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REVIEW ARTICLE

Effects of packaging methods on shelf life of ratite meats

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Abstract

Over the last years a growing demand for ratite meat, including ostrich, emu, and rhea has been observed in the world. Ratite meat is recognised as a dietetic product because of low level of fat, high share of PUFA, favourable n6/n3 ratio, and higher amounts of iron content in comparison with beef and chicken meat. The abundance of bioactive compounds, *e.g.* PUFA, makes ratite meat highly susceptible to oxidation processes. Moreover, pH over 6 creates favourable environment for fast microbial growth during storage conditions affecting its shelf life. However, availability of information on ratite meat shelf life among consumers and industry is still limited. Thus, the aim of the present review is to provide current information about the effect of ratite meat packaging type, *i.e.* air packaging, vacuum packaging with skin pack, modified atmosphere packaging (MAP), on its shelf life quality during storage, including technological and nutritional properties.

Keywords: meat, ratite, packaging type, shelf life, quality.

Introduction

Over the last years a growing demand for ratite meat, including ostrich, emu, and rhea has been observed in the world (12, 13, 22, 24, 35, 38, 39, 42). The global market of ratite meats is gaining popularity due to health-conscious consumers, who are becoming increasingly careful in choosing lean alternatives over traditional red meats (31). One of the reasons for such interest is that ratite meat is recognised as a valuable dietetic meat mainly because of its low level of fat, high share of polyunsaturated fatty acids (PUFAs) (10, 36), favourable n6/n3 ratio, and significantly higher amount iron (haeme form) in comparison with beef and chicken meat. Moreover, ratite meat is rich in group B vitamin, selenium, copper, and biologically active peptides, such as carnosine (emu) and anserine (ostrich). The abundance of bioactive compounds (PUFA or iron-containing compounds) makes ratite meat highly susceptible to oxidation processes. It should be noted that the oxidative deterioration of the PUFAs causes formation of hydroperoxides, and finally leads to formation of short-chain aldehydes, ketones, and other oxygenated compounds, which are considered to be responsible for the development of rancidity in stored food. Oxidation in meat is also closely related to the breakdown of haeme-iron and release of iron from the porphyrin ring (14). Lipid oxidation accelerates in the immediate post-slaughter period and during handling, processing, storage, and cooking, producing discolouration, drip losses, off-odour, off-flavour, and texture defects (40). Lipid oxidation is an important factor regarding shelf life and consumer acceptance of fresh meat. Dark visual appearance of ostrich meat can affect consumer preferences. The meat maturation is also followed by the second phase, where proteins are degraded, with the accumulation of low-molecular nitrogenous compounds and a slight rise in pH (26). Thus, protein oxidation is responsible for many biological modifications, such as protein fragmentation or aggregation, decreased protein solubility, and decreased amino acid bioavailability (43). Active oxygen species attack the side chain of basic amino acids and can convert them into carbonyl derivatives.

Moreover, ratite meat is characterised by high pH (over 6), which creates a favourable environment for fast microbial spoilage under packaging conditions (2). Poławska *et al.* (37) concluded that poor microbial

quality and high pH of ostrich meat post-slaughter could be responsible for high microbial loads during storage. High final pH causes dark colour, high water-holding capacity, and limited shelf life of meat, and is normally associated with pre-slaughter stress. Thus, such factors as pH, which has been considered as one of the main parameters in the microbiological quality of the meat, together with the initial bacterial contamination, temperature of the meat during storage, as well as type of packaging, all play a major role in the final quality of the meat (9).

As mentioned above, on the one hand ratite meat is a high-quality dietetic product, but on the other it is very sensitive to deterioration during storage. Moreover, the consumption of ratite meat, especially ostrich meat, is increasing in the world, and therefore improving the extent of its shelf life and protection of the bioactive compounds as well as technological and food safety aspects are crucial for potential consumers and for further development of this new meat industry. However, the knowledge regarding these issues compared to beef or chicken meat is still limited. Thus, the aim of the review is to provide scientific knowledge about the influence that the type of packaging has on ratite meat shelf life quality, including technological and nutritional properties.

Type of packaging and ratite meat shelf life quality

Ratite carcasses are typically chilled for 24–48 h post-mortem, cut, and immediately packed before marketing (40). Different types of packaging of ratite meat are currently available on the market: traditional air packaging (AP), vacuum-packaging (VP) including vacuum skin pack (VSP), and modified atmosphere packaging (MAP). VP offers anaerobic conditions inside the package, which leads to further shelf life extension and provides stable colour. VSP is an advanced type of VP which helps to avoid the formation of film wrinkles by making upper film shrink tightly around meat. MAP is a useful technique to maintain the sensory quality and to extend the shelf life of meat (1, 11). The principle of MAP is the replacement of the atmosphere surrounding a product before sealing; carbon dioxide, oxygen, and nitrogen are the most commonly used gases.

Air-packaging and vacuum packaging including skin pack

One of the first publications regarding the impact of the type of packaging on ratite meat shelf quality was reported by Otremba *et al.* (34). They worked on previously frozen (at –40°C for five days) ostrich meat (steaks and ground meat vacuum-packaged) which was then placed for 28 days into a 0°C walk-in cooler and its shelf life was evaluated. The authors demonstrated that the meat had aerobic plate counts of less than 6 log CFU/g during a refrigerated storage for 14 days. Aroma was also acceptable after 14 days. After this period the aroma and colour were less acceptable and more than 50% of the surface of ostrich meat turned brown (Table 1). The authors suggested that previously frozen, vacuum-packaged ostrich meat, stored under refrigerated conditions, should be used within 10 days.

Shelf life quality of ostrich meat steak air- and vacuum-packed and stored at different temperatures (4°C and 10°C) was investigated by Gonzalez-Montalvo *et al.* (19). They reported that pH was higher in AP in comparison with VP after six days of observations. In their study, VP ostrich meat showed lower microbial count as compared to AP at 10°C for *Listeria monocytogenes* and at 4°C and 10°C for *Escherichia coli*. Storage temperature influenced the bacteria count during the time of storage, especially in AP. General acceptability of this meat for consumption was 6 days for AP, and 9–12 days for VP stored at 10°C and 4°C, respectively. Similar results were demonstrated by Balamatsia *et al.* (3) who stored chicken breast fillets at 4°C under AP and VP conditions; although VP was most effective in reducing the growth of aerobic bacteria, the shelf life of fresh chicken meat was 6–7 and 9–10 days, respectively. Capita *et al.* (9) stored ostrich meat at similar temperatures under AP and VP and stated that for most microbial groups temperature significantly influenced bacterial levels up to day 6 of storage, while gas atmosphere had a significant effect on days 6 and 9. VP ostrich meat stored at 4°C demonstrated the lowest microbial loads on day 9. Ntzimani *et al.* (33) found inhibition of microbial growth, including *Pseudomonas* spp., on turkey fillets stored under AP, VP, and VSP at 4°C. According to them, VSP is the most effective, followed by VP. The results of the study by Brenesselova *et al.* (7) showed that the shelf life of ostrich meat stored at 2°C was affected by different packaging conditions (vacuum against the normal atmosphere). The storage of ostrich meat in VP had a positive effect on the biochemical, microbiological, and sensory parameters compared to non-vacuum packed meat. In VP samples not only was the oxidation process reduced, but the microbial spoilage as well. The microbial levels of refrigerated VP ostrich steaks were also assessed by Alonso-Calleja *et al.* (2), who investigated meat samples purchased in retail outlets in Spain within three to seven days after storage. They showed that the samples with pH higher than 5.8 had the highest ($P > 0.05$) counts of most of the microbial groups, and the samples with pH lower than 5.8 had the lowest level. Vázquez *et al.* (46) studied beef under VP and VPS stored at 4°C and demonstrated a decrease in pH under both packaging methods. Moreover, microbiological quality after VSP proved to be superior with aerobic mesophiles and aerobes showing a slower growth.

In turn, vacuum-packed hot- and cold-deboned ostrich meat was stored for 21 days at 4°C in the study by Botha *et al.* (5), who focused on the influence of hot-deboning on the quality of ostrich meat during refrigerated storage. Muscle pH did not differ ($P > 0.05$)

between hot- and cold-deboned muscles during storage. Hot-deboned muscles were tougher than cold-deboned muscles from 24 h up to 5 days. Moreover, hot-deboning caused more purge in the VP of the hot-deboned (1.8%) than in the cold-deboned muscles (0.7%) during the 21-day aging period. In the case of beef, Lagerstedt *et al.* (27), who compared three types of meat packaging: VP, VSP, and MAP (80% O_2/20% CO_2), reported that VSP samples demonstrated the lowest amount of purge loss during storage, while VP samples had the highest one.

In the study by Seydim *et al.* (45), fresh ground ostrich meat was packaged under high oxygen (O_2), high nitrogen (N_2), vacuum (VA), and ambient air (AIR) atmospheres, and stored at 4°C for nine days. Initial pH of the meat was 6.1 and it declined slightly during storage. TBA values and hexanal content were the highest in O_2 and the lowest in VA and N_2 atmospheres. All packaging methods had generally similar effects on microbial outgrowth. Ground ostrich meat was below saleable quality in less than six days based on all of the meat attributes. For O_2 packaging, however, quality based on lipid oxidation and colour properties indicated a shelf life of less than three days. According to the authors, oxidation is likely the limiting factor for shelf life of ground ostrich meat (45). However, in order to decrease the rate of oxidation in chicken meat, Keokamnerd *et al*. (25) supplied commercial rosemary oleoresin preparations to ground thigh meat under 80% O_2 /20% CO_2, achieving a positive effect on raw meat appearance during storage. Oxidation was slowed in meat with rosemary as indicated by lower TBA values, lower hexanal concentrations, and sensory scores.

Interesting research regarding quality characteristics and storage stability of three types of burgers prepared with ostrich meat (alone or mixed with pork or beef meat) were evaluated by Fernandez-Lopez *et al.* (15). Burgers consisting of ostrich and pork meat had a faster oxidation rate and became more oxidised than the others. Regarding their shelf life, all types of burgers had an unacceptable microbial load at the end of the storage time, which is a sign of spoilage. The authors concluded that further studies should assess the use of preservatives and antioxidants in order to enhance the presentation of burgers. Such study on increasing the antioxidant capacity of rosemary extract on minced chicken breast meat showed that active packaging is capable of delaying the lipid oxidation generated by the application of high pressure, and thus extends the shelf life of the meat (6).

Poławska *et al.* (37) evaluated the physical traits and fatty acids profile of ostrich meat enriched in n-3 fatty acids affected by type of packaging (VA *vs*. skin-packaging – VSP) in relation to refrigerated storage (for 14 days). During storage time, drip loss after seven days was significantly higher ($P < 0.001$) in VA when compared to VSP samples. A significant decrease in the content of PUFA after 7 and 14 days of storage was also observed in VA packed meat compared to fresh meat, whereas no differences in the PUFA concentration were shown when VSP was used.

Another study evaluated the influence of frozen storage (–20ºC) for 120 days on the fatty acid composition of ostrich VP meat enriched with linseed and rapeseed (36). A decrease was noted in the PUFA content in the meat as related to frozen storage duration. The results suggest that freezing (−20ºC) is an acceptable method of preservation for ostrich meat enriched with n-3 fatty acids for up to 60 days. However, the changes in PUFA profile in the second period of storage (61–120 days) indicate that further research should be conducted to evaluate a prolonged frozen storage for 180 days or longer.

In the case of emu meat, the first available literature was supplied by Naveena *et al.* (32), who studied the effect of aging on the quality of emu meat under AP and VP conditions at 4°C for 9 and 15 days. Microbial counts of emu meat (total plate and *Enterobacteriaceae*) remained higher in the AP in relation to the VP. The microbial load observed in emu meat remained below the threshold level of 7–8 log cfu/g. Emu meat packed under AP condition also showed a significantly higher oxidation rate (TBARS – 1.2 mg MDA/kg in comparison to VP – 0.1 mg MDA/kg). The authors demonstrated that the quality characteristics, especially tenderness of emu meat, can be improved through post-mortem aging: six and nine days of storage under AP and VP conditions, at 4°C. On the other hand, Łopacka *et al.* (29) showed that storage of beef for up to 12 days is not sufficient to impact its tenderness, regardless of the packaging type: VSP, MAP, and their combination with semi-permeable inner VSP film (VSP-MAP). TBARS values obtained for steaks packaged in VSP-MAP system were similar to those obtained in VSP and significantly lower than in MAP samples.

In the case of rhea meat there are only a few reports available in the current literature. The shelf life of rhea meat during storage under AP (5 days) at 4°C and VP (28 days) was investigated by Filgueras *et al.* (16), who also determined the influence of the muscle type: *gastrocnemius (*GN*)* and *iliofiburalis (*IF) on the rate of oxidation processes. Although the ultimate pH was similar in both muscles, the IF muscle presented higher lipid content and lower PUFA/SFA ratio than GN muscle. With storage under AP, lipid oxidation of rhea muscles increased up to 275% (Table 1). This increase was more rapid and marked in IF muscle. IF muscle presented higher oxidation processes and instability than GN muscle, altering its quality attributes. It can be partly explained by the fatty acid composition and the higher myoglobin content in IF than in GN muscle. The authors suggested that rhea meat industry should prioritise the adoption of VP storage instead of AP. In turn, Filgueras *et al.* (17) investigated the influence of frozen storage duration (at −20°C and −80°C) until 180 days and cooking of rhea vacuum packed meat on its physical and oxidative changes. Generally in rhea meat, muscle type had no effect on physical parameters during frozen storage. However, the *M. iliofiburalis* was more susceptible to oxidation than the *M. gastrocnemius.*

Table 1. The effect of chosen types of packaging and storage temperature on shelf life of ratite meats

Meat type	Type of packaging	Storage temperature	Storage time days (d)	Quality meat evaluation	Reference
Ostrich	VP	frozen in –40° C for 5 days, later stored up to 28 d at 0°	up to 28 d	Aerobic plate counts of less than 6 log CFU/g during a refrigerated shelf life of 14 days. Aroma was acceptable at 14 days.	(34)
Ostrich	VP and AP	4°C and 10°C	6–12 d	VP -lower microbial count as compared to AP at 10°C for *Listeria monocytogenes* and at 4°and 10°C for *Escherichia coli*. Storage temperature influenced the bacteria count during time of storage, especially in AP.	(19)
Ostrich	VP and VPS	4°C	3–7 d	Meat with pH higher than 5.8 had the highest (P> 0.05) counts for most of microbial groups, these with pH lower than 5.8 had the lowest level.	(2)
Fresh ground ostrich	VP and AIR	4°C	up to 9 d	Initial pH was 6.1 declined slightly during storage. TBA values and hexanal content were lowest in VP.	(45)
Hot- and cold-deboned ostrich meat	VP	4°C	up to 21 d	Hot-deboned muscles were tougher than cold-deboned muscles from 24 h up to five days.	(5)
Ostrich	VP	2°C	up to 21 d	VP had a positive effect on microbiological and sensory features as compared to non-VP meat.	(7)
Emu	VP and AP	4°C	9–15 d	Microbial counts of emu meat – total plate count and *Enterobacteriaceae* counts were higher in AP than in VP. Microbial load was below 7–8 log cfu/g	(32)
Rhea (2 muscles)	VP and AP	4°C	5–28 d	Ultimate pH was similar in both muscles. With storage under AP, lipid oxidation of rhea muscles increased up to 275%.	(16)

VP – vacuum packaging, AP – air packaging, VPS –vacuum skin packaging

Table 2. The effect of modified atmosphere packaging (MAP) on shelf life of ostrich meat

Type of packaging	Gas mix	Storage temperature	Storage time in days	Quality meat evaluation	Reference
MAP	O_2;CO_2;N_2 - 80:20:0, - 60:20:20, - 60:40:0 - 40:40:20	4°C	10	Meat packaged with high CO_2 concentrations had lower mean TBARS values during the 10 days of storage as compared to meat packaged in O_2.	(4)
MAP MAP+CO	CO_2: N_2 - 80:20% CO_2:Ar:CO - 30:69.8:0.2	4°C	12	The presence of CO_2 extends the shelf life of ostrich steaks by stabilisation of red colour and sensory techniques, and maintenance of fresh meat odour.	(15)
OMAP NMAP	CO_2/O_2 - 30:70 CO_2/N_2 - 30:70	4°C	10	MAP enhances the shelf life of fresh meat and could be applied in the industry and the overwrap packaging was found not suitable for meat packaging due to the rapid oxidation of myoglobin and great loss of moisture	(28)

At the end of storage duration, the percentage of metmyoglobin and the levels of lipid oxidation (TBARS) were more than two-fold higher in the *M. iliofiburalis* than in the *M. gastrocnemius.* Ultimately, long-term frozen storage only slightly affected the overall quality of rhea meat. Nutritional value and digestion rate of rhea meat proteins in association with storage and cooking processes were also investigated by this research group (18). Storage influenced Schiff bases formation indicating the presence of protein-aldehyde adducts after cooking. High content of Schiff bases was found after cooking of samples stored for five days. The study showed that storage time had less impact on protein changes in rhea

meat than cooking. The formation of Schiff bases and aggregates seemed to be the result of both hydrophobic and covalent interactions of proteins and lipid oxidation products. Moreover, a combined effect of storage under air and heating on protein aggregation was reported (18).

Modified atmosphere packaging (MAP)

It should be noted that a very limited research was conducted in relation to the influence of modified atmosphere packaging (MAP) on shelf life quality of ratite meat, including its technological and nutritional properties. There are only a few papers including ostrich meat (Table 2). Fernandez-Lopez *et al.* (15) assessed the shelf life of ostrich steaks stored in four different packaging types: air exposure, vacuum, and two different types of MAP: 80% CO_2+ 20% N_2, and MAP + CO: 30% CO_2 + 69.8% argon + 0.2% CO. They observed that the sharpest decline in pH and related decrease in lactic acid bacteria count were in the VP samples, and AP meat showed a significantly higher aerobic bacteria count when compared to VP. Based on aerobic bacteria counts, the shelf life of ostrich steaks stored under AP would be 8 days at most, whereas under vacuum, MAP or MAP + CO it would amount to 12 days. The presence of CO extends the shelf life of ostrich steaks by stabilisation of red colour and sensory techniques, and maintenance of fresh meat aroma. Interesting results were obtained by Sakowska *et al.* (44) for beef where the authors investigated the impact of 0.5% carbon monoxide in MAP on selected quality parameters of beef muscles. The authors showed that the use of 0.5% CO as a component in the gas mixture in MAP enabled to maintain the preferred red colour of beef under anaerobic conditions for 21 days. Bingol *et al.* (4) studied the effects of various concentrations of O_2/C_2 in MAP on the shelf life quality of ostrich meat. They packaged ostrich meat under five various gas mixtures: air and O_2; CO_2; N_2 ratios of 80:20:0, 60:20:20, 60:40:0, and 40:40:20 at 4° C for 10 days (Table 2). As a result, the meat quality and shelf life of ostrich meat under various gas compositions were improved. For example, the high CO_2 content (40%) prevented increased lipid oxidation and increased acceptable shelf life. Ostrich meat packaged with high CO_2 concentrations had lower mean TBARS values during the 10 days of storage compared to meat in O_2 packages. The longer the exposure to high CO_2 concentration, the more effective the inhibition of microbial growth and shelf life were. They increased by 5–7 days. Although high concentrations of CO_2 may be beneficial for inhibiting microorganism growth, high CO_2 level in MAP is often the cause of darkening in meat products due to the formation of metmyoglobin. According to Martinez *et al*. (30) in order to reach higher colour retention and freshness, it is advisable to use low CO_2 concentrations (20%), rather than high ones (60%). In turn, high O_2 (80%) concentration led to higher lipid oxidation and to the development of undesirable flavours, and did not extend the shelf life of ostrich meats compared to air-packaged ones. According to Veberg *et al.* (47), pork meat is more stable against lipid oxidation and no development of fluorescent lipid oxidation products was detected when stored at 4°C under high-oxygen (O_2) MAP and vacuum. However, TBARS values of pork meat (4°C) increase with the increase in O_2 concentration inside the package. MAP of 55% O_2 or more is necessary for maintaining a good colour of beef loins. On the other hand, according to Jakobsen *et al*. (21), oxygen levels have a smaller effect on lipid oxidation compared to temperature during storage.

Leygonie *et al.* (28) in the study on quality of packaged ostrich meat under different MAP packaging conditions: 30:70, CO_2/O_2 (OMAP), 30:70 CO_2/N_2 (NMAP) compared to traditional air packaging method, and stored at 4°C for 10 days showed that pH was constant in the MAP groups, whereas it increased in air packaging conditions. The same tendency occurred for drip loss. In turn, TBARS remained constant for NMAP (2,4 MDA/kg meat and 3.1 for air packaging), whereas increased significantly for OMAP – 10 mg MDA/kg of meat. The colour stability was greatly enhanced in OMAP. The authors concluded that MAP enhances the shelf life of fresh ostrich meat and could be applied in the industry, whereas the overwrap packaging was found not suitable for ostrich meat packaging due to the rapid oxidation of myoglobin and great loss of moisture, diminishing the shelf life. According to Camo *et al.* (8), rapid oxidation can be decreased using active packaging systems (80% O_2/20% CO_2) containing oregano extract, which was evaluated with reference to beef steaks.

Based on the delivered data we can assume that generally the shelf life of ratite meat is similar to that in poultry meat (3, 19), but shorter in comparison to other popular red meats like beef, pork, lamb (8, 9), and can be associated with the high ultimate pH, initial microbioal loads (2), and relatively high amounts of PUFA and haeme-iron in ratite meat.

Conclusions

This article provides updated information regarding the type of packaging of ratite meat currently in use on the market. These data may be useful for both consumers and the industry, since appropriate method of packaging affects the shelf life quality of this healthy, exotic meat. However, the knowledge about this issue is still limited, compared to available data on traditional meats like beef, pork, and chicken. Thus, it can be concluded that since the emu ratite meat is relatively new and unfamiliar to processors and consumers, it is important that the meat is extensively tested to determine proper aging duration and suitable packaging requirements to encourage greater consumption and production. More complete and comprehensive studies on the

microbiological quality of rhea meat during storage and the use of modified atmosphere packaging are necessary. For better distribution and promotion of ostrich, emu, and rhea meat, further studies on improvement and optimisation of the storage packaging conditions of these meats should be carried out. Moreover, there is a need for research aiming at extending the shelf life of ratite meat (taking into account its high susceptibility to oxidation processes), including development of an innovative, alternative packaging system for better preservation of nutritional and technological properties.

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