expressed as a percentage of the initial sample weight.

The shear force measurements of the cooked meat samples (the same samples as used for cooking loss determination) were obtained with a Warner Bratzler shear (WBS) attachment, fitted to an Instron Universal Testing Machine (Model 4444). These readings were taken within 24 h of cooking. Three cylindrical cores were cut randomly from the centre of each meat sample using a 12.7 mm diameter bore. Care being taken not to include visible collagen in the core. Maximum WBS values (N) required to shear a cylindrical core of cooked muscle, perpendicular to the muscle fibre longitudinal axis (at a crosshead speed of 200 mm/min), were recorded for each sample and the mean was calculated for each muscle. A larger value indicated greater shear force and therefore, tougher meat. No readings were obtained for period 6, due to unforeseen apparatus breakage.

Fatty acid methyl esters (FAME) were prepared according to the method of Morrison & Smith (1964). The FAME were analysed with a GLC: Varian Model 3300, equipped with flame ionisation detection and two 30 m fused silica megabore DB-225 columns of 0.53 mm internal diameter (J&W Scientific Folsom, CA). Gas flow rates were: hydrogen, 25 ml/min; air, 250ml/min; and nitrogen, (carrier gas) 5-8 ml/min. Temperature programming was linear at 4°C/min; initial temperature, 160°C; final temperature, 220°C held for 10 min; injector temperature, 240°C; and detector temperature, 250°C. The Fame were identified by comparison of the retention times to those of a standard FAME mixture (Nu-Chek-Prep Inc., Elysian Minnesota).

The conjugated dienoic acid content was determined according to AOCS standard techniques (AOCS Ti 1a-64, 1997). The fat used for the determination of conjugated dienoic acid, was extracted according to the method described by Lee, Trevino & Chaiyawat (1996), by using chloroform:methanol (2:1) solvent.

The moisture content (105℃, 24 h) was measured for all samples, while the protein (using a Leco FP-528 Nitrogen analyser) and fat content (using chloroform:methanol 2:1 as solvent) (Lee, Trevino & Chaiyawat, 1996), were only measured for period 1.

The vitamin E content was determined using the high performance liquid chromatoghraphy method described by Stahr (1991).

2.6 Statistical analyses

Analysis of variance was performed on all the variables measured for the sensory analysis using the Linear Models (GLM) procedure of SAS Enterprise Guide (SAS, 1990). The sensory analysis experiment consisted of four periods, each with four treatment combinations. Every treatment x period combination was replicated four times by eight panel members in a completely randomised design. The effect of the feed and packaging method on the physical and chemical properties of the meat were also evaluated by analysis of variance, using the GLM procedure. The physical and chemical changes of the meat were evaluated over seven periods (81 days), for the four treatment combinations. An effect with a probability smaller than 0.05% ($P<0.05$) is considered to be significant. Where applicable, either Pearsons correlations or a linear regression equation were fitted to the data (SAS, 1990).

3. RESULTS AND DISCUSSION

The vitamin E content of the muscle was found to differ significantly between the control group and the Vit E group, as outlined in Table 4. This indicates that ostriches absorb and deposit additional dietary vitamin E in their muscle. This vitamin E content is high in comparison with what Faustman *et al.,* (1989) found in beef. They noted that this vitamin is essential (at 0.3-0.35 mg/100 g meat) in beef in order to effectively reduce oxidation and to extend the shelf life of meat.

Table 4

The vitamin E content of ostrich meat receiving a control diet or a Vitamin E enriched diet.

	Control	Vit E
Vitamin E inclusion in the feed	40 mg/kg feed	150 mg/kg feed
Vitamin E in muscle	63.0±5.86[a] mg/kg meat	131.5±3.5[b] mg/kg meat

[a-b] Values within the same row with different superscripts differ significantly (P<0.05)

As pertaining to the sensory quality of the ostrich meat, there was no significant diet and packaging effect as well as no interactions between periods, diet and packaging for any of the attributes except rancidity. The data was therefore pooled together in order to evaluate the changes occurring over the storage period (Table 5). The data are presented as the overall means for the different periods. All of the sensory attributes except juiciness, decreased over time (Table 5). However, juiciness also had a tendency to become more dry with storage time. Rancid odours, on the other hand, showed significant differences between the feed treatment samples (packaging not taken in consideration) and the different packaging methods (feed treatment not taken in consideration) over time (Figure 1).

Table 5

The effect of prolonged storage (0°C) shelf life on the sensory quality of ostrich muscle (means ± SE).

Attribute	Period 1 (day 1)	Period 2 (day 14)	Period 3 (day 27)	Period 4 (day 40)
Off meat aroma	13.73±1.52[a]	21.13±1.52[b]	23.02±1.52[b]	28.84±1.52[c]
Rancid aroma	12.79±1.32[a]	17.57±1.32[ab]	20.69±1.32[bc]	22.47±1.32[c]
Sour flavour	13.90±1.27[a]	17.64±1.27[ab]	19.08±1.27[b]	24.80±1.27[c]
Juiciness	30.30±1.38	32.34±1.38	34.88±1.38	34.60±1.38
Mealiness	18.65±1.71[a]	32.25±1.71[b]	37.60±1.71[b]	37.33±1.71[b]

[a-c] Means within a row with no common letter differ significantly (P<0.05).

An undesirable flavour and aroma may develop in meat during storage as a result of microbial growth, chemical deterioration on the surface or tainting from extraneous agents. The onset of aerobic spoilage in normal meat is governed by the availability of glucose in relation to the spoilage flora (Newton & Gill, 1981). While glucose serves as a major energy source, no spoilage odours or off-flavours can be detected (Pollok *et al.,* 1997). When glucose as an energy source is exhausted, the bacteria start to degrade amino acids and shortly afterwards the production of ammonia spoilage odours occurs. A

sour odour is also a common aromatic by-product of lactic acid producing bacteria. In their shelf life studies, Pollok *et al.* (1997) found that a slight metallic flavour also develops during the storage period of ostrich meat. They also found an increase in cowy and soured odour during a storage period of 12 days. In this study, it was found that the flavours not associated with fresh, cooked ostrich meat formed (Table 5).

It is, however, difficult to define the origin of the off-flavours, although they may be the result of microbial growth despite the fact that the product was found to be microbiologically safe at period 4. The sour flavour detected in the samples can be related to the growth of lactic acid bacteria (LAB), which also caused the muscle pH to decrease over time (Figure 2) due to the formation of lactic acid.

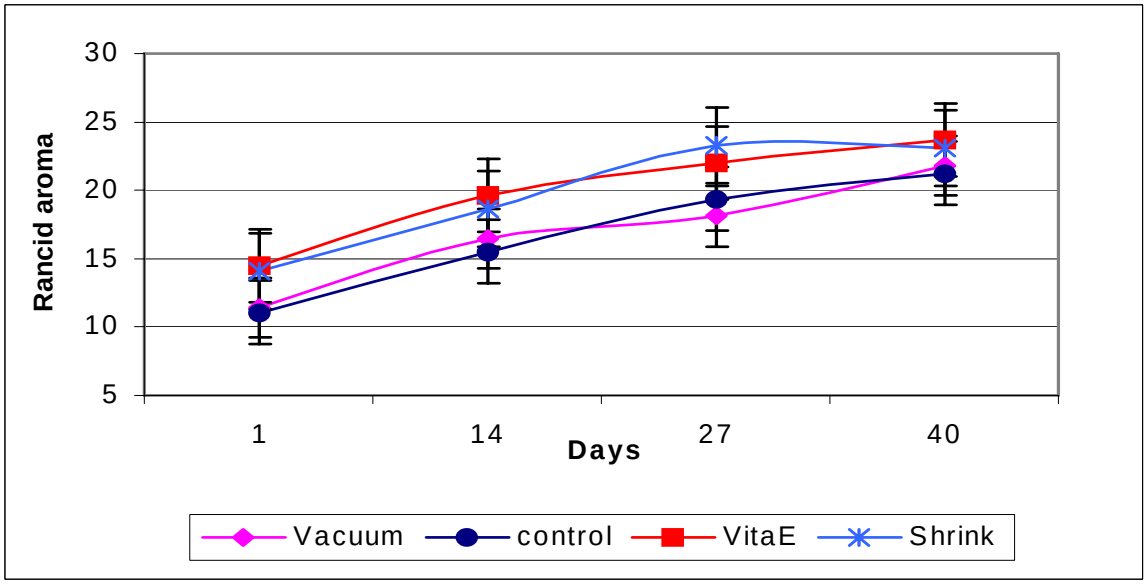

Figure 1. Rancid aroma values for different treatments over a 40 day storage period (0°C) as obtained by a sensory panel for ostrich meat.

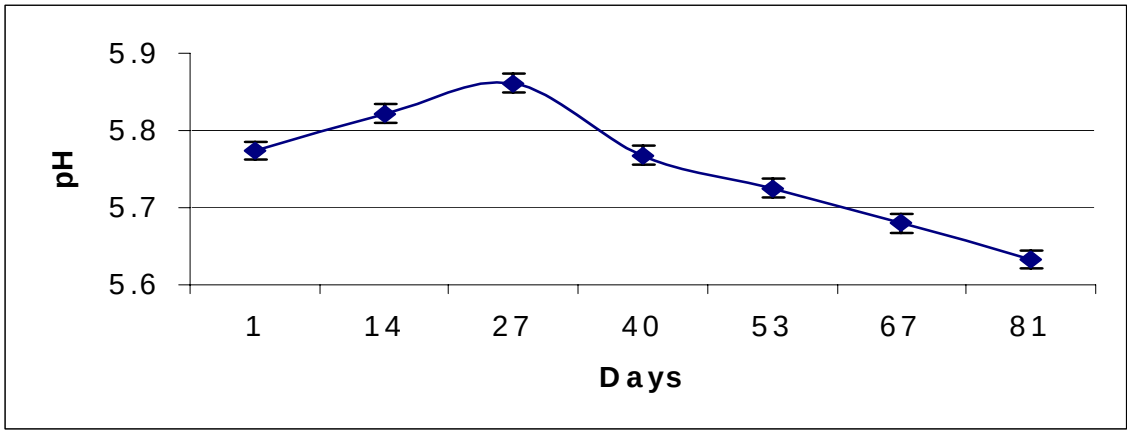

Figure 2. Pooled pH changes with Standard errors over 81 days in the *M. flexor cruris lateralis* when stored at 0°C.

The TVC and coliform numbers are generally used as indicators of hygiene during the slaughtering process. Pollok *et al.* (1997) found in their study on the *M. iliofibularis* and *M. gastrocnemius pars externa,* that the meat had a storage life of 14 days, if stored at 1.7°C, according to the results of the aerobic plate counts (with log values above 6 being classified as unacceptable). In this study, the *M. flexor cruris lateralis* has a shelf life of at least 67 days when only TVC and coliforms numbers are the determining criteria. However, the data obtained for the anaerobic plate counts and LAB suggest otherwise. Results obtained for those two groups of organisms (Table 6) indicate that the specific muscle used in the experiment has a shelf life of 40 days if stored at 0°C, which is still longer than the 14 days of the study found by Pollock *et al.* (1997). It is also interesting that vitamin E seems to have had a slight anti-microbial function (Table 6), something not previously reported in ostrich meat.

Table 6

Mean values for TVC and coliform counts (log cfu/g) of the *M. flexor cruris lateralis* from the vitamin E and control diet, when stored at 0°C.

Periods	TVC*	Coliforms		SE
		Control	Vit E	
1 (day 1)	3.268±0.25[a]	2.21	2.16[a]	3.03
2 (day 14)	4.021±0.25[b]	1.10	1.24[a]	3.02
3 (day 27)	2.706±0.25[a]	0	0[a]	3.07
4 (day 40)	4.572±0.25b	1.97	1.55[a]	3.03
5 (day 53)	5.795±0.25[c]	0.83	0.23[a]	3.08
6 (day 67)	5.656±0.25[c]	2.52	2.43[a]	3.03
7 (day 81)	6.589±0.25[d]	3.09[v]	4.02[bw]	3.02

[a-b] Means in column with different superscripts differ significantly (P<0.05)
[vw] Means in rows with different superscripts differ significantly (P<0.05)
* Diet had no effect on TVC, therefore pooled data depicted in Table

The longer shelf life in this investigation may be the result of low initial bacterial counts and a slightly lower storage temperature than that used by Pollock *et al*. (1997). The TVC counts increased over time, with the exception of period 3, which had a slightly lower value (Table 6). This result may be an indication of the end of aerobic growth before the onset of facultative anaerobic growth, which includes LAB. LAB and anaerobic plate counts were tested for during periods 4, 5 and 6. The results for both were $>10^5$, $>10^7$ and $>10^8$ CFU/g for the three periods respectively. At period 6, gas formation was

detected, which is a by-product of LAB. The coliforms found on the meat increased significantly at period 7, but stayed statistically constant during the first 6 periods (Table 6). The presence of *E. coli, Salmonella* and *Clostridium*, which are indicators of faecal contamination, were also tested for. None of these organisms were found in the meat. These results were expected due to the fact that the abattoir conforms to European Union standards that have strict hygiene control and a viable HACCP program.

The formation of rancid flavours and aroma is normally the result of oxidation that occurs during storage and is then further enhanced by cooking. During the testing by the panel, no rancid flavours could be detected, but a rancid aroma (Table 5) was present in the meat. It was expected that the Vit E and shrinked-packed samples would have lower rancidity levels because of the known anti-oxidant effect of vitamin E and the lower oxygen permeability of the shrinked plastic bags. However, the opposite was true for those two treatments. The differences were, however, not significant, which complies with the results found for the conjugated dienoic acid (Table 7). As mentioned earlier, the vitamin E content of the control diet was most probably sufficient to affect the oxidative shelf life of the meat positively. Or the difference in dietary vitamin E levels that were fed to the ostriches, may have been too insignificant to indicate a difference in the effectiveness of dietary vitamin E. The conjugated dienoic acid content suggested that oxidation was prevented to a great extent, which is possible due to the selenium present in the diet. Glutahione peroxidase, a selenium dependent antioxidant, is responsible for the prevention of the initiation of oxidation (Halliwell, 1987).

Table 7

Mean values for the conjugated dienes of the ostrich *M. flexor cruris lateralis* as influenced by vitamin E and time.

Period	Control	Vit E	Vacuum	Shrink	SE
1 (day 1)	0.007^{av}	0.028^{aw}	0.014^{ay}	0.021^{az}	0.003
2 (day 14)	0.037^{b}	0.029^{a}	0.041^{bd}	0.025^{a}	0.003
3 (day27)	0.012^{av}	0.046^{bw}	0.027^{c}	0.030^{a}	0.003
4 (day40)	0.052^{cv}	0.009^{cw}	0.033^{bc}	0.028^{c}	0.003
5 (day 53)	0.031^{bv}	0.050^{bw}	0.033^{bcy}	0.047^{bz}	0.003
6 (day 67)	0.032^{bv}	0.008^{cw}	0.030^{cy}	0.010^{cz}	0.003
7 (day81)	0.047^{b}	0.050^{b}	0.049^{d}	0.048^{b}	0.003

$^{a-d}$ Means in column with different superscripts differ significantly ($P<0.05$)
$^{vw}/^{yz}$ Means in rows with different superscripts differ significantly ($P<0.05$)

The susceptibility of muscle tissues to lipid oxidation depends on a number of factors. The most important factor would be the levels of PUFA's present in the muscle system. The phospholipids present in subcellular membranes are high in PUFA and the vulnerability of membranes to peroxidation is increased due to the close proximity of a range of pro-oxidants. Vitamin E, a major lipid-soluble anti-oxidant, is responsible for the chain breaking reaction of the lipid peroxidation in cell membranes and therefore prevents the formation of lipid hydroperoxides. One of the first steps in the oxidation of C18:2*n*-6 or higher PUFA is a shift in the position of the double-bonds. The greater the amount of PUFA, the greater the potential increase in the formation of conjugated dienes (Gunstone, 1996). Conjugated dienoic acid is a primary oxidation product and measures the onset of oxidation. It is, however, clear that oxidation is of no importance in vacuum-packed ostrich meat (Table 7) when selenium (and Vitamin E) is included in the diet, as no significant onset of oxidation was detected during the entire shelf life period of 81 days.

Statistical differences between dietary treatments for the muscle fatty acids were tested between period 1 and 4 (Table 8), whereafter differences between packaging methods for each dietary treatment of period 1 and period 4 were tested. Only a few fatty acids differed statistically between the different feed treatments or the packaging methods used. There were, however, tendencies detected in the data. The saturated fatty acids (SFA) were constantly slightly higher for the Vit E group of samples as well as higher for period 4 than 1. Lower PUFA values were obtained for the Vit E group in period 1, while a higher value was obtained in period 4. A slightly lower value was detected for the vacuum-packed samples, relative to the shrinked-packed samples during both periods 1 and 4.

With an increase in oxidation, a decrease in the unsaturated fatty acids, oleic acid (C18:1*n*-9), linoleic acid (C18:2*n*-6) and linolenic acid (C18:3*n*-3) can usually be observed (Crapiste, Brevedan & Carelli, 1999). During period 4, a slightly lower value for C18:2*n*-6 and C18:3*n*-3 as well as for C18:1*n*-9 were obtained for the shrink packaging in relation to the normal vacuum packaging, although not significant. It thus seems as if the PUFA content mostly decreased over time. The heat shrink treatment showed a tendency to have a lower oxidation susceptibility than normal vacuum packaging, when stored at 0°C. Although the changes in the fatty acid profile were slight, the trained taste panel did detect a slight increase in the rancid aroma over time.

Juiciness is the impression of wetness in the mouth, during the first few chews, and is produced by the release of meat juices. The impression of sustainable juiciness is also affected by the presence of fat as the latter stimulates the secretion of saliva. The storage period of the meat had no significant effect on the juiciness of the meat. There was,

Table 8

The fatty acid profile of ostrich meat, comparing the effect of vitamin E with normal feed for periods 1 and 4.

Fatty Acids (%)	Period 1 (day 1)		Period 4 (day 40)	
	Control	Vit E	Control	Vit E
SFA				
C14:0	0.514±0.19	0.989±0.26	0.921±.0.38	0.743±0.36
C16:0	21.948±0.56	22.166±0.81	21.283±1.13	21.609±0.88
C18:0	14.224±0.53	14.058±0.53	16.290±1.80	17.040±1.86
C20:0	0.286±0.03^{m}	0.361±0.050	0.595±0.02^{nx}	0.413±0.05^{y}
C22:0	0.205±0.03	0.155±0.04	0.254±0.06	0.215±0.02
C24:0	0.246±0.05	0.285±0.07	0.266±0.07	0.239±0.05
Total	37.501±0.49	37.722±0.55	39.609±1.36	40.259±1.20
MUFA				
C16:1*n*-7	3.676±0.32^{a}	5.050±0.34^{b}	3.716±0.65	4.082±0.54
C18:1*n*-9	25.791±1.0	26.746±0.69^{m}	24.717±0.94	23.570±0.77^{n}
C24:1	0.225±0.04	0.248±0.04	0.217±0.04	0.165±0.03
Total	29.692±1.23	32.044±0.85^{m}	29.423±1.75	28.023±1.17^{n}
PUFA				
C18:2*n*-6	20.252±0.55^{a}	18.432±0.68^{b}	19.327±0.59	19.316±0.56
C18:3*n*-6	0.162±0.04	0.123±0.04	0.118±0.02	0.131±0.02
C18:3*n*-3	2.881±0.34^{m}	2.526±0.17	1.900±0.26^{n}	2.467±0.30
C20:3	0.775±0.06	0.737±0.09	0.666±0.07	0.799±0.09
C20:4*n*-6	5.606±0.61	4.879±0.38^{m}	7.036±0.70	6.561±0.43^{n}
C20:5*n*-3	1.011±0.10	0.999±0.09	1.014±0.12	0.978±0.12
C22:2*n*-6	0.359±0.08	0.369±0.09	0.205±0.04	0.251±0.06
C22:4*n*-6	1.282±0.17	1.385±0.25	0.984±0.22	0.877±0.24
C22:5*n*-3	0.335±0.03	0.265±0.02	0.334±0.04	0.302±0.04
C22:6*n*-3	0.012±0.02^{m}	0.155±0.02	0.209±0.03^{n}	0.169±0.04
Total	33.092±1.05^{a}	29.915±0.99^{b}	31.563±1.22	32.130±0.84

$^{a-b}$ Values in the same row, within a period, with different superscripts differ significantly (P<0.05).

$^{n-m}$ Values in the same row, between same treatments, with different superscripts differ significantly (P<0.05).

however, a tendency for a decrease in juiciness over time (Table 5). This could be related to a slight increase in purge loss with time (Figure 3).

The meat samples showed a gradual increase in cooking loss over time (Table 9). At period 3, a lowered cooking loss value was detected which could be correlated to the pH (r=0.53). The purge loss (Figure 3) increased linearly with time at a rate of 0.72% for every period (R^2=0.73), whilst the drip loss stayed relatively constant (decline of –0.0058% per period, R^2=0.002). This resulted in a combined total moisture loss of 0.75% per period (R^2=0.71) over 81 days. It is well known that the pH and the tempo of pH decrease have an effect on the water holding capacity of the meat (Swatland, 1995). The higher the ultimate pH, the stronger the WHC and the lower the moisture loss will be that occurs. As expected, the purge loss, drip loss and total moisture loss revealed no feeding effect, since the feed did not have an effect on the muscle pH. Although statistically significant, the moisture content of the meat (Table 10) only differed slightly and would most probably be of little industrial significance.

Table 9

The mean values for cooking loss of the ostrich muscle stored at 0°C for 81 days.

Period	Cooking loss (%)	SE
1 (day 1)	36.532[ab]	0.32
2 (day 14)	37.352[ac]	0.32
3 (day27)	35.914[b]	0.32
4 (day40)	37.055[ac]	0.32
5 (day 53)	41.196[d]	0.32
6 (day 67)	39.221[e]	0.32
7 (day81)	37.570[c]	0.32

[a-f] Means in column with different superscripts differ significantly (P<0.05)

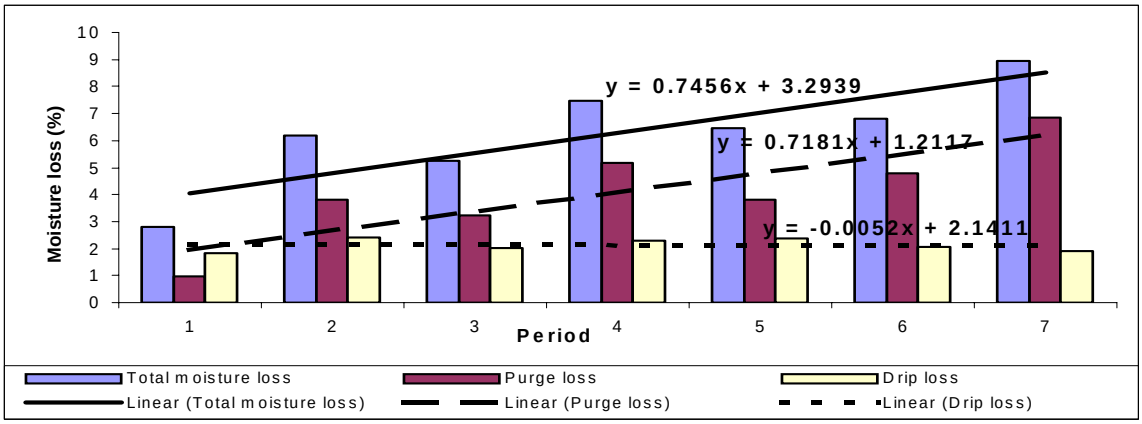

Figure 3. The effect of storage time (0°C) on the water holding capacity of ostrich meat.

Table 10
Mean values for total moisture content of ostrich meat stored at 0°C from birds consuming vitamin E and a normal diet.

Period	Diet		Packaging		SE
	Control	Vit E	Vacuum	Shrink	
1 (day 1)	74.264^{ab}	74.689^{ab}	74.019^{ay}	74.934^{abz}	0.18
2 (day 14)	75.364^{a}	75.006^{a}	75.175^{b}	75.195^{a}	0.18
3 (day27)	74.380^{b}	75.475^{b}	74.844^{b}	75.011^{a}	0.18
4 (day40)	75.154^{cv}	74.800^{aw}	74.770^{b}	75.184^{a}	0.18
5 (day 53)	74.703^{cd}	75.260^{cd}	74.853^{b}	75.111^{a}	0.18
6 (day 67)	74.990^{cd}	74.613^{c}	75.361^{by}	74.242^{bz}	0.18
7 (day81)	75.601^{d}	75.128^{d}	75.319^{b}	75.411^{a}	0.18

$^{a-d}$ Means in column with different superscripts differ significantly (P<0.05)
$^{vw}/^{yz}$ Means in rows with different superscripts differ significantly (P<0.05)

Mealiness refers to the disintegration of the fibres upon mastication. A significant increase in the mealiness attribute was found by the panel for all of the treatments as the storage period continued (Table 5). The addition of heat by way of cooking results in the conversion of collagen to gelatin. On the other hand, myofibrillar proteins coagulate on heating. Enzymatic reactions also play a possible role in the mealiness of the samples. Ca^{2+}-dependent protease (CDP) and lysosomal enzymes like cathepsins B, B+L, H and D, appear to be the best candidates to bring about an increase in mealiness and tenderness, during the post mortem storage (Van Jaarsveld, Naudé & Oelofsen, 1997a). Cathepsins B, B+L and D were all found to be stable over a 12 day storage period (2-4°C, 12 days) in an experiment reported by Van Jaarsveld, Naudé & Oelofsen (1997b). They also found that CDPs were the causative factor that produced changes in myofibrillar proteins during storage. Those changes could also lead to an increase in the mealiness attribute of the meat. This increase in mealiness detected as the shelf life proceeded correlates well with the WBS values for tenderness (Figure 4). Tenderness and mealiness respectively revealed a significant decrease and increase after period 1. Factors such as the rate of glycolysis, the ultimate pH and the rate of temperature decline, affect meat tenderness by their influence on the proteolytic systems involved (Sales, Mellett & Heydenrych, 1996). It is generally accepted that tenderisation occurs mainly during the first 3 or 4 days after death (the ripening period) and this could be the reason for the plateau detected after period 1 (day 1). However, Marks, Stadelman, Linton, Shmieder & Adams (1998) found no effect of ageing on the tenderness of the *M. flexor cruris lateralis,* over a period of 7, days while a definite decrease was found in this study.

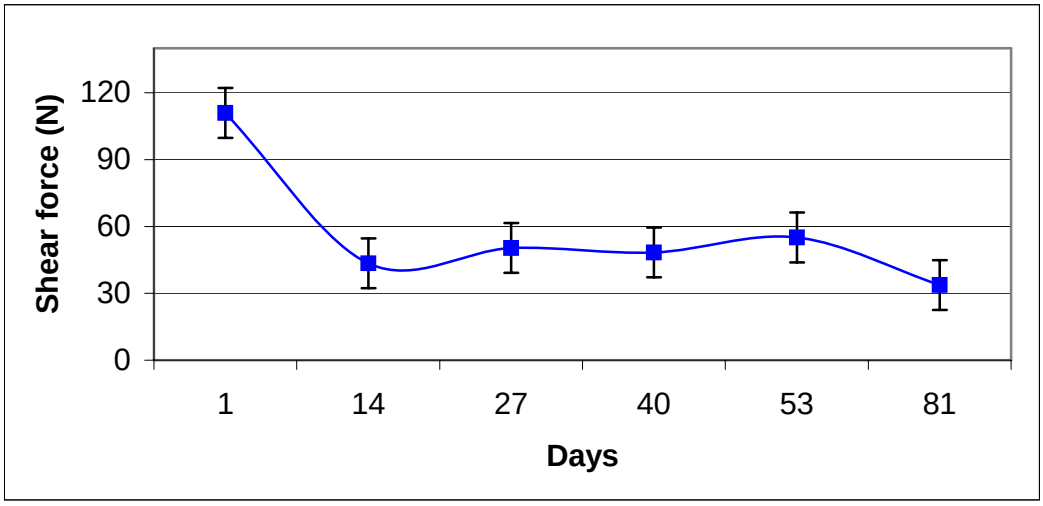

Figure 4. WBS values (N per 1.27 cm diameter) for cooked ostrich muscle as observed over a storage time (81 days, 0°C).

Significant differences were found between the feed treatment combinations over time for the Hunter colour parameters L, a and b (Table 11), as measured on the raw meat. However, in all three colour measurements, the values obtained were extremely variable considering the different periods and treatments. No sensible conclusion can be made regarding the effect of storage time and dietary vitamin E concentration on the meat colour. These results are similar to the results of Pollok *et al.* (1997), who found that the length of storage time in vacuum packages did not have any affect on the colour of fresh ostrich steaks.

As expected, the muscle protein content did not differ significantly between the treatments and a mean value of 22.9±0.14% was obtained, while a mean value of 1.3±0.03% for the total lipid content of the meat was analysed. Theses values are within the range report for ostrich muscles (Harris *et al*., 1993; Horbañczuk *et al*.,1998; Paleari *et al*., 1998; Sales, 1996; Sales & Hayes 1996).

4. CONCLUSIONS

Vitamin E (at the levels tested) and the heat shrink treatment of vacuum-packed samples seems to have no effect on most of the sensory qualities or the chemical and physical properties of ostrich meat, although a significant storage time (0°C) effect was detected. The eating quality with regards to all attributes that have been measured decreased over time. However, the ostrich meat was not perceived to be unacceptable, with all of the mean values obtained through the sensory evaluation indicating a measurement of below 50 on a scale ranging from 0-100. Rancidity increased

significantly over time, while the vitamin E and heat-shrinked samples revealed an unexpected tendency towards a constant higher oxidation status than for the control and vacuum-packed samples. The differences were, however, very diminutive and not significant.

It was found that purge loss increased over time, regardless of the packaging method or the inclusion of vitamin E in the diet of the animal, when stored at low temperatures. The diet or packaging method had no logical influence on the colour parameters of the meat. Vitamin E was found to have had a slight anti-microbial action, with regards to coliforms. This has not been previously noted in ostrich meat. This aspect warrants further research.

In this investigation, the ostrich meat was found to be microbiologically safe for up to 40 days at 0°C. After 40 days, the anaerobic and LAB count exceeded their safety limits, while the coliforms and TVC only exceeded the safety limits after 67 days. It is thus important that coliforms and TVC are not the only organisms tested for when determining when the product is regarded as being safe.

Table 11

Mean values for different colour parameters for ostrich meat stored for a period of 81 days (0°C) from bird consuming vitamin E and the control diet.

Period	Parameter	Control	VitE	SE
1 (day 1)	L	26.702^{acd}	24.369^{a}	0.25
	a	17.860^{abv}	15.247^{aw}	0.45
	b	6.298^{a}	4.955^{a}	0.15
2 (day 14)	L	25.844^{bd}	26.078^{b}	0.25
	a	20.362^{cd}	19.205^{b}	0.45
	b	6.403^{a}	6.286^{b}	0.15
3 (day 27)	L	26.030^{a}	24.985^{ac}	0.25
	a	20.814^{c}	19.785^{c}	0.45
	b	6.356^{a}	6.103^{b}	0.15
4 (day 40)	L	25.154^{b}	24.921^{a}	0.25
	a	17.048^{ab}	17.598^{b}	0.45
	b	5.736^{ab}	5.771^{b}	0.15
5 (day 53)	L	26.046^{bc}	26.387^{b}	0.25
	a	19.982^{cd}	18.744^{bc}	0.45
	b	6.322^{a}	6.344^{b}	0.15
6 (day 67)	L	25.566^{b}	25.593^{bc}	0.25
	a	16.915^{dv}	19.447^{cw}	0.45
	b	5.459^{b}	6.027^{b}	0.15
7 (day 81)	L	26.964^{ac}	26.212^{b}	0.25
	a	18.732^{bd}	18.551^{bc}	0.45
	b	6.082^{a}	5.874^{b}	0.15

$^{a-d}$ Means in column (for each specific parameter) column with different superscripts differ significantly (P<0.05)

^{vw} Means in rows differ column with different superscripts differ significantly (P<0.05)

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GENERAL CONCLUSION

The inclusion of oil in the diet of ostriches is essential in preventing the onset of respiratory diseases. However, in other animals, fish oil results in the development of fishy flavours and aroma, but it also changes the fatty acid profile of these animals by increasing the PUFA content of the meat. PUFA is the main component responsible for oxidation in meat and thereby reduces the shelf life of the meat. Dietary vitamin E is recognised as one of the world's best anti-oxidants for meat products. Together with vitamin E, vacuum packaging also helps with the prevention of the oxidation of meat products. The properties of vacuum packaging are enhanced by the heat shrink treatment thereof. Vacuum packaging also reduces the tempo of microbiological spoilage, thereby prolonging the shelf life.

In this investigation, the effect of fish oil on the sensory properties and fatty acid profile of the *M. iliofibularis* of the ostrich were evaluated. In the second experiment, the effect of additional vitamin E and heat shrink packaging, versus the normal ostrich diet and vacuum packaging on the lipid stability and shelf life of the *M. flexor cruris lateralis* of the ostrich, was evaluated.

The maximum amount of fish oil (1.8% of the supplementary diet, 43.5 g/day) consumed was found to have no significant effect on the sensory characteristics of ostrich meat, although a tendency for an increase in fishiness for both aroma and flavour were detected. However, increased concentrations of fish oil did have a significant effect on the aroma and flavour of the abdominal fat pads. This could lead one to postulate that higher levels of fish oil in the diet of ostriches may lead to the development of significant fishy flavours and aroma. Before use in the industry, further research with different levels of dietary fish oil, fed to ostriches under different conditions, is required to confirm this postulation.

The muscle pH_f and muscle lightness (L*) showed a significant reduction with increased dietary energy intake. The lower pH_f found for the ostrich meat should have a positive effect on the shelf life of ostrich meat, since meat with a pH_f higher than 6 is more susceptible to microbiological growth.

The increased energy intake had no effect on the chemical composition (protein, fat, ash and moisture content) of the meat, while the fatty acid profiles of both fat and meat were affected by the consumption of fish oil. The SFA concentration increased, while the PUFA concentration decreased with increasing dietary levels. The decrease of

the PUFA results from the decrease of the *n*-6 fatty acids. The *n*-3 fatty acids increased with an increase of dietary fish oil concentration. Oxidation may also have led to a decrease in the PUFA content of the meat. The MUFA concentration stayed constant for all four groups.

The differences between the levels of vitamin E fed to the ostriches were not big enough to have a noticeable effect on the lipid stability of the meat. The difference in oxygen permeability between the vacuum and heat shrink packaging material was also not substantial enough to have a significant effect on the quality of the meat.

Vitamin E and heat shrink treatments were found to have had no significant effect on the sensory characteristics: off-meat aroma, sourness, juiciness and mealiness. A significant decrease in organoleptic qualities of the meat over a 40 day shelf life period was observed. However, the meat was not perceived to be unacceptable after 40 days of storage at 0°C. Rancidity was found to be slightly more pronounced (although not statistically significant) in the vitamin E and heat shrink groups than in the control and vacuum-packed groups.

The pH and muscle tenderness showed a significant reduction with increased storage time. The purge loss increased over time with no change in drip loss regardless of the packaging method. The colour, conjugated dienoic acid and fatty acid content showed no significant changes over time, or with regards to the treatment. As pertaining to microbial growth, the TVC and coliform numbers increased over time with the coliforms being slightly suppressed due to the inclusion of vitamin E in the diet. This phenomenon has not been previously noted in ostrich meat and warrants further research. The shelf life of ostrich meat has been determined in this study to be 40 days at 0°C as indicated by the anaerobic and lactic acid bacteria counts. However, with regards to the TVC and coliform counts, the ostrich meat had a shelf life of 67 days.

In order to determine the shelf life of vacuum packed meat products, it is clear that TVC and coliforms are not suitable indicators of shelf life. It is also very important to consider anaerobic and lactic acid bacteria counts. Regardless of the feed treatment or packaging treatment, a decrease in quality still occurs in refrigerated ostrich meat products.