CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

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EFFECTS OF SEMI-PERMEABLE BAG AGEING ON THE PHYSICAL, CHEMICAL, AND SENSORY QUALITY OF COMMON ELAND MEAT

MASTER'S THESIS

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Declaration

I hereby declare that I have done this thesis entitled "Effects of semi-permeable bag ageing on the physical, chemical, and sensory quality of common eland meat" independently; all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague, August 2022

Tumelo Moyo

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Abstract

This study evaluated the effects of semi-permeable bag ageing on the physical, chemical, and sensory quality of the *longissimus lumborum* (LL) region of the *longissimus thoracis et lumborum* muscle, from six adult common eland (*Taurotragus oryx*) females, aged between 14 and 15 years. Samples were randomly allocated to three ageing techniques namely wet (WA), dry (DA), and semi-permeable bag (SBA) ageing over either a 14 or 28 day period in a controlled chamber, at a temperature of 2°C and relative humidity of 80%.

Semipermeable bag ageing produced similar meat pH and colour (which was darker than WA meat) profiles to dry-aged meat. The effect on cooking losses and meat chemical composition were as expected, given the moisture losses during ageing. The moisture lost during ageing was improved by using the SBA technique, compared to DA, which will improve yields. Interestingly, all treatments showed similar effects on tenderness, with D14 and D28 being comparable. This result was also reflected by the sensory panel. However, ageing to D28 allowed for better flavour and aroma development in both SBA and DA. Attributes like beef aroma intensity, game flavour intensity and juiciness have been associated with DA meat according to various studies. SBA had comparable results for these attributes which asserts the advantages that SBA decreases moisture loss and aids in the development of positive aroma and flavour attributes.

Overall there was little variation recorded in sensory attributes between SBA and DA, compared to WA. WA had the highest game flavour intensity at D14 compared to DA. At D28, SBA had similar scores to DA in terms of beef aroma intensity, game aroma intensity and overall acceptance, whereas consequently they both scored lower on abnormal odour intensity and liver flavour compared to WA. Further research on microbial effects on physical, chemical and sensory attributes of aged eland meat need to be explored so as to investigate if microbial status has a positive or negative bearing on the various meat attributes. Additionally, a combination of these ageing techniques can be explored further to optimise the balance between quality improvement and yield losses.

Key words: weight loss, cooking loss, flavour, aroma, tenderness

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List of the abbreviations used in the thesis

CP: Crude protein

DA: Dry aged

DAB: Dry aged beef

DFD: Dark, firm, and dry

DM: Dry matter

EB: *Enterobacteriaceae*

FAA: Free amino acids

GIT: Gastrointestinal tract

GMO: Genetically modified

IMF: Intramuscular fat

LL: *Longissimus lumborum* muscle

LSM: Least square means

LTL: *Longissimus thoracis et lumborum* muscle

PSE: Pale, soft, and exudative

PUFA: Poly-unsaturated fatty acids

SBA: Semi-permeable bag ageing

SEM: Standard error of the mean

VEPAC: Variance estimation and precision

WA: Wet aged

WAB: Wet aged beef

WBSF: Warner-Bratzler shear force

WHC: Water-holding capacity

1. Introduction and Literature Review

1.1. Introduction

With the growing human population and increasing demand for animal protein, the use of game meat offers a feasible contribution to help cater for the ever-growing demand. Antelope species, for example, have gained popularity in the meat production industry due to its lean meat production, their ability to withstand harsh arid environments, low susceptibility to diseases and overgrazing, and ability to utilize low-quality vegetation (Oberem 2016). Production systems for these species, particularly in South Africa, are expanding and being intensified, as explained by Taylor et al. (2020), further supporting commercial game meat production. In addition to their adaptability, antelope tend to have high dressing percentages, carcass yields, and meat protein content, while being low in intramuscular fat (Needham et al. 2020; Hoffman 2003).

Despite the common eland (*Taurotragus oryx*) being identified as a suitable game species for game ranching and domestication early in the 1960's-1970's (Lightfoot & Posselt 1977), very little is known regarding optimization of its meat quality for commercial purposes. One of the challenges when it comes to game meat is that it is considered to be tough and dry by consumers when compared to livestock meat (Radder et al. 2005). This challenge is exacerbated by the fact that there is a knowledge gap in the optimal methods of processing, preparation, and cooking of game meat (Radder et al. 2005). Furthermore, game animals currently have no carcass grading system, hence carcass yield is being used as the sole performance and quality parameter. Despite the carcass yield being the most important economic factor currently, it does very little to address consumer expectations for meat tenderness and taste (Miller et al. 2001).

A few studies have addressed the ways to optimize major eating quality aspects of game meat, like tenderness, which consumers consider when assessing fresh meat quality (Grunert et al. 2004). Factors such as juiciness, tenderness, and flavour are known to influence meat quality, hence, studies focused on these aspects have proven that various methods of ageing can help improve these quality parameters (Neethling et al. 2016). There are different methods of ageing, including dry-, vacuum- (or wet), and semipermeable bag ageing. However, the most commonly used method in industry is currently vacuum-ageing, due to its benefits such as minimal ageing losses during storage (Hodges et al. 1974; Warren & Kastner 1992). However, dry ageing and semipermeable bag ageing provide benefits in terms of flavour development, which cannot be achieved during vacuum-ageing (Terjung et al. 2021). Adapting ageing periods depends on various factors, like the age of animal, pre-slaughter practises, and the sex of animal, just to mention a few. The early game meat ageing studies of North and Hoffman (2015) showed that springbok meat is tender and requires only 5 days of ageing to reach maximum tenderness. However, due to various factors like species/breed, age, sex, feeding regime, pre- and post-slaughter practises etc (Judge & Aberte 1982; Huff-Lonergan et al. 1995) that result in a variation of initial shear force values of fresh meat, the same ageing protocols cannot simply be applied across species, or even to animals of the same species differing in age or sex, without investigation into the efficiency of the protocol.

A recent study was done where the effects of wet and dry ageing techniques on various quality aspects of common eland meat were compared; Luciano (2021) highlighted that these techniques had no significance effect on shear force, the sensory panel preferred dry-aged meat, as it had better flavour and aroma development than wet aged meat. However, significant losses were experienced during the dry ageing process, and thus alternative techniques, such as semi-permeable ageing, could allow for similar flavour development as dry ageing while limiting the extent of moisture loss during the process. Thus, in the current study, the use of three different ageing techniques were compared, namely dry, wet, and semi-permeable ageing on the physical, chemical, and sensory qualities of common eland meat.

1.2. Literature Review

Extensive farming of indigenous game species has been common practice for more than 30 years in Europe, Africa, and North America, which has contributed to the increase in game meat consumption in the last few years (Bures et al. 2015). This increase has been due to different reasons, including the perceived health benefit of game meat, its unique taste and flavour, and the experience of tasting exotic meats (Costa et al. 2016). Game meat is generally considered to be healthy by consumers, due to its high protein content and, as explained by Barton et al. (2014), its low IMF content which has a higher proportion of essential polyunsaturated fatty acids compared to beef. Consumer's demand for meat is guided by factors like freshness, tenderness, juiciness, flavour, and recently leanness; however, as explained by Dransfield (2001), and Ngapo and Dransfield (2006), they are becoming more concerned by the safety and ethics of meat products as well. This includes the environment in which the animals were raised in, the use of organic, natural products (e.g, non-GMO feeds, no feed additives or pharmaceutical use) and low input methods (Dransfield 2003; Steenkamp 1997) thus, game meat is an attractive product for such consumers considering the current game farming practices. In South Africa, game meat is widely consumed and eating a dish with game meat has become part of the African experience, especially for tourists (Hoffman et al. 2003). Some of the most popular game species farmed and consumed include springbok (*Antidorcas marsupialis*), blesbok (*Damaliscus pugargus phillipsi*), kudu (*Tragelaphus strepsiceros*), Impala (*Aepyceros melampus*), gemsbok (*Oryx gazelle*), zebra (*Equus burchelli*), blue wildebeest (*Connochaetes taurinus*) and common eland (*Taurotagus oryx*), just to mention a few (Hoffman & Wiklund 2006). Common eland is one of the widely distributed species that has been recommended for domestication due to its body mass, ease of habituation to routine handling and management practises that are closely similar to that of cattle (Scherf 2000). These nice attributes have paved way for its intensification and another motivation for this intensification is its tasty gamey flavoured meat (Barton et al. 2014).

Not only does the average consumer expect meat products to be safe and healthy (Kristensen et al. 2014), they also prioritize eating qualities like taste, appearance, tenderness, and juiciness (Grunert 1997). Producing meat products that are consistent in meat quality is difficult to achieve with game meat production compared with domestic meat production, due to the current nature of production and harvesting. Consumers, however, will judge the quality the quality of game meat under the same criteria as they would beef meat (Hoffman and Wiklund 2006), which presents challenges for game meat producers to improve game meat quality characteristics, primality using post-harvesting techniques as they require no animal husbandry intervention.

1.2.1. Meat quality parameters

Meat quality characteristics that are pivotal include aroma, taste, texture, appearance, and nutritional value. However, there is a lot of variability in raw meat, even within the same muscle, which can lead to a number of variable products being marketed without a controlled level of quality (Damez & Clerjon 2008). Additionally, this problem is exacerbated when the industry is not able to fully characterize this level of quality and hence fail to market products with certain quality levels which is essential for the survival of any modern industry.

Meat quality often depends on the same criteria generally attached to other food. The basic attributes like proteins, fats, fiber, vitamins and minerals (like iron) relate to the nutritional content (Damez & Clerjon 2008). Pre- and peri-slaughter factors also influence meat quality (and its nutritional content), and include age, sex, feed type, slaughtering, methods, physiological conditions, physical activity of the animal, its body weight, and microbiological load on the carcass (Owen et al. 1978). For example, beef is very high in protein (19.87-21.73%), rich in all essential amino acids and a good source of zinc, vitamin B12, selenium, phosphorus, niacin, vitamin B6, iron and riboflavin 1 (Wazir et al. 2021). Wazir et al. (2021) added that it is low in carbohydrates and fiber; however, its fat content varies depending on species (typically between 1.98-3.1%). Game meat has higher protein and lower fat contents compared to domestic livestock (Hoffman & Cawthorn 2012). The protein content of game meat is generally >20g/100g and IMF content is .3g/100g (Van Schalkwyk & Hoffman 2016). The meat fatty acid composition is also considered to be better form a human health perspective in the meat from wild ruminants than in grain-fed cattle; Cordain et al. (2002) reported that meat from African wild ruminants contains less saturated fatty acids and more polyunsaturated fatty acids (PUFA) than beef. Additionally, the fat of wild ruminants has a favourable n3/n6 fatty acid ratio. These differences seem to be caused by diet, and game animals like deer and/or antelope species that are fed concentrates tend to have high total fat and saturated fatty acid content and decreased PUFA content (Manley & Forss 1979; Poli et al. 1993; Secchiari et al. 2001; Cordain et al. 2002; Rule et al. 2002; Wiklund et al. 2003a). Physical characteristics like pH, water holding capacity, cooking loss, drip loss, colour, and shear force are also important attributes with regards to meat quality, and are also influenced by these pre- and peri-slaughter factors.

There is a close correlation amongst many physiochemical meat quality parameters, like pH, colour, moisture content, and water-holding capacity. Typical ultimate pH values of e.g., beef ranges from 5.53-6, according to Wazir et al. (2021). Meat pH is important not only because it influences other physical meat properties (like colour, moisture loss, and shelf-life), but it also affects the processing of meat, because it relates to the ability of the meat muscle to bind water (Ribeiro et al. 2021). If meat pH is high, spaces within and between muscle myofibrils increases and hence increases water holding capacity. In the case of beef (and game meat), high meat pH results in dark, firm, and dry (DFD) or dark-cutting meat (Grayson et al. 2016); according to Ribeiro et al. (2021), the mean pH values of dark cutting loins and normal loins pH were 6.69 vs

5.47. However, meat colour development is further affected by a number of factors, including muscle myoglobin concentration, oxygen penetration, rate and degree of pH decline post-mortem, and the amount of free water on the surface of the meat (Ramanathan et al. 2020). The high myoglobin content and pH values result in the darker colour of game meat (Marsico et al. 2007b) and additionally as water holding capacity is related to pH which can also cause DFD. This carcass quality condition gives meat an abnormal colour making it unattractive to customers (Klont et al. 1998).

Consumer demand is highly consistent regarding tenderness; according to Boleman et al. (1997) almost 95% of consumers use tenderness as the main characteristic to determine quality of beef. Game meat is believed to be tougher than beef due to the short sarcomeres that characterise muscle structure (Wiklund et al. 1997). Meat tenderness (and thus its shear force) depends on myofibrillar structure and connective tissue (and its organization) which are strongly influenced by the inherent animal factors (species, breed, age, sex, etc.) and animal rearing conditions (Greenwood et al. 2007).

Consumers also evaluate meat quality based on taste, aroma, juiciness, and thus another key aspect is those parameters of quality that deals with the sensory properties of taste and appearance (Grunert 1997). Other sensory properties that are associated with meat eating include texture, palatability, chewiness, juiciness, flavour, crusting and pastiness, amongst others (Damez & Clerjon 2008). These are associated with a number of physiochemical properties, like sarcomere length, fat content and spatial organization, collagen content, and myofibers type, just to mention a few (Damez & Clerjon 2008). Meat water (moisture) content and pH are of the physical properties associated with sensory parameters like juiciness and tenderness, as well as defects like pale, soft and exudative (PSE) and dark, firm and dry (DFD) meat. As explained by Kuo and Chu (2003), these defects are specifically connected to water holding capacity (WHC), which determines meat juiciness.

In addition to nutritional, physical, and sensory meat quality, microbial quality and safety are important factors. Meat should be safe in terms of chemical residues, micro-organisms, heavy metals, and pathogens. The microbiological conditions of meat depend on a lot of factors, both intrinsic and extrinsic. They include micro-organisms found on the hide, in the GIT, on the muscle tissue itself, and are largely influenced by the conditions under which the animal was killed and/or dressed (Rahman et al. 2005). The intrinsic properties of fresh meat like pH, high water activity, and availability of glycogen and protein makes it a good substrate for microbial growth and consequently it is a highly perishable commodity (Rahman et al. 2005). The storage conditions and intrinsic biochemical qualities of meat are responsible for the microflora that develops during storage (Gill 2007). During meat processing methods that require drying, the meat is exposed to air that contains aerosolized micro-organisms, particularly moulds and spores, which are resistant to the drying process. Dry ageing encourages the growth of both beneficial and undesirable moulds. *Thamnidium* which is the most desirable mould is normally found on the surface of dry-aged meat (Dashdorj et al. 2016). This type of mould creates collagenolytic enzymes that have the ability to penetrate through the meat and break down muscle and connective tissues thus enhancing tenderness and taste (PrimeSafe 2017).

1.2.2. Using dry ageing to improve meat quality

Traditionally, the common types of ageing known and used were dry ageing (DA) and wet ageing (WA). Dry ageing is a process that has been adopted by many restaurants and upscale hotels as a way of enhancing beef flavour and tenderness. Dry ageing is described as a process that allows cuts or carcasses to be stored without protective packaging at refrigeration temperatures, to allow natural enzymatic and biological processes to take place (Savell 2008). Whereas wet ageing is a process in which meat is packaged in a water-impervious bag (Ahnstrom et al. 2006) and optimal duration is 14 days or longer at optimal temperature of 0°C to -1°C (Leroy et al. 2004). Important factors to consider in dry ageing are the length of ageing, storage temperature, relative humidity and air flow, as further articulated by Savell (2008); these factors are important as they relate to attributes like flavour, shelf life, shrinkage, microbial spoilage, and other quality and economic issues.

Basically, as explained by Draper (2018), ageing does two things that enhances the positive flavour aspects of meat; it breaks down connective tissue via the naturally occurring enzymes and it dehydrates the moisture within the muscles, usually improving flavour. Kim et al. (2018) explained the processes that occur during dry ageing, which includes Maillard reactions, growth of yeast, fatty acid oxidation, enzymatic proteolysis, etc which result in more intense flavoured beef. Additionally, as articulated by Campbell et al. (2001); Kim et al. (2016); Warren and Kastner

(1992), dry ageing enhances unique flavours, which can be described in terms of brown-roasted, beefy, buttery, nutty, roasted nut and sweet flavours.

Dry ageing is an ageing technique that exposes meat to air flow in the absence of vacuum packaging (Khan et al. 2016). Thus, this exposure leads to the meat surface drying and forming a crust. Growth of micro-organisms, particularly moulds and yeast, have been observed on the crust (Kim et al. 2020). As articulated by Oh et al. (2019), moulds and yeast observed on dry-aged beef (DAB) have been reported to have proteolytic and lipolytic activities that can induce the breakdown of myofibrils in DAB. Hence, the tenderness of DAB has been related to the presence of moulds, yeast and endogenous enzymatic activity in beef muscle (Kemp et al. 2010).

With factors like the effect of air flow rate, purveyors use some parameters like perforated shelves or special racks to help ensure the process is conducted in the best manner possible (Savell 2008). Storage temperature needs to be prioritized because optimal temperatures aid in the enzymatic processes involved with ageing. If the temperatures are below freezing point (-2 to -3°C) the enzymatic process will cease, and if the temperature is too high not only will the ageing process work well but the microbial spoilage will take place as well leading to off-flavours and colours (Savell 2008). Dry ageing literature has reported storage temperatures of around 0-4°C and a relative humidity of approximately 80% (Savell 2008). Relative humidity is another important factor because if it's not controlled or is set too high it can lead to growth of spoilage bacteria, and if it's too low it can lead to excess product shrinkage. A number of studies were done where an approximate of 80% relative humidity was used. These include Parish et al. (1991) who used a range of 80-85%, Warren and Kastrer (1992) used 78-80%, just to mention a few.

In terms of ageing periods, Smith (2007) compared dry ageing and wet ageing of beef over periods of 14, 21, 28 and 35 days and found no differences in overall flavour and level of tenderness. However, a significance decrease in shear force from 14-35 days was observed. Another study done by Campbell et al. (2001) compared dry ageing periods of 7, 14 and 21 days for beef. Only minor benefits on some palatability traits were found. Thus, dry ageing periods of 14-35 days have shown to be effective for beef (Savell 2008), but unfortunately there is limited scientific information/support to recommend the best period of dry ageing for game meat. Luciano (2021), who investigated the effects of dry ageing on common eland meat quality, reported a higher preference for dry aged meat amongst the sensory panel, as dry ageing eland meat showed better flavour and aroma development. However, overall there were no differences in overall acceptance of either dry aged or wet aged, despite dry aged eland meat having more favourable scores regarding liver flavour and abnormal aroma intensity, which were higher in wet aged meat.

The unique flavours associated with dry aged beef develop through reactions between compounds during ageing (Lee et al. 2019). These flavour compounds include taste-related compounds and aroma volatiles, where taste related compounds include inosine 5'-monophosphate, reducing sugars, and free amino acids. Aroma volatiles are derived from the oxidation of lipids such as triglycerides, phospholipids and free fatty acids (Lee et al. 2019). During dry ageing, as moisture is lost, the flavour compounds become concentrated (Kim et al. 2016; Lee et al. 2019). This observation agrees with Warren and Kastner's (1992) study that reported higher levels of beefiness and brown-roasted flavours in dry aged strip loins than vacuum (wet) aged strip loins (WA).

Bacterial growth is another important parameter that relates to the safe production of aged beef. Mikami et al. 2021 recorded higher lactic acid bacteria in wet aged beef (WAB) compared to DAB. This could have been due to the anaerobic conditions of vacuum packaging that allows lactic acid bacteria to predominate (Ahnstrom et al. 2006; Parris, Boles et al. 1991). The differences in the abundance of lactic acid bacteria in WAB and DAB may also be used to explain the differences in pH. Mikami et al. (2021) recorded a high pH in dry aged beef with *Mucoraceae* fungi compared to WAB. The same was observed in a study done by Ha et al. (2019) on Australian beef loins that were aged for 35 days.

There are fungi species that grow well at 15-25°C that are associated with dry aged meat and these include *Penicillium* species and *Debaryomyes* species (Ryu et al. 2018). One of the yeast complexes that is commonly found in food products, including dry aged meat, is a member of *Debaryomyces hansenii* complex (Oh et al. 2019). *Penicillium* species are often associated with bad taste and smell, however, members of the *Debaryomyces hansenii* complex have been observed to play a role in inhibiting the growth of *Penicillium* species (Medina-Cordova et al. 2018).

A study that was conducted by Mikami et al. (2021) observed *Mucoraceae* to be the predominant fungi on the dry aged beef, with two distinct isolated strains, namely *M.flavus* and *H.pulchrum*. *M.flavus* has been reported to play a major role in the dry ageing of beef (Hanagasaki & Asato 2018) and Mikami et al. (2021) reported that the *Mucoraceae* strains grew at 4°C indicating that they are psychophilic. The *M.flavus* strains were compared to other know strains and it was discovered that they were closely related to *M.flavus* CBS 992.68, PG 268 and PG 272 which were isolated in Antarctica (Walther et al. 2013), suggesting that they prefer a cold environment including refrigeration for dry ageing. The characteristics of *M.flavus* strain being a psychophile suggests that it is not pathogenic to humans and endothermic animals making it safe for dry aged beef production (Mikami et al. 2021).

In the case of meat ageing, ageing bags can protect meat from being contaminated and can also modify the growth of micro-organisms already present in meat, depending on the permeability of the packaging. Li et al. (2013) supported this theory through a study that reported same mould and *enterobacteriaceae* (EB) counts from samples aged in dry ageing bags and those from vacuum-aged. Parish et al. (1991) reported similar results which were likely due to the anaerobic conditions of meat in vacuum packaging that may result in the dominance of this type of bacteria compared to meat exposed to aerobic conditions. Additionally, Ahnstrom et al. (2006) reported that ageing meat in dry aging bags decreased the yeast count compared to the traditional unpacked dry aging, hence supporting the advantage of using dry ageing bags to decrease the risk of microbiological contamination and ensuring food safety.

Wet ageing, on the other hand, has been popular for improving meat tenderness and extending shelf life (Jayasingh et al. 2001) and decreasing losses during ageing. It is the most dominant packaging method in the current commercial meat industry. Vacuum packaging also removes oxygen which eliminates the oxidizing effect hence allowing longer ageing times to delay lipid oxidation and meat discoloration (Filgueras et al. 2010; Lindahl 2011; Ijaz et al. 2021; Pietrasik et al. 2006). Wet ageing is also advantageous in that it is associated with low cost (Ahnstrom et al. 2006; Smith et al. 2008) in terms of product shrinkage, trimming loss, storage, and transportation. Wet ageing also prevents weight loss caused by water evaporation bacterial growth (Campbell et al. 2001). The effect of wet ageing on tenderness is similar to that of dry ageing as both techniques results in meat that is tenderer. Hence, as Warren and Kastner (1992) explained, the preference for one ageing technique over the other based on tenderness is not necessarily justified, however preference can be based on flavour differences. Wet ageing results in a sour and strong bloody flavour with slimy surface and odour (Adegoke & Falade 2005). Luciano (2021) explained how the levels of malondialdehyde can impact the development of flavours in aged common eland meat, and that dry aged eland meat also benefits from the development of unique flavours. On the contrary, wet aged eland meat did not necessarily benefit from the development of more complex flavour compared to dry aged meat, and had a more intense abnormal odour compared to the dry aged meat. However, dry aged common eland meat suffered high yield losses, as game meat does not have a protective layer of subcutaneous fat to prevent moisture loss.

Many studies have shown that consumers are willing to pay more for the dry aged beef flavour profile. Meyerding et al. (2018) reported that German consumers were willing to pay 36.5% more for dry-aged beef. The greatest detriment to dry ageing is the high cost related to great weight losses and decreased yields due to trimming (Parish et al. 1991). Nonetheless, it still remains the most popular technique for ageing beef used by upscale restaurants due to consumer's perception of premium quality. However, semi-permeable bag ageing offers an alternative option that could reduce weight and yield loss, prevent the slimy surface and off-odour caused by wet ageing, and at the same time, enhancing meat eating qualities like flavour and juiciness that are achieved through dry ageing.

1.2.3. Semipermeable bag ageing – balancing flavour development, microbial safety, and yield losses

Recently, a new packaging technology for meat ageing was introduced, which simulates traditional dry ageing as it has a one-way water vapour transmission and are oxygen-permeable (Berger et al. 2018; Kim et al. 2018; Setyabrated et al. 2021; Jaspal et al. 2022). Ahnstrom et al. (2006) and DeGeer et al. (2009) observed that the use of permeable ageing bags (also known as dry bag ageing, or in-the-bag ageing) had no negative effects on meat quality, reduced microbial spoilage, and had positive effects on yields. The fact that traditional dry ageing is done without packaging under strict cooler quality control means that the product will be accompanied by high costs due to decreased yields during ageing (from moisture loss) and trimming of the hardened crust (Smaldone et al. 2019; Warren and Kashner 1992). Dry ageing bags are a scientifically synthesised bag-system based on specially formulated and breathable membrane technology that block oxygen and allows moisture out. This bag-system takes into consideration humidity, temperature, air flow and microbiological activities involved in beef ageing process without the risk of spoilage (Jaspal et al. 2022).

A number of studies were done that explained the effects of (semi)permeable ageing bags on various attributes like flavour, tenderness, microbial activities, just to mention a few. Ahnstrom et al. (2006) conducted a study which compared dry ageing versus semi-permeable bag dry ageing for 14-21 days in an attempt to demonstrate the principal effects of permeable ageing bags. The study showed that there were no differences in weight and trim loss between the two ageing methods after 14 days, however, after 21 days dry aged beef had the highest trim loss whereas bag dry ageing did not differ between the ageing period used. Ahnstrom et al. (2006) also reported that there were no differences recorded between ageing methods and times on physical attributes like cooking loss and shear force.

Permeable bag ageing has been reported to enhance flavour, particularly the beef and brown-roasted flavour that was normally observed in dry aged meat (Barragan-Hernandez et al. 2022). Additionally, this report was supported by Ahnstrom et al. (2006) who explained that descriptive sensory attributes also showed no differences between dry ageing and bag ageing methods although the panellists rated tenderness, aged-beef flavour, beef flavour and brown roasted flavour highly desirable.

Permeable bag ageing, just like wet ageing, has been known to prevent bacteria growth (Campbell et al. 2001) and limit microbial contamination (Ahnstrom et al. 2006). Ahnstrom et al. (2006) reported that there was a significant difference activity between the dry ageing and bag ageing treatments in microbial for lactic acid bacteria and yeast counts. The adipose tissue on loin sections aged in the bag had higher number of lactic acid bacteria, and Parish et al. (1991) explained that the reason is the fact that lactic acid bacteria predominates in vacuum packaged meat in contrast to meat exposed to aerobic conditions. Additionally, yeast counts increased with ageing period for both treatments and this could have been due to the fact that yeast has a lower water requirement than bacteria (Ahnstrom et al. 2006).

Another study that endeavoured to show the effect of permeable bag ageing was conducted by Barragan-Hernandez et al. (2022). They conducted their semipermeable bag ageing study at 2°C storage temperature and 80% relative humidity, where the effect of permeable bag ageing on cow and steer meat on different attributes like meat quality, sensory characteristics, and volatile compounds was investigated. The effect of ageing method in volatile compounds, for example, varies with the technique regardless of animal sex. To support this observation, Barragan-Hernandez et al. (2022) explained that the concentration of volatile compounds like hexadecanal, (Z)-9 hexadecenal, I-dodecanol and I-butanol derived from lipid oxidation decreased in dry-aged meat, which could have resulted in the variation in sensory characteristics like livery flavour.

However, despite the permeable bag ageing only affecting a few volatile compounds, Yancey et al. (2006) concluded that the decrease in livery flavour in meat from both cows and steers is of enough value for the permeable bag ageing to be considered by the beef industry for processing.

Flavour is one of the most crucial palatability attributes that is used to enhance overall product flavour and it is related to the concentration of volatile compounds. An extensive study done by Campbell et al. (2001) on certified Angus beef®, particularly striploins and short loins, found that flavour increased in cuts dry aged at least for 14 days. Specifically, Barragan-Hernandez et al. (2022) highlighted that dry ageing increased the salty taste and sour-dairy flavour whereas livery flavour decreased, compared to wet ageing. Additionally, permeable bag ageing also resulted in an increased salty taste of beef compared to wet ageing (Li et al. 2014; Kim et al. 2019). Gredell et al. (2018) found higher intensity of sour flavour in dry-aged beef than fresh beef, while Foraker et al. (2020) observed a decreased in sour flavours in dry-permeable bag and wet aged meat.

The lack of significant differences between traditional dry ageing and permeable ageing methods for most quality traits showed the effectiveness of permeable bag ageing. The advantages that were gained through higher yields without sacrificing the sensory traits show that the method can be an alternative solution for both large and small processers for aged meat products, especially game meat that does not have a protective subcutaneous fat layer. Ageing in the bag increased yields, limits microbial contamination, enhances the unique flavour that is similar to that of traditional dry ageing and allows for more economic feasibility (Ahnstrom et al. 2006). As reported by Barragan-Hernandez et al. (2022), semi-permeable bag ageing enhances the beef and brown roasted flavour that was normally observed in traditionally dry aged meat. Coupled with the lack of subcutaneous fat and generally higher liver-like and sour flavour and aroma intensities in many game species, and the high moisture losses during dry ageing, semipermeable bag ageing could be a viable solution to improve the tenderness of game meat, while improving its flavour profile.

2. Aims

The aim of this thesis is to compare the effects three different ageing techniques, namely: wet, dry, and semi-permeable bag ageing, on the physical, chemical, and sensory qualities of common eland meat. The specific objectives were:

- to compare the weight loss experienced during wet, dry, and semi-permeable bag ageing over two time periods;
- to evaluate the effect of different ageing techniques over two ageing periods on the physiochemical characteristics of common eland meat;
- to compare the effects of the three ageing techniques on the sensorial attributes of common eland meat, as assessed by a trained panel.

2.1 Research questions

1. Will the ageing techniques improve the overall eating quality of farmed eland meat when compared to non-aged/fresh meat?
2. Will there be a significant difference amongst the three ageing techniques in terms of the physical, chemical, and sensory qualities of the meat?
3. Does ageing period influence the meat quality of common eland meat for each of the three different ageing techniques?

2.2 Hypotheses

Firstly, H_0: Ageing will not affect the overall quality of common eland meat

H_1: Ageing will affect the overall quality of common eland meat

Secondly, H_0: There is no significant difference amongst the three ageing techniques or ageing periods in terms of physiochemical and sensory qualities of meat.

H_1: There is a significant difference amongst the three ageing techniques and/or ageing periods in terms of physiochemical and sensory qualities of meat.

3. Materials and Methods

3.1. Experimental design, animals, and slaughter

Animals were selected from the Common Eland Research Facility in Lány (50°7'41.704"N, 13°57'31.370"E) in the Central Bohemia region, Czech Republic (accreditation no. 63479_2016-MZE-17214; ethical clearance no. CZU 20/19). As described by Barton et al. (2014), the eland is kept under conditions that are similar those for cattle husbandry and production. The animals were reared in a barn on deep litter straw bedding and fed with a mixed feed ration consisting of corn silage, lucerne haylage, meadow hay, straw, a mineral supplement and concentrated pelleted cattle feed (19% crude protein). During spring to autumn, they have access to paddocks with pasture.

Six adult females (282.2 ± 28.32 kg live weight and between 14 and 15 years old, according to birth records) were randomly selected for the experiment. These animals were chosen as prime candidates for implementing post-mortem meat ageing, as females are usually only slaughtered after their reproductive lifespan, resulting in larger muscles with potentially higher initial shear force values when compared to younger animals. Slaughtering and exsanguination was carried out at the research facilities under supervision of the state veterinarian, while evisceration and carcass processing was done at the accredited abattoir at the Institute of Animal Sciences Prague. Animals were briefly held in a squeeze chute (which they were habituated to) for slaughtering, so as to minimize pre-mortem stress. The first step in slaughtering was rendering the animal unconscious by stunning using a captive bolt, and then immediately bleeding by a thoracic stick while the animal was suspended. Carcasses were then transported to the abattoir for evisceration, where all internal organs were removed, as well as the head, skin, and feet. Carcasses were weighed, split along the spinal column, and then placed in a cool room for 24 hours at ± 4°C while suspended by the Achilles tendon. The cold carcass weight was recorded again at 24 hours post-mortem (131.6 ± 20.50 kg; 40.9 ± 3.91 % dressing percentage).

3.2. Sampling and meat ageing

After cooling for 24 hours (i.e., D1-Day 1), the left and right *longissimus lumborum* (LL) region of the *longissimus thoracis et lumborum* (LTL) muscles were removed from the carcasses. The LL muscles were placed on a sterilized cutting board and 250g was sampled for proximate chemical analyses from the left LL muscle. Then, three steaks (2cm-thick) were cut from the right LL muscle, which was used for physical meat quality analysis. The remaining LL muscles were then each cut into three pieces. Each piece was randomly assigned to either wet (WA), dry (DA), or semi-permeable bag (SBA) ageing, for either 14 or 28 days (i.e., six treatment combinations). Upon assigning samples to specific analyses, the LL muscle pieces were weighed and either vacuum-packaged (wet ageing), left unpacked (dry ageing), or packaged in semi-permeable bags (DryAgingBags™ Size: 10x20 in / 25x50cm) which were scientifically synthesised and used a breathable membrane technology according to the manufacturer's recommendations. The samples were then placed in a controlled chamber (Friulinox AS-EN2-VTR, Friulinox Ali Group Srl A Socio, Italy) at a temperature of 2°C, humidity of 80%, with the air exchange being 15%, and exhaust air rate of 1.8 m^3 / hour.

3.3. Physical meat quality analyses

At Day 1, the steaks that were cut from the LL muscle were used to analyse pH, using a pH and integrated temperature probe for automatic adjustment (InoLab pH 730 set, WTW, Weilheim, Germany) and surface colour. According to Needham et al. (2019), one steak per meat sample was bloomed for 45 minutes and then measured for CIE Lab surface colour with a portable spectrophotometer (CM-700d, Konica Minolta, Osaka Japan, aperture diameter, 8mm illuminant: D65, observer angle:10° and specular component: 0% UV). For each sample, six colour measurements were randomly taken at different positions and then averaged for each of the L*, a* and b* values. The second steak was used to determine cooking loss percentage. Each steak was weighed, placed within plastic bags and into a preheated water bath at 80°C. Time frame for cooking was determined by the steaks reaching an internal temperature of 75°C, as explained by Needham et al. (2020). Temperature was measured by a thermometer probe placed into the centre of the steak.

Cooked samples were cooled down to room temperature, their weight was measured, and they were then used for shear force determination. This was done using an Instron Universal Texture Analyzer 3365 (Instron Canton, MA, USA), fitted with a standard Warner-Bratzler blade, at a crosshead speed of 100mm/ minute. Six rectangles, measuring 1×2cm, were cut from each cooked sample. The Warner-Bratzler blade cut each cube perpendicular to the direction of the muscle fibres, and the peak shear force was recorded as an average of the six measurements per meat sample. At day 14 and 28 of ageing (D14/D28), muscles pieces were removed from the ageing chamber (and packaging), and weighed so as to determine the moisture loss over the respective ageing period. Samples were taken for chemical analyses, as previously stated. The physical measurements performed on D1 were then repeated.

3.4. Chemical composition analyses

Approximately 250 g of the LL samples set aside for chemical analyses were homogenized in a food blender and frozen at −20°C. Parameters analysed were dry matter, crude protein, intramuscular fat, and ash content. Dry matter percentage was determined by oven drying at 105°C to a constant weight, and comparing the initial vs final weights (AOAC 2005). The dried samples were then pulverized using a Grindomix GM 200 knife mill (Retsch, Haan Germany) and crude protein was analysed using a Kjeltec 2400 (FOSS Tecator AB, Höganäs, Sweden) (AOAC 979.09 2005). Intramuscular fat was analysed according to Soxhlet (ISO 1444 Meat and Meat Products – Determination of Free Fat Content) through extraction with petroleum ether (Soxtec Avanti 2055, FOSS Tecator AB, Höganäs, Sweden). Crude ash was analyzed by incineration at 550 °C using an electric furnace (LAC L15/12, LAC, Židlochovice, Czech Republic) for 24 hours (AOAC 942.05 2005).

3.5. Sensory evaluation

After weighing and sampling, the remaining aged meat samples were cut into 2cm-thick steaks and cooked on a double glass-ceramic plate grill, preheated at 200°C, until the steaks reached an internal temperature of 70°C. The temperature was measured using a temperature probe (AD14TH, Ama-digit, *Kreuzwertheim* Germany). Cooking loss was determined by comparing pre- and post-grilled weights of the steaks. Cooked samples were cut into cubes measuring 2×2×2cm, placed in labelled glass jars (according to randomized coding for presentation to the panellists), and maintained at 50°C for approximately an hour in preparation for sensory evaluation. A further six cubes were used to determine WBSF, as articulated earlier.

The sensory evaluation was performed by 10 trained panellists (ISO 8586-1993), each allocated to an individual booth equipped with necessary utensils, under a red lighting (ISO 8589-1988), according to Barton et al. (2014). Panellists were provided with 3 samples (wet, dry and semi-permeable aged meat) from the same animal per evaluation set. Each panellist received the animal samples in a randomized manner, to avoid crossover effects. Panellists were asked to record their evaluation of the sensory attributes of the samples from the three ageing techniques using an evaluation form provided (Table 1). Attributes like aroma, texture, and flavour were assessed on a continuous scale from 0 to 100, according to Luciano (2021). The overall descriptor sensory analysis included 18 samples during one trial and the evaluation included two sensory sessions. (14 and 28 days of ageing). Lastly, panellists were provided with bread and water to cleanse their pallets between samples.

Table 1. Description and scale of the sensory attributes used to evaluate eland meat after wet, dry, or semipermeable bag ageing for female common eland (*Taurotragus oryx*) *longissimus lumborum* muscles.

Attribute	Evaluation	Scale
Beef aroma intensity Game aroma intensity Abnormal odor intensity	Before eating sample	0 = very low 100 = very high
Tenderness	After first two or three chews	0 = very tough 100 = very tender
Juiciness	After first five or ten chews	0 = very low 100 = very high
Fineness		0 = very coarse 100 = very fine
Chewiness	After at least fifteen chews	0 = difficult to chew 100 = easily chewable
Beef flavour intensity Game flavour intensity Abnormal flavour intensity Liver flavour Sour flavour Nutty flavour Roasted flavour	After first five or ten chews	0 = very low 100 = very high
Overall acceptance	After completion of evaluation	0 = not acceptable 100 = highly acceptable

3.6.Statistical analyses

Data from the physiochemical quality evaluations were analysed using STATISTICA (StatSoft Inc.). Normality of the residuals were ensured and Levene's test was used to confirm homogeneity of variances. The Variance Estimation and Precision (VEPAC) approach using restricted maximum likelihood was used, with the model including the fixed effects of *ageing method* and *ageing period*, and the random effect of *animal*. Means were compared using Fisher's Least Significant Difference post-hoc testing. Sensory data were analysed in SAS (Version 9.4, SAS Institute Inc., United States), using mixed linear models, with the fixed effects of *ageing method* and *ageing period*, and random effect of *animal* and *assessor*. Differences between treatments were tested Tukey's method. A significance level of 5 % was used throughout and results are presented as Least Squares means (LSMeans).

4. Results

4.1. Physical meat quality attributes

The interaction between ageing method and days was significant for weight loss, pH, L*, a*, b*, and cooking loss (boiled and grilled) (Table 2). The WA meat had the least weight loss of all ageing treatments ($P < 0.01$), with no differences between the ageing period of 14 or 28 days. The DA meat had the greatest weight loss ($P < 0.01$), increasing from D14 to D28 ($P < 0.01$), while SBA showed intermediary levels of weight loss between WA and DA, also increasing from D14 to D28 ($P < 0.01$). The changes in meat pH depended on the ageing method and period (Table 2); WA meat showed a higher pH on D14 than D1 ($P < 0.01$) and D28 ($P < 0.01$), as well as compared to SBA ($P = 0.014$) and DA ($P = 0.024$) meat at this time point, while SBA meat showed no significant change in pH over the ageing periods (Figure 1). The DA meat showed an increase in pH from D1 to D28 ($P = 0.031$). On D28, the pH of the WA meat was lower than the DA meat, with SBA meat pH being intermediate (Figure 1).

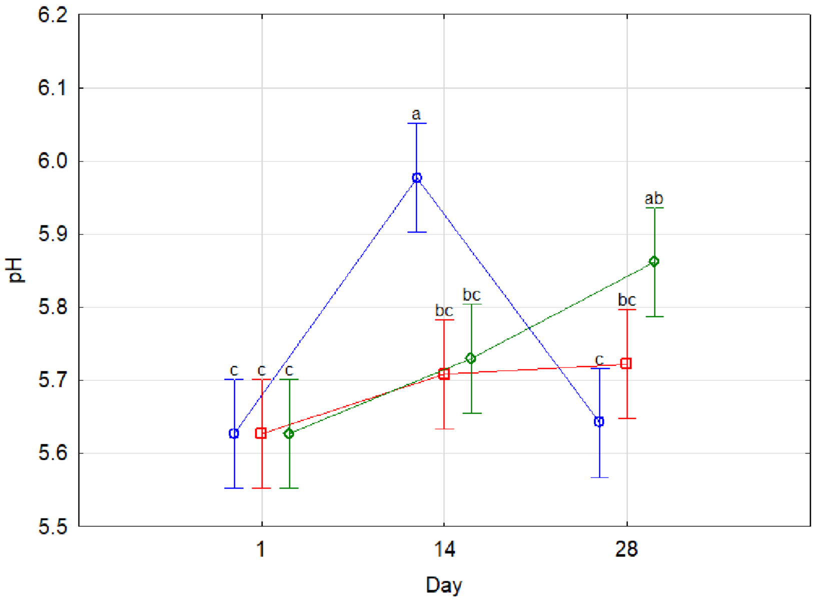

Figure 1. The pH values for female common eland (*Taurotragus oryx*) *longissimus lumborum* meat over 28 days of wet (blue), dry (green), or semi-permeable bag (red) ageing post-mortem. Different letters represent significant differences between treatment means (P < 0.05). Error bars represent standard errors of the means

The L* colour values for the cut and bloomed meat surfaces showed no difference between ageing methods or periods until D28, where SBA and DA meat had lower (P < 0.01) L* values (i.e., were darker) than the WA meat (Table 2; Figure 2). The a* colour values of the WA meat did not differ over the ageing period (Table 2; Figure 3). The SBA and DA meat showed equivalent a* values as the WA meat until D28, where they showed decreased a* values (i.e., were less red) than the WA meat (P = 0.040 and 0.012, respectively). The same result was observed for the b* colour values (Table 2; Figure 4), until D28, where the SBA and DA meat showed decreased b* values (i.e., were less yellow) than the WA meat (P < 0.01).

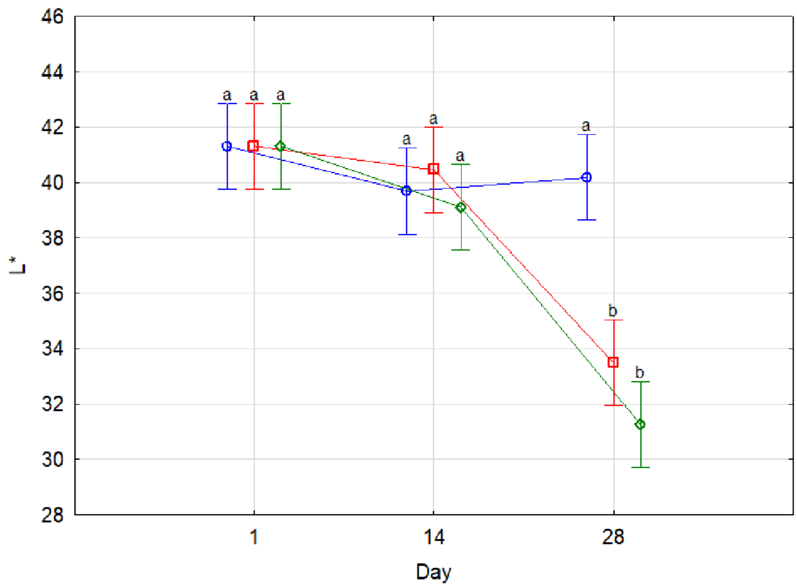

Figure 2. The L*(lightness) values for female common eland (*Taurotragus oryx*) *longissimus lumborum* meat surface colour over 28 days of wet (blue), dry (green), or semi-permeable bag (red) ageing post-mortem. Different letters represent significant differences between treatment means (P < 0.05). Error bars represent standard errors of the means.

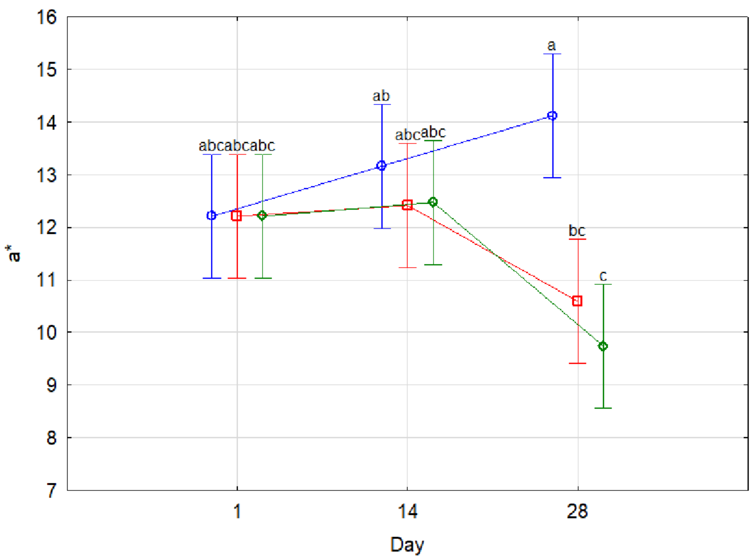

Figure 3. The a* (redness) values for female common eland (*Taurotragus oryx*) *longissimus lumborum* meat surface colour, over 28 days of wet (blue), dry (green), or semi-permeable bag (red) ageing post-mortem. Different letters represent significant differences between treatment means (P < 0.05). Error bars represent standard errors of the means.

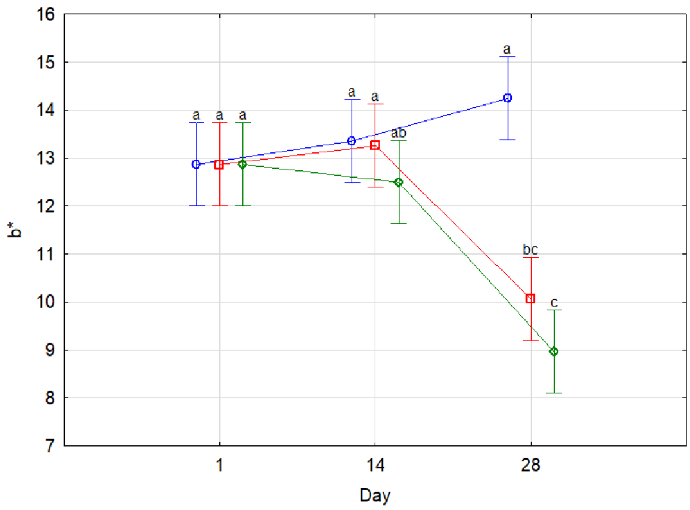

Figure 4. The b* values (yellowness) for female common eland (*Taurotragus oryx*) *longissimus lumborum* meat surface colour over 28 days of wet (blue), dry (green), or semi-permeable bag (red). Different letters represent significant differences between treatment means ($P < 0.05$). Error bars represent standard errors of the means.

The percentage of moisture lost during cooking of the boiled meat (i.e., in the water-bath) showed little differences between ageing methods over the ageing period, but was lowest in DA meat on D28 ($P < 0.0001$) due to a high level of moisture loss from the cuts throughout the ageing period (Figure 5; Table 2). The SBA meat also recorded a lower cooking loss at D28 compared to D1 and D14 ($P < 0.0001$); the SBA meat showed comparable cooking losses to WA meat, until D28, when it was comparable to DA meat (Table 2). On the contrary, WA meat showed no significance changes in cooking loss for boiled meat throughout the ageing period. Similar trends were seen for the grilled cooking method; however, the WA meat showed higher cooking losses on D14 and D28 compared to other ageing methods (Table 2).

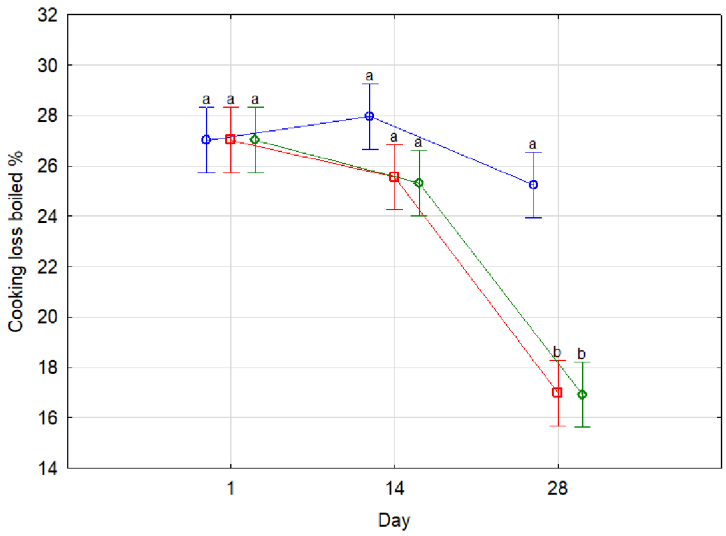

Figure 5. The cooking loss percentage for boiled female common eland (*Taurotragus oryx*) *longissimus lumborum* meat over 28 days of wet (blue), dry (green), or semi-permeable bag (red) ageing. Different letters represent significant differences between treatment means (P < 0.05). Error bars represent standard errors of the means.

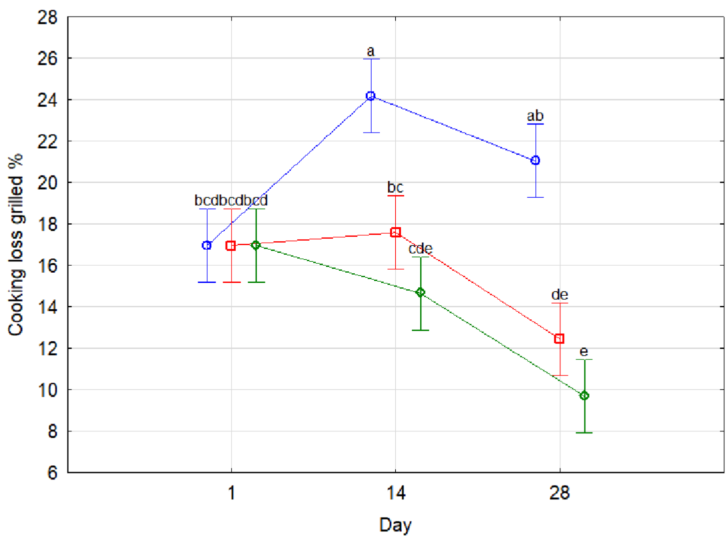

Figure 6. The cooking loss percentage for grilled female common eland (*Taurotragus oryx*) *longissimus lumborum* over 28 days of wet (blue), dry (green), or semi-permeable bag (red) ageing. Different letters represent significant differences between treatment means (P < 0.05). Error bars represent standard errors of the means.

The WBSF values showed no statistical significance regarding the interaction term for ageing method and days, for both boiled and grilled meat (P > 0.491 and P > 0.704, respectively)

(Figure 7 and 8; Table 2). For the main effect of days, D1 recording the highest WBSF value for all ageing treatments. Shear force, however, reduced with ageing period (D14 to D28) over all treatments (Table 2).

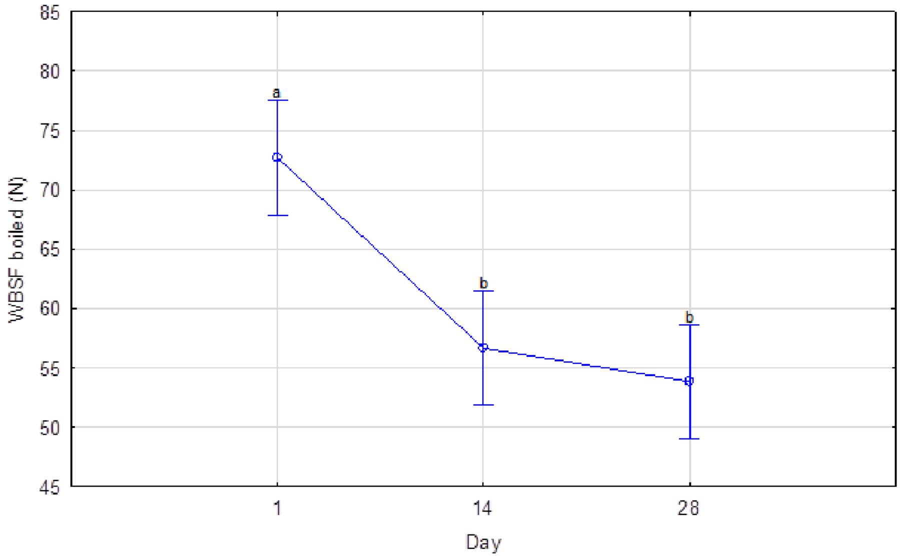

Figure 7. The Warner-Bratzler shear force (WBSF) of female common eland (*Taurotragus oryx*) *longissimus lumborum* meat over 28 days of ageing, after boiling. Different letters represent significant differences between treatment means (P < 0.05). Error bars represent standard errors of the means.

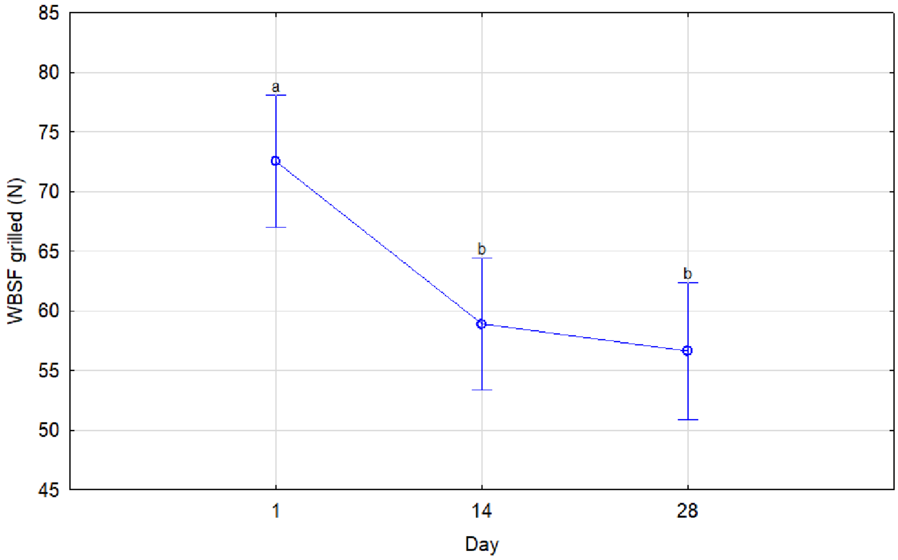

Figure 8. The Warner-Bratzler shear force (WBSF) of female common eland (*Taurotragus oryx*) *longissimus lumborum* meat over 28 days of ageing, after grilling. Different letters represent significant differences between treatment means ($P < 0.05$). Error bars represent standard errors of the means.

Table 2. The effect of ageing method and period (days) on the physical meat quality of the *longissimus lumborum* muscle harvested from mature female common eland at 24 h post-mortem (Day 1). Results are reported as Least Square Means and their pooled standard errors.

Treatment			Weight loss (%)	pH	L*	a*	b*	Cooking loss (%) boiled meat	WBSF (N) boiled meat	Cooking loss (%) grilled meat	WBSF (N) grilled meat
Ageing method		**Wet**	2.5	5.75	40.4	13.2	13.5	26.7	62.8	20.7	62.6
		SBA	23.1	5.69	38.4	11.7	12.1	23.2	60.4	15.7	63.5
		Dry	31.2	5.74	37.2	11.5	11.4	23.1	60.1	13.8	62.1
		SEM	0.98	0.046	1.31	1.06	0.75	0.97	7.04	1.33	8.44
		P-value	< 0.0001	0.519	0.002	0.005	< 0.0001	< 0.001	0.798	< 0.0001	0.957
Days		**1**	-	5.63	41.3	12.2	12.9	27.0	72.7^{a}	17.0	72.5^{a}
		14	13.0	5.81	39.8	12.7	13.0	26.3	56.7^{b}	18.8	58.9^{b}
		28	26.2	5.74	35.0	11.5	11.1	19.7	53.9^{b}	14.4	56.5^{b}
		SEM	0.80	0.046	1.31	1.06	0.75	0.97	7.04	1.33	8.44
		P-value	< 0.0001	0.014	< 0.0001	0.078	< 0.0001	< 0.0001	< 0.0001	0.002	0.030
Ageing method & days	**Wet**	**1**	-	5.63^{c}	41.3^{a}	12.2^{abc}	12.9^{a}	27.0^{a}	72.7	17.0^{bcd}	72.5
		14	2.2^{e}	5.98^{a}	39.7^{a}	13.2^{ab}	13.4^{a}	28.0^{a}	58.3	24.2^{a}	58.2
		28	2.8^{e}	5.64^{c}	40.2^{a}	14.1^{a}	14.2^{a}	25.3^{a}	57.4	21.0^{ab}	57.1
	SBA	**1**	-	5.63^{c}	41.3^{a}	12.2^{abc}	12.9^{a}	27.0^{a}	72.7	17.0^{bcd}	72.5
		14	14.9^{d}	5.7^{bc}	40.5^{a}	12.4^{abc}	13.3^{a}	25.6^{a}	51.3	17.6^{bc}	63.4
		28	31.4^{b}	5.72^{bc}	33.5^{b}	10.6^{bc}	10.1^{b}	17.0^{b}	57.1	12.4^{de}	54.7
	Dry	**1**	-	5.63^{c}	41.3^{a}	12.2^{abc}	12.9^{a}	27.0^{a}	72.7	17.0^{bcd}	72.5
		14	21.8^{c}	5.73^{bc}	39.1^{a}	12.5^{abc}	12.5^{a}	25.3^{a}	60.5	14.7^{cde}	55.1
		28	40.7^{a}	5.86^{bc}	31.3^{b}	9.7^{c}	9.0^{b}	16.9^{b}	47.1	9.7^{e}	58.1
		SEM	1.38	0.075	1.55	1.18	0.86	1.30	8.31	1.77	9.78
		P-value	< 0.0001	0.030	< 0.001	0.010	< 0.0001	0.002	0.491	0.003	0.704

$^{a, b}$ means with different superscripts indicate significant differences within each main effect/interaction ($P < 0.05$). Main effect differences are only indicated when interaction is not significant; SBA = semipermeable bag ageing; SEM = standard error of the mean; a* = redness; b* = yellowness; L* = lightness.

4.2. Meat chemical composition

The interaction between ageing method and days was significant for dry matter, crude protein, and ash content (Table 3). WA meat showed no differences in dry matter (DM) percentage throughout the ageing period (D1-D28), and thus no differences in protein, fat or ash contents Figure 9; Table 3). There was a gradual increase in DM in SBA and DA meat from D1 to D28, with the highest DM percentage recorded on D28 for DA meat ($P < 0.0001$) (Table 3). Consequently, SBA meat showed an increase in CP percentage from D1 to D14 ($P = 0.002$) and D28 ($P < 0.0001$) (Figure 10; Table 3). The DA meat also increased in protein content over the ageing period, as moisture was lost from the meat cut, with the highest percentage recorded on D28 ($P < 0.05$). Intramuscular fat (IMF) percentage showed no statistical difference ($P > 0.490$) in all three ageing techniques and over the ageing period (Table 3). The WA showed no differences in ash percentage throughout the ageing period (D1, D14, and D28) compared to SBA and DA. Ash percentage increased in SBA and DA meat on D14 and D28, with DA recording the highest percentage on D28 ($P < 0.0001$) (Figure 11; Table 3).

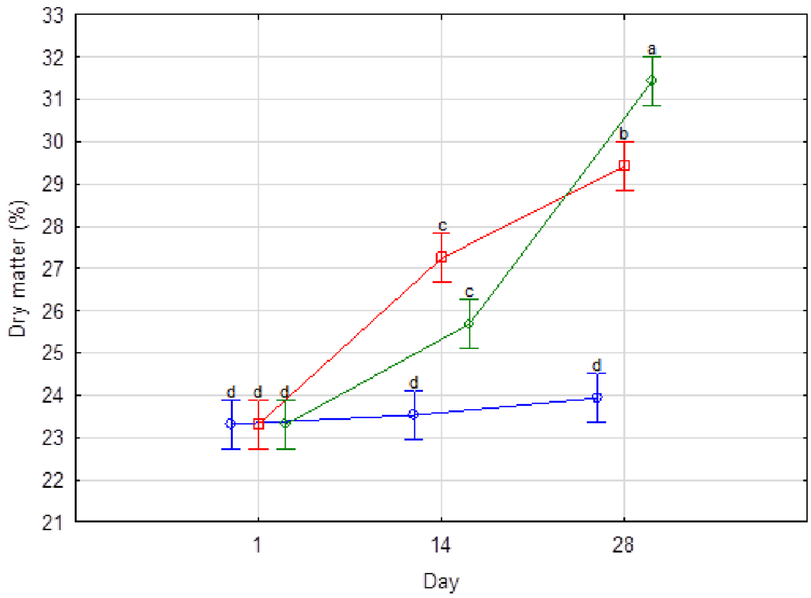

Figure 9. The dry matter percentage for female common eland (*Taurotragus oryx*) *longissimus lumborum* meat during 28 days of wet (blue), dry (green), or semi-permeable bag (red) ageing. Different letters represent significant differences between treatment means ($P < 0.05$). Error bars represent standard errors of the means.

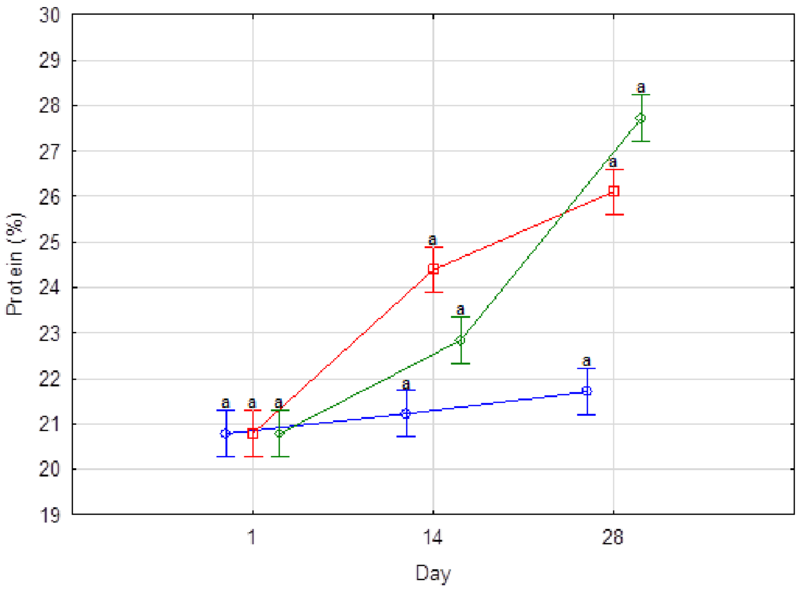

Figure 10. The protein percentage of female common eland (*Taurotragus oryx*) *longissimus lumborum* meat during 28 days of wet (blue), dry (green), or semi-permeable bag (red) ageing. Different letters represent significant differences between treatment means (P < 0.05). Error bars represent standard errors of the means**.**

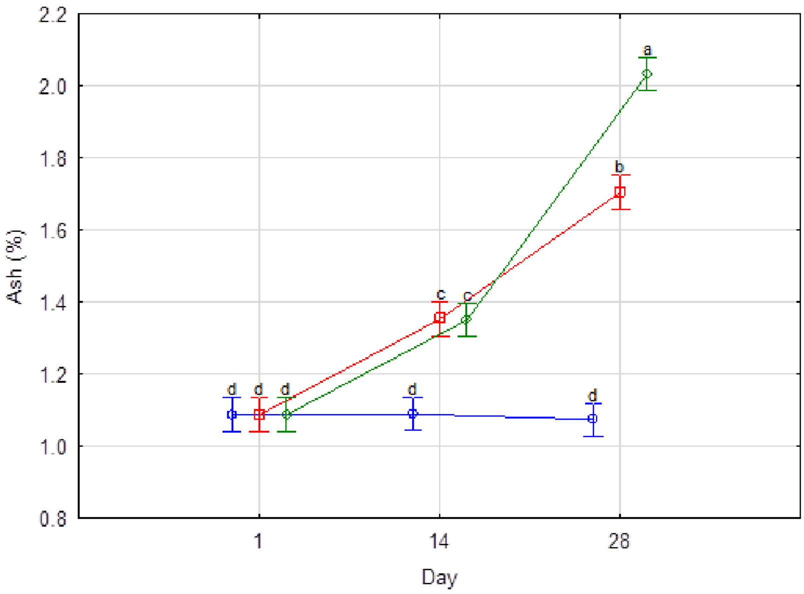

Figure 11. The ash percentage for female common eland (*Taurotragus oryx*) *longissimus lumborum* meat during 28 days of wet (blue), dry (green), or semi-permeable bag (red) ageing. Different letters represent significant differences between treatment means (P < 0.05). Error bars represent standard errors of the means

Table 3. The effect of ageing method and period (days) on the chemical composition of the *longissimus lumborum* muscle harvested from mature female common eland at 24 h post-mortem (Day 1). Results are reported as Least Square Means and their pooled standard errors.

Treatment			**Dry Matter (%)**	**Crude protein (%)**	**Intramuscular fat (%)**	**Ash (%)**
Ageing Method		**Wet**	23.6	21.2	0.24	1.08
		SBA	26.7	23.8	0.30	1.38
		Dry	26.8	23.8	0.26	1.49
		SEM	0.68	0.42	0.103	0.029
		P-value	< 0.001	0.001	0.933	< 0.0001
Days		**1**	23.3	20.8	0.27	1.09
		14	25.5	22.8	0.29	1.27
		28	28.3	25.2	0.24	1.61
		SEM	0.33	0.29	0.062	0.027
		P-value	< 0.0001	< 0.0001	0.232	< 0.0001
Ageing method & days	**Wet**	1	23.3^{d}	20.8^{e}	0.27	1.09^{d}
		14	23.5^{d}	21.2^{e}	0.25	1.09^{d}
		28	23.9^{d}	21.7^{de}	0.21	1.07^{d}
	SBA	**1**	23.3^{d}	20.8^{e}	0.27	1.09^{d}
		14	27.2^{c}	24.4^{c}	0.36	1.35^{c}
		28	29.4^{b}	26.1^{b}	0.26	1.71^{b}
	Dry	**1**	23.3^{d}	20.8^{e}	0.27	1.09^{d}
		14	25.7^{c}	22.8^{d}	0.26	1.35^{c}
		28	31.4^{a}	27.7^{a}	0.25	2.03^{a}
		SEM	0.58	0.42	0.107	0.047
		P-value	< 0.0001	< 0.0001	0.490	< 0.0001

$^{a, b}$ means with different superscripts indicate significant differences within each main effect/interaction (P < 0.05). Main effect differences are only indicated when interaction is not significant; SBA = semipermeable bag ageing; SEM = standard error of the mean.

4.3. Sensory attributes evaluation

The results of the meat sensory evaluation from the trained panellists after 14 days of ageing, as shown in Table 4. Game flavour intensity (P = 0.020) differed amongst the three treatments, with SBA meat recording a higher game flavour intensity compared to WA and DA. Attributes like beef aroma intensity, game aroma intensity, abnormal odour intensity, tenderness, juiciness, fineness, chewiness, beef flavour intensity, abnormal flavour intensity, liver flavour, sour flavour, nutty flavour, roasted flavour and overall acceptance did not differ amongst the treatments.

Sensory evaluation was also conducted at day 28, as shown in Table 5. Game aroma intensity, tenderness, beef flavour intensity, game flavour intensity, abnormal flavour intensity, sour flavour, liver flavour, and nutty flavour did not differ amongst the treatments. However beef aroma intensity (P < 0.0001), abnormal odour intensity (P = 0.003), juiciness (P = 0.0001), chewiness (P = 0.031), roasted flavour (P = 0.015), and overall acceptance (P = 0.027) differed amongst the three treatments. WA meat differed significantly in beef aroma intensity, juiciness and overall acceptance whereas DA differed in abnormal odour intensity, chewiness and roasted flavour.

Table 4. Organoleptic properties of *longissimus lumborum* meat from mature common eland females, after ageing for 14 days, as assessed by a trained sensory panel. Results are reported as Least Square Means and their pooled standard errors.

	Ageing method			*SEM*	*P*-value
	Wet	**SBA**	**Dry**		
Beef aroma intensity	44.0	40.4	37.7	4.17	0.184
Game aroma intensity	45.6	46.0	44.8	6.03	0.950
Abnormal odour intensity	25.5	26.5	29.1	6.67	0.518
Tenderness	52.6	48.8	48.1	3.88	0.556
Juiciness	54.6	57.0	55.8	3.96	0.829
Fineness	49.9	46.2	49.1	3.82	0.660
Chewiness	48.2	47.3	52.4	3.67	0.469
Beef flavour intensity	45.3	46.2	41.3	5.18	0.269
Game flavour intensity	41.6^{ab}	43.7^{a}	35.0^{b}	4.94	0.020
Abnormal flavour intensity	21.2	21.0	25.6	5.44	0.119
Liver flavour	28.1	28.5	29.5	5.40	0.911
Sour flavour	28.5	32.9	36.5	4.74	0.116
Nutty flavour	33.2	35.5	30.4	7.13	0.261
Roasted flavour	32.0	31.7	28.0	7.59	0.357
Overall acceptance	51.4	46.5	45.2	3.75	0.257

$^{a, b}$ means with different superscripts indicate significant differences within each main effect/interaction ($P < 0.05$).; SBA = semipermeable bag ageing; SEM = standard error of the mean.

Table 5. Organoleptic properties of *longissimus lumborum* meat from mature common eland females, after ageing for 28 days, as assessed by a trained sensory panel. Results are reported as Least Square Means and their pooled standard errors.

	Ageing method			*SEM*	***P*-value**
	Wet	**SBA**	**Dry**		
Beef aroma intensity	37.5^{b}	54.4^{a}	54.3^{a}	4.34	<0.0001
Game aroma intensity	44.4	50.5	48.8	4.46	0.331
Abnormal odour intensity	41.1^{a}	29.8^{b}	28.0^{b}	7.16	0.003
Tenderness	45.4	49.4	55.1	3.41	0.111
Juiciness	61.3^{a}	50.4^{b}	44.2^{b}	3.51	0.0001
Fineness	46.2	51.0	53.2	3.91	0.207
Chewiness	47.1^{b}	48.3^{ab}	58.5^{a}	3.32	0.031
Beef flavour intensity	50.2	56.3	55.7	5.08	0.155
Game flavour intensity	45.6	45.6	44.4	4.45	0.943
Abnormal flavour intensity	32.8	27.5	31.0	6.46	0.360
Liver flavour	27.7	28.9	35.1	4.87	0.098
Sour flavour	43.6	38.3	39.5	6.55	0.364
Nutty flavour	29.1	33.7	31.4	7.41	0.377
Roasted flavour	27.9^{b}	32.7^{ab}	39.1^{a}	6.11	0.015
Overall acceptance	42.0^{b}	51.0^{ab}	52.7^{a}	4.19	0.027

$^{a, b}$ means with different superscripts indicate significant differences within each main effect/interaction ($P < 0.05$); SBA = semipermeable bag ageing; SEM = standard error of the mean.

5. Discussion

This study observed that DA meat had the highest weight loss from D14 to D28, WA had the least weight loss while SBA recorded intermediary losses, which gradually increased from D14 to D28. Similarly, Luciano (2021) reported higher weight losses in dry aged eland meat compared to wet aged eland meat. Smith et al. (2014), who investigated retail yields from wet and dry aged beef rib-eyes and top sirloin butts, also showed similar results. Dry-aged rib-eyes produced greater percentages of crust and cooler shrink due to high moisture loss, whereas wet-aged rib-eyes produced a high percentage of fat trimmings, while wet-aged rib-eyes had higher saleable yields than dry-aged rib-eyes. In addition to higher moisture loss rates in dry aged eland meat, Luciano (2021) also reported that there was a 16.7% loss in surface area of *longissimus lumborum* steaks from dry aged common eland meat due to crust formation. However, when compared to dry ageing in the current study, the semipermeable bag ageing method decreased the extent of moisture loss in eland meat, which is particularly important as it does not have a protective layer of subcutaneous fat, which is often favoured when choosing cuts for dry ageing beef. In contrast to the present study, that recorded different weight losses between WA and SBA meat, Berger et al. (2018) reported no statistical difference in weight loss at D28 between WA and in-the-bag dry aged beef meat. These discrepancies in results, as explained by Kim et al. (2016), could have been due to differences in the controlled processing conditions like temperature, humidity, air flow, types of packaging used, and shape and size of the meat cuts, as well as presence/absence of subcutaneous fat.

In general, game meat is darker in colour than domestic species because of a high myoglobin content in the muscles (Onyanga et al. 1998) and often high pH values (Marsico et al. 2007b). For example, Barton et al. (2014) compared the meat quality between eland and cattle fed the similar diet, and recorded that the same muscle from the cattle was lighter and yellower at 24hr post-slaughter compared to that from the eland. Barton et al. (2014) also confirmed that eland meat had higher pH values than that of cattle. Gill and Newton (1981) highlighted that the normal pH of meat, which is about 5.5, is a prerequisite for a long-term storage, tenderness (Devine et al. 1993), and desirable colour (Lawrie 1958). High pH values can also be due to stress caused by hunting methods and improper carcass treatment (Hoffman 2000; Dhanda et al. 2003) and as a consequence, dark, firm and dry (DFD) meat can be produced by hunted game, which can lead to poor microbiological quality and meat that us unsuitable for processing into other products that should have a long shelf-life (Wiklund et al. 2001). Poor meat colour stability has been seen as a limitation factor, particularly in game meat marketing (Onyango et al. 1998; Wiklund et al. 2005).

In the present study, the animals were slaughtered on-site, without transportation, within facilities to which they were habituated and thus the initial pH values at D1 post-mortem were within the normal range. However, during ageing, changes in meat pH depended on the ageing method and period, which may also explain the differences seen in meat colour, together with the differences in moisture loss during ageing. SBA meat showed no significant change in pH over the ageing periods, whereas WA meat had a higher pH on D14 than D1 and D28, and DA meat pH increased from D1 to D28. The rate and degree of pH decline post-mortem influences colour development in meat, as well as oxygen penetration, myoglobin concentration, and the amount of free water on the surface of the meat, all of which have a significant impact on meat surface colour (Ramanathan et al. 2020). A higher pH increases the spaces between muscle myofibrils, which in turn results in a higher water holding capacity (Ramanathan et al. 2020), which influences light reflectance. In the present study, the L* (lightness) for the cut and bloomed meat surfaces showed no difference between ageing period until D28, at which point the SBA and DA meat was darker than the WA meat. SBA and DA meat showed equivalent values for both a* (redness) and b* (yellowness) than WA until D28 where meat surfaces were less red and less yellow respectively. The lighter colour observed in WA meat agrees with Kim and Hunt's (2011) findings that this lighter colour is due to the high moisture content in the WA meat after ageing, resulting in a higher degree of light reflection.

The cooking loss of meat is another important attribute for meat quality, which influences the yield and quality of other meat products (Li et al. 2013). The DA meat in the present study had a lower cooking loss percentage for both boiled and grilled cooking methods compared to WA meat, with meat on D28 recording lower values due to moisture loss throughout the ageing period. Additionally, SBA also recorded a lower cooking loss at D28 compared to D1 and D14, comparable to those of the DA meat; however, WA had no significant change throughout the ageing period, which is not surprising considering it retained its moisture during ageing. Similar results were observed by Barragan-Hernandez et al. (2022); Laster et al. (2008); and Li et al. (2013) regarding dry aged meat, consequently increasing cooking time and decreasing cooking loss of DA meat. As explained by Sitz et al. (2006), the low moisture content in DA meat leads to a slower heat transfer rate and hence increases the time to reach the same internal temperature. In contrast to the present study on eland, no differences were observed between WA and in-the-bag dry aged beef for cooking loss (Sitz et al. 2006). This could be due to a number of factors, like differences in the technical parameters of the ageing bags used and thus water vapour transmission rates. Additionally, Ueda et al. (2007) explained the correlation between moisture and crude fat content, and how fat becomes more concentrated as moisture is lost during the dry ageing process. This observation agreed with Mikami et al. (2021), where the moisture content of dry aged beef was lower than wet aged beef, and the crude fat content in dry aged beef was significantly higher than that in wet aged beef.

Meat shear force, and thus tenderness, is influenced by a number of factors, both intrinsic and extrinsic, like species, sex, age, feeding regime of animals, pre- and post-slaughter practises, just to mention a few. Wiklund et al. (1997) explained that the toughness of game meat, compared to domestic species, may be due to short sarcomere lengths and other characteristics of the muscle (like muscle fibre composition and size). Additionally, the toughness of game meat may also be influenced by its low intramuscular fat content which reduces juiciness (Kaufmann 1993; Hoffman 2000; Dhanda et al. 2003). Thus, tools such as carcass grading according to intrinsic factors (which is not commonly done for African game species) to sort the carcasses according to expected meat quality traits, and processing strategies, such as meat ageing, can be valuable in controlling this variability in meat shear force. Ageing improves the shear force of eland meat (Needham et al. 2020; Luciano 2021), as shown in the present study; however, the choice of ageing method did not significantly impact this, showing similar results. In the present study, D1 recorded the highest shear force value compared to D28. Shear force, however, reduced with ageing period (D14 to D28) proving that tenderness can be improved further with an increase in ageing period. High shear values can be explained by the ageing factor of the animals as they were older females past their reproductive lifespan. This is in contrast with Kim et al. (2016) and Smaldone et al. (2019), who recorded that dry ageing beef for at least 21 days decreased shear force values compared to wet ageing. Traditional dry ageing methods are coupled with proteolytic enzyme activity from aerobic bacteria, mould, and yeast on the surface, which aids in shear force improvement (Dashdorj et al. 2016; Flores & Toldra 2011; Lee et al. 2019). Thus, the conditions of the ageing chamber, and thus the development of different aerobic bacteria, mould, and yeast, may have an impact on the degree of effect of dry ageing on shear force, as well as flavour and aroma development.

Similarly, the pore size of semipermeable bags may also affect these parameters through different oxygen and water vapour transmission rates that may either limit or support certain microorganisms, thus impacting tenderization (Berger et al. 2018; Kahraman & Gurbuz 2019; Osterhout et al. 2019; Shi et al. 2020). This may explain the lack of effect of SBA, compared to other ageing methods, on the shear force in the current study, and in previous studies (Berger et al. 2018; Kahraman & Gurbuz 2019; Osterhout et al. 2019; Shi et al. 2020).

Sensorial attributes such as flavour, tenderness and juiciness are important parameters used to measure meat quality. Tenderness and juiciness are some of the main characteristics that consumers use to determine the quality of beef during eating (Boleman et al. 1997). The current study recorded high scores of tenderness for DA meat at D28 and for WA at D14, but they were not significant. Dikeman et al. (2013); Kahraman and Gürbüz (2019) and Osterhout (2019) also found no significance difference in tenderness according to sensory values between D21 and D42 of the in-the-bag drying and wet-aged beef samples. However, the eland meat differed in juiciness in the current study on D28, with WA meat recording the highest score compared to both SBA and DA meat, due to moisture loss during ageing, also impacting moisture lost during cooking. Campbell et al. (2001) mentioned that panellists found steaks that were dry aged for 14 days were significantly tenderer and juicer compared to those dry aged for 7 days, which shows the positive effect that longer ageing days can have on such meat-eating qualities. Additionally, the panellists did not rate the steaks that were further dry aged for 21 days as more tender, even though the WBSF was significantly lower compared to those aged for 7 and 14 days. This reiterates the importance of combining both physical and sensory quality assessments within a single study.

Traditional dry ageing facilitates an increase in two well-known amino acids, namely glutamic and aspartic acids, which are involved in umami taste development. This is affected by proteolytic enzyme activity from aerobic bacteria, mould, and yeast (Dashdorj et al. 2015; Mikami et al. 2021). Attributes like roasted flavour and overall acceptance in the current study were significantly different at D28, with DA recording highest scores. Additionally, dry-ageing eland meat for 28 days showed some improvement in a number of positive attributes, like beef aroma intensity and juiciness. The SBA method had comparable results for these attributes, showing benefits regarding both decreased moisture loss during ageing and development of positive aroma and flavour attributes. At D14, only game flavour intensity differed significantly, where WA and SBA meat had higher game flavour intensity compared to DA; however, at D28, all methods had comparable scores (i.e., DA meat increased in game flavour intensity). Generally, DA is one traditional method that has been known to enhance meat quality and palatability attributes compared to wet ageing (Warren and Kreshner 1992). Kim et al. (2016) also reported an improvement in juiciness in DA beef meat as compared to wet aged meat. One important aspect to note as expressed by Dashdorj et al. (2015) is that since beef flavour is key for eating quality and overall acceptability, there is need to control the increase of fatty acids as they can in turn cause undesirable after taste (Gorraiz, et al. 2002) and bitterness due to lipid-oxidized volatiles. There are various outcomes and explanations noted in different literature in terms of flavour and aroma development during ageing. Kim et al. (2016) reported that overall liking and flavour was enhanced by dry ageing compared to wet ageing. In contrast, Ahnstrom et al. (2006), and DeGeer et al. (2009) found no differences in flavour between dry and wet ageing and / or dry ageing in the bag. Panellists in the study of Ha et al. (2019) found minor differences in flavour, whereas in the study of Warren and Kastner (1992) found a more pronounced bloody, sour and serumy flavour in wet aged meat, and beefy, brown-roasted flavour in dry aged meat. Additionally, the dry ageing bag method resulted in a higher salty taste (Prieto et al. 2017). Terjung et al. (2021) discussed the importance of considering the raw materials used and processing parameters as they can aid in explaining the variations between dry and wet aged beef. Additionally, similar results were observed in game meat ageing studies particularly eland meat. Luciano (2021) observed flavour development in dry aged eland meat whereas wet aged had a more intense abnormal aroma and liver flavor. Rodbotten et al. (2004) also reported a high gamey flavour amongst the wild and domesticated species whose sensory profiles were quantified. Despite eland meat considered as being tough, the study of Needham et al. (2020) observed positive changes in the attributes like tenderness and colour. As highlighted by Kolbabek (2018) Aging of eland meat can be recommended with special regards on the chemical and sensory benefits that it can produce.

In addition to the dry bag ageing method, Terjung et al. (2021) mentioned the stepwise ageing method as a good applicable method that can be used for ageing eland meat and that creates a balance between dry and wet aged meat in terms of maintaining high palatability values. DeGeer et al. (2009) explained that the stepwise process involves storing dry aged beef in a vacuum after the dry ageing process without losing the palatability attributes. Microbiological activity that occurs during ageing is another beneficial aspect that needs to be explored further. A number of studies have articulated the benefits from safe production of aged meat as mentioned by Mikami et al. 2021 to the breakdown of myofibrils in dry aged meat due to the proteolytic activities of moulds and yeast. This could prove to be a game changer in the commercial production of aged meat products particularly using a technique like SBA that aids in improving meat eating qualities like flavour, aroma and juiciness and at the same time reducing moisture and yield losses through ageing and trimming.

6. Conclusion

There have been many advantages attached to meat ageing, including improvement in meat eating qualities like flavour, aroma, and tenderness. Based on the physiochemical results, the SBA technique improved the moisture lost during ageing as compared to dry ageing. SBA and DA techniques produced similar pH and meat which was darker than wet aged. The treatments has similar effects on tenderness as supported by the sensory panel, however D14 and D28 were comparable. Despite the lack of differences in tenderness, beef flavour and aroma was well developed in both SBA and DA at D28. SBA and DA had comparable results for these attributes, and the fact that these attributes have been associated with DA, it confirms the benefits of SBA in improving flavour and aroma attributes at the same time decreasing moisture and yield loss.

On the other hand, wet (vacuum) ageing is currently the most used in the meat commercial industry because of the convenient storage, transport and its ability to increase tenderness while controlling shrinkage. One of the biggest quality issues of wet ageing is that it results in meat with a sour, strong bloody flavour, slimy surface, odour and metallic taste. The SBA technique offers a balance in terms of meat quality benefits and yield losses as compared to DA and WA which could allow for more economic feasibility. Therefore, it is a technique that is worth researching more as an alternative ageing method that might add value in the commercial game meat industry. Further research on the microbial effects on physical, chemical and sensory attributes of eland meat need to be explored, so as to determine if microbial has a positive or negative bearing on the various meat attributes. Additionally, a combination of these ageing techniques can be explored further using game meat.

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8 Appendices

APPENDIX I: Sensory assessment form used by the panellists to score wet, dry and semi-permeable aged eland meat, using a continuous line scale method

protocol for sensory assessment **"eland 2021"**	**box num:**	**set num:**
kód hodnotitele / assessor:	**dne: 27.10.2021**	

Intenzita vůně hovězího m. (beef aroma intensity)

velmi nízká		**velmi vysoká**

Intenzita vůně zvěřiny (game meat aroma intensity)

velmi nízká		**velmi vysoká**

Intenzita abnormální vůně (abnomal odour intensity)

very low velmi nízká		**very high velmi vysoká**

Křehkost (tenderness)

very low velmi nízká		**very high velmi vysoká**

Šťavnatost (juiciness)

very low velmi nízká		**very high velmi vysoká**

Vláknitost (fineness)

very low velmi nízká		**very high velmi vysoká**

Žvýkatelnost (Chewability)

very low velmi nízká		**very high velmi vysoká**

Intenzita chuti hovězího m (beef flavour intensity)

very low velmi nízká		**very high velmi vysoká**

Intenzita chuti zvěřiny (game meat flavour intensity)

very low velmi nízká		very high velmi vysoká

Intenzita abnormální chuti (abnormal flavour intensity)

very low velmi nízká		very high velmi vysoká

Chuť jater (liver flavour)

very low velmi nízká		very high velmi vysoká

Chuť kyselá (sour flavour)

very low velmi nízká		very high velmi vysoká

Chuť oříšková (nutty flavour)

very low velmi nízká		very high velmi vysoká

Chuť pečeného masa (roasted flavour)

very low velmi nízká		very high velmi vysoká

Celková přijatelnost (overall acceptance)

very low velmi nízká		very high velmi vysoká

APPENDIX II: Image of the dry aged untrimmed LL muscle of the common eland meat, at D28 in the controlled chamber

APPENDIX III: Image for the wet aged LL muscle of the common eland meat at D28 in the controlled chamber

APPENDIX IV: Image for the semi-permeable aged LL muscle of the common eland meat at D28 in the controlled chamber