Physico-chemical composition and oxidative stability of South African beef, game, ostrich and pork droëwors

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Revised: 30 August 2018 / Accepted: 5 September 2018 / Published online: 17 September 2018
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Abstract Droëwors are traditional South African salted and dried sausages, made without nitrites/nitrates and non-fermented. Different meat sources (beef, game and ostrich) are traditionally used in droëwors processing, while the use of pork is uncommon, as it is said to lead to rancidity. The first part of the study analysed the physico-chemical composition of commercially available beef, game and ostrich meat droëwors ($n = 20$). On average, they were composed of 26.3–29.2 g/100 g moisture, 41.3–44.0 g/100 g protein, 26.2–33.1 g/100 g fat and 5.9–6.5 g/100 g ash and 5.0–5.4 pH. Water activity (0.76–0.82) was sufficiently low to ensure shelf stability at ambient temperatures. In the second part beef and pork droëwors were formulated in accordance with these results and with similar fat content, dried for 2 days (30 °C, 40% relative humidity) and stored for 26 days (25 °C, 50% relative humidity); measuring moisture, water activity, pH and lipid oxidative stability (thiobarbituric acid reactive substances (TBARS)) weekly. At day 5, moisture and thus water activity of pork droëwors was slightly higher compared to

beef ones and fat and ash content slightly lower ($P \leq 0.05$) despite similar weight loss. Even with slightly less fat, TBARS in pork droëwors were significantly higher after drying and throughout storage (3.83 vs 0.99 mg MDA equivalents/kg dry matter at a maximum).

Keywords Nitrite free · Unfermented dry sausages · Droëwors · TBARS · Water activity · Shelf stability

Introduction

Drying is one of the oldest methods of food preservation (Mujumdar and Devahastin 2004); and it is used in the preparation of many traditional delicacies from different regions of the world. Droëwors are shelf-stable, ready to eat salted and dried sausages; produced and consumed widely in South Africa and growing in popularity on the international market (Jones et al. 2015a). These dry sausages are commonly made from a mixture of meat (usually beef but also ostrich and game meat; Hoffman et al. 2014) and animal fat, salted and dried in a similar way to biltong; which is another traditional dried meat product from South Africa that has been more widely studied. Traditionally, droëwors are made from pieces of meat that are not suitable for biltong production. Biltong is made using whole pieces or strips of meat which are seasoned and dried. The typical drying conditions used to process biltong range from 1 to 2 weeks at ambient temperatures in a well ventilated area, or a few days in a controlled drying chamber (Jones et al. 2017). Studies in which droëwors have been processed in drying chambers mention the setting of temperature and relative humidity (RH) at 15 °C and 75–82%, respectively for 15 days (Hoffman et al. 2014); or higher temperature and lower RH for a shorter time (25–30 °C,

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RH 30% for 2–3 days; Jones et al. 2015a, b). Drying times are driven by the targeted moisture loss of 45–50% which is commonly used by droëwors producers. Spices (usually pepper and coriander) and vinegar but no nitrites/nitrates are added to the formulation.

Processing methods have a significant effect on the safety and nutritional value of meat products. Certain meat processing steps such as smoking, exposure to high temperature and even the growth of some microorganisms during fermentation can increase the presence of hazardous compounds such as polycyclic aromatic hydrocarbons and biogenic amines (Alves et al. 2017). Under the temperature conditions described for droëwors production and as there is no fermentation step, there is minimal exposure to these risk; as well as minimal protein denaturation, degradation of vitamins and functional compounds (Guerrero-Legarreta and García-Barrientos 2012). However, after processing, droëwors are often left unpackaged under ambient conditions prior to sale, and are commonly stored by consumers for several days to a few weeks before consumption; during which they are susceptible to oxidative deterioration (Jones et al. 2015b). Lipid oxidation is the main non microbial cause of quality deterioration in muscle foods; especially in meat and meat products containing high levels of fat, or more specifically, high levels of polyunsaturated fatty acids (PUFA) (Aalhus and Dugan 2004). Droëwors are a high fat product, with reported fat content ranging from 20.1 to 35.6 g/100 g (Burnham et al. 2008; Hoffman et al. 2014; Jones et al. 2015a, b). Additionally, the pro oxidant effect of salt (Mariutti and Bragagnolo 2017), amplified by the reduction of moisture and the increase in salt concentration during drying, further increases the susceptibility of droëwors to oxidation. Deteriorative changes that manifest as a consequence of lipid oxidation include adverse changes in colour, flavour, texture, nutritive value and possible production of toxic compounds (Gray et al. 1996).

Unlike the majority of dry sausage products in the international market, pork is not commonly used for droëwors production because it is considered to be more prone to rancidity when dried (Biltong Makers 2010). Research has indeed reported that the ratio of PUFA has increased in modern pork as a consequence of the efforts to obtain leaner carcasses, these two parameters being inversely correlated (Wood et al. 2003). While an increase of PUFA may be viewed as beneficial to consumers from a health perspective, it presents a challenge for pork processors as PUFA are more susceptible to oxidation (Rosenvold and Andersen 2003). Furthermore, pigs are highly susceptible to pre-slaughter stress; which can cause the overproduction of reactive oxygen species in muscle tissues and accelerate the rate of oxidation. Lipid oxidation

contributes to the flavour of dry cured pork products such as fermented dry sausages and dry-cured ham (Demeyer 2014). As these products are processed and stored at lower temperatures than droëwors, the susceptibility of pork droëwors to oxidative deterioration could be arguably higher. Furthermore, the addition of nitrites in dry cured pork products has an antioxidant effect, as nitrites act as oxygen scavengers when oxidised to nitrates (Honikel 2007). Pork droëwors could be a lucrative value-added product and add to the variety of droëwors available in local and international markets. The price/kg of pork in South Africa is generally lower than that of beef and game meat; and the shelf-stability of the product would make pork droëwors a dietary protein source that would meet consumer demands for convenience and affordability. However, limited research has been conducted on lipid oxidation in droëwors made from different meat types, resulting in no substantive data validating that pork droëwors are indeed more susceptible to oxidation than the commonly used meat sources (beef, game and ostrich). The aim of this study was to determine the proximate composition and other physico-chemical properties of commercial droëwors, as there is scarcity of literature documenting this; and to compare the level of lipid oxidation in beef and pork droëwors produced according to the results on commercial droëwors and the same raw batter physico-chemical composition to validate whether droëwors made from pork are more prone to rancidity.

Materials and methods

Sampling of commercial droëwors

Droëwors made from beef ($n = 9$), game ($n = 8$) and ostrich ($n = 3$) meat were randomly purchased from supermarkets, butcheries and retail outlets in Stellenbosch, South Africa. A 100 g sub sample was taken from each sample, chopped and then ground using a blender (Braun PowerMax MX2050) for 1 min, and vacuum sealed. Samples were stored at -20°C until analysed for proximate, salt content, water activity (a_w) and pH.

Beef and pork droëwors processing and sampling

Lean beef, beef fat, lean pork and pork fat were purchased from a local supplier. Dehydrated natural sheep casings (stored in salt and rehydrated in water prior to use) (22 mm diameter) were used for stuffing. The lean meat and fat were cut into cubes (2×2 cm) and representative 100 g samples ($n = 3$) of each (lean beef, lean pork, beef fat, pork

fat) were taken, blended (Ampa Cutter CT 35 N, Golasecca, Italy) and analysed for moisture and fat content.

Batches of droëwors (2 kg each) were prepared by hand-mixing lean beef and beef fat cubes in the ratio of 80:20 for beef batches and lean pork and pork fat cubes in the ratio of 85:15 for pork batches with 2 g/100 g salt and 0.5 g/100 g pepper. Six batches for each species were made and each batch was minced separately through a 5 mm grinder. Casings were filled with the minced mixtures and dried in an environmentally controlled chamber (Airmaster, Reich, Schechingen, Germany) set at 30 °C and 40% RH for 48 h. The batches were equally represented on each tier in the drier. The weight of each batch was recorded before and after drying to monitor the weight loss.

Uncovered and unpackaged, the droëwors were stored in an environmentally controlled Stagionelli chamber (Stagionelli, Italy) set at 25 °C and 50% RH for 26 days. The weight of each batch was also recorded during storage.

A representative 50 g sample was taken from each batch of droëwors at day 0 (before drying) and day 5 (after drying and 3 days of storage) for analysis of proximate composition, salt content, a_w , pH and lipid oxidation. A representative 35 g sample was taken from each batch on days 12, 21 and 28 for analysis of moisture, a_w , pH and lipid oxidation. Samples were cut into small cubes, grinded using a KnifetecTM 1095 Mill (FOSS, Höganäs, Sweden) and stored under vacuum at − 20 °C for proximate, salt content, a_w and pH measurement; and at − 80 °C for lipid oxidation analysis.

Proximate analysis

Moisture (Method 934.01) and ash (Method 924.05) contents were determined according to the procedures outlined in AOAC (2002). The protein content was determined according to AOAC (1992) Method 992.15 and fat content was determined using the chloroform/methanol (2:1) fat extraction method according to Lee et al. (1996). All analyses were conducted in duplicate. Due to the low repeatability of the fat content measurement on raw materials (pork fat and beef fat) and droëwors at day 0 (data not shown), fat content of beef and pork droëwors was calculated by subtracting moisture, protein and ash contents from 100.

Salt content

For salt determination, 50 mL of 0.3 M nitric acid was added to 0.3 g of sample in duplicate and the solution was stirred with a magnetic stirrer for at least 2 h. Thereafter, the chloride content (mg/L) was measured using a chloride analyser (Model 962, Sherwood, Cambridge, UK).

pH

For pH analysis, 3 g of ground sample was added to 27 mL distilled water in duplicate, mixed using a magnetic stirrer for 30 min. Thereafter, pH was measured during continuous stirring using a Crison PH25 pH meter, calibrated with pH 4 and pH 7 standard solutions at 25 ± 1 °C.

a_w

The a_w was measured in duplicate using an a_w meter (AquaLab 4TE, accuracy 0.003) at 18 ± 0.5 °C.

Lipid oxidation

Lipid oxidation was analysed by measuring thiobarbituric acid reactive substances (TBARS) using a modified acid-precipitation technique. Two grams of each sample in duplicate were homogenized (Polytron, Kinematica, Switzerland) with 6.25 mL of trichloroacetic acid (2.8 g/100 mL) and 6.25 mL distilled water for 20 s. Slurry was left to filter through a Whatman n°1 filter paper and duplicate samples of filtrate (1 mL) were added to an equal volume of 0.02 M thiobarbituric acid. An equal volume of distilled water was added to the third replicate to act as a turbidity blank for each sample. Samples were vortexed for 10 s, incubated in a water bath at 70 °C for 1 h until pink colour development, allowed to cool for 10 min and the absorbance was read at 530 nm. TBARS were calculated using 1,1,3,3-tetramethoxypropan as a standard. Results were expressed as mg of malonaldehyde (MDA) equivalents/kg of dry matter (DM).

Statistical analysis

Data on proximate composition and other physico-chemical properties of commercial beef, game and ostrich meat droëwors were analysed using PROC GLM procedures of SAS version 9 with the main effect of meat type. Pair wise comparisons of least square means were done using t-tests (PDIF option). Differences were significant at $P \leq 0.05$. Data on moisture and fat content of the raw materials for beef and pork droëwors were analysed in the same way, with raw material type as the main effect. For the proximate composition and other physico-chemical properties and TBARS of beef and pork droëwors, a 2×5 factorial completely randomised design was used, with two meat types (beef and pork) and day (0, 5, 12, 21, 28) as the main effects. A mixed model repeated measures ANOVA was conducted using Statistica 13.2, with meat type and time as fixed effects and the batches (nested in meat type) as random effect. Pair wise comparisons of least square means

were done using the LSD test and differences were significant at $P \leq 0.05$.

Results and discussion

Physico-chemical composition of commercial droëwors

The physico-chemical composition of commercial droëwors is shown in Table 1. Beef, game and ostrich droëwors were composed of 26.3–29.2 g/100 g moisture, 41.3–44.0 g/100 g protein, 26.2–33.1 g/100 g fat and 5.9–6.5 g/100 g ash on average. The mean pH and a_w were 5.0–5.4 and 0.76–0.82 respectively. However, the results show wide variations, as shown by the minimum and maximum values for each characteristic. Jones et al. (2017) noted variations in processing methods as a source of widely varying physico-chemical properties in biltong. Moreover, there were no significant differences ($P > 0.05$) in the moisture, protein, fat, ash and salt contents, a_w and pH between beef, game and ostrich meat droëwors. Jones et al. (2015b) reported mean values of moisture (36.9 g/100 g), protein (35.4 g/100 g), fat (20.3 g/100 g) and ash (6.9 g/100 g) in droëwors made from blesbok, springbok and fallow deer meat that fall in the ranges measured on game droëwors in the present study. Hoffman et al. (2014) reported similar moisture and fat content but less protein and more fat and ash (on average 27.3, 28.9, 32.1 and 8.65 respectively) in ostrich droëwors compared to the composition reported in this study (on average 29.2, 44.0, 26.2 and 5.9 g/100 g respectively for moisture, protein, fat and ash). On beef droëwors, Burnham et al. (2008) reported lower a_w ranging from 0.60 to 0.74 and similar fat content (35.5 g/100 g) and pH (on average 5.5) compared to the results found in this study (0.71–0.86 and 32.9 g/100 g on average respectively for a_w and fat).

The physico-chemical properties of the analysed samples were consistent with the requirements for shelf stability at ambient temperatures and inhibition of microbial growth. In non-fermented meat products, the a_w , moisture and salt content are key determinants to prolong shelf life without the use of refrigerated storage (Earle and Earle 2008). The a_w of the analysed samples ranged from 0.67–0.86 which complies with the requirements (a_w of < 0.91) for meat to be storable at ambient temperature (Leistner and Rodel 1975). While most bacteria do not grow at $a_w < 0.91$ (Mujumdar and Devahastin 2004), specific microorganisms of concern in droëwors production and storage are *Listeria monocytogenes* and *Staphylococcus aureus* reportedly known to be able to withstand high salt concentrations and reduced a_w (Burnham et al. 2008). Under aerobic conditions, *S. aureus* and *L. monocytogenes* growth is inhibited when a_w is ≤ 0.85 and 0.92, respectively (Burnham et al. 2008). Moreover, yeasts and mould can grow until the a_w is decreased to 0.70–0.60 (Zukál and Incze 2010).

Based on dietary guidelines recommending a daily allowance of 4–6 g salt/day (Bertram et al. 2012), droëwors has a high salt content (3.5–4.9 g/100 g). At these levels, consumption of 100 g of droëwors/day will constitute almost the entire recommended daily consumption limit. Droëwors is known to have a high salt content (Burnham et al. 2008). However, to the author's knowledge, no scientific literature detailing the salt content of droëwors is available.

Comparison of beef and pork droëwors

Lean beef (70.2 ± 1.25 g/100 g) and lean pork (70.2 ± 0.96 g/100 g) had the same ($P > 0.05$) moisture content and similar ($P > 0.05$) fat (4.9 ± 0.51 and 5.9 ± 1.03 g/100 g, respectively) contents. The moisture and fat content of the pork fat (12.7 ± 0.73 and 77.1 ± 2.60 g/100 g, respectively) and beef fat

Table 1 Physico-chemical composition of commercial beef, game and ostrich meat droëwors (LSMeans $\pm$ standard errors)

Physico-chemical characteristics	Beef (n = 9)			Game (n = 8)			Ostrich (n = 3)			P value
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	
Moisture	26.3 ± 1.82	19.9	31.7	23.7 ± 1.93	17.6	35.3	29.2 ± 3.15	27.3	31.5	0.25
Protein	41.3 ± 1.82	33.1	48.2	42.0 ± 1.93	32.4	51.4	44.0 ± 3.15	41.7	45.9	0.77
Fat	32.9 ± 2.57	25.0	40.3	33.1 ± 2.72	16.8	47.0	26.2 ± 4.45	23.5	28.8	0.38
Ash	6.1 ± 0.20	5.5	7.5	6.5 ± 0.21	6.0	7.4	5.9 ± 0.34	5.4	6.9	0.34
Salt	4.0 ± 0.13	3.5	4.9	4.4 ± 0.14	4.0	4.9	4.0 ± 0.23	3.5	4.7	0.09
a_w	0.81 ± 0.021	0.71	0.86	0.76 ± 0.022	0.67	0.86	0.82 ± 0.036	0.81	0.86	0.10
pH	5.3 ± 0.07	5.1	5.7	5.4 ± 0.08	4.9	5.6	5.0 ± 0.13	4.9	5.5	0.22

Moisture, protein, fat, ash and salt contents are expressed in g/100 g; a_w : Water activity

(19.4 ± 0.64 and 51.4 ± 11.24 g/100 g, respectively) was significantly ($P \leq 0.05$) different, with high variations of fat content, especially in beef. These variations were of the same order as the variations between duplicates analyses (data not shown). The fat content between duplicates analysis of droëwors samples before drying were also not repeatable (data not shown). Inaccuracies in the chloroform methanol extraction could be attributed to evaporation of chloroform during homogenisation, causing an over estimation of fat content in the final value. Hence, this method of fat extraction may not be suitable for fat tissues. For this reason, the fat content of droëwors was subsequently calculated by subtracting moisture, protein and ash contents from 100. According to Habeck et al. (2013), differences can arise in the determination of total fat; dependant on the level of fat in the meat and whether it is cooked or uncooked. As pork fat contained a higher percentage of fat and lower percentage of moisture than beef fat, a lower ratio lean meat to fat was used in pork droëwors (85:15) than in beef droëwors (80:20) in order to formulate beef and pork droëwors with similar fat content.

Beef and pork droëwors showed similar ($P > 0.05$) percentage weight loss during drying (50.4 and 48.2% respectively). Further loss of moisture was recorded during storage as shown in Fig. 1, depicting the moisture content dry basis during processing and storage. Jones et al. (2015b) reported similar weight loss percentages (45–50%) during drying in blesbok, springbok and fallow deer droëwors, using similar drying conditions (30 °C and 30% RH for 48 h). These findings are an indication that the loss

of weight during drying is not influenced by the type of meat.

On day 0 (before drying), beef and pork droëwors had similar ($P > 0.05$) proximate composition, salt content and a_w (Table 2). This was consistent with the methodology followed. There was, however, significantly higher moisture content in pork droëwors after drying (Fig. 1) and on day 5 and thus higher a_w , and lower fat and ash content (Table 2). The a_w remained higher in pork droëwors until the end of the storage while the moisture content became similar from day 21. Since the raw materials had similar moisture contents, different rates of drying were not expected. Although the pork and beef sausage batters had similar fat content prior to drying, the type of the fat (added vs intramuscular) appeared to have a significant effect. Pork has been reported to have higher levels of intramuscular fat than beef (Heinz and Hautzinger 2007); which likely contributed to the higher moisture content of pork droëwors after drying due to the barrier effect of fat on water transfer (Santchurn et al. 2012). The difference may also be attributed to the fact that the product is not perfectly homogenous in terms of width and thinner sausages are likely to dry at a faster rate than thicker ones. The protein, fat, ash and salt content were higher on day 5 than day 0 due to the reduction in moisture and are consistent with the percentage of weight loss during drying and 3 days of storage (55.2 and 53.9% in beef and pork droëwors, respectively). Moisture loss during drying automatically results in the concentration of dry solids. Protein, fat, ash and salt content were not measured on day 12, 21 and 28, because they were expected to only change in concentration due to changes in moisture content. The moisture content and a_w of all droëwors significantly decreased up to day 21. Nortjé et al. (2005) reported that in biltong, preferences have been noted for “moist” biltong, which is more tender and less dehydrated; there is however no research indicating the moisture preference level of consumers for droëwors. While the continued reduction of water promotes shelf stability and especially the inhibition of the growth of yeasts and mould (which can grow until the a_w is decreased to 0.70–0.60 as previously stated), excessive loss of moisture may compromise consumer acceptability and satisfaction, it could be recommended that when prolonged storage is required, protective packaging material that prevents moisture loss should be used; as beyond day 5, the moisture content of the droëwors samples was much lower than the minimal values measured on the commercial droëwors (17.6 g/100 g and 0.67 for moisture and a_w respectively, Table 1). The pH of pork droëwors was significantly higher ($P \leq 0.05$) than beef droëwors from day 0 to day 28. This could be attributed to the fact that pigs are more susceptible to stress at slaughter than cattle, hence pork is more likely to have higher

Fig. 1 Moisture content of beef and pork droëwors during processing and storage. (a–f) Means with different superscripts are significantly different ($P \leq 0.05$). Day 2 moisture was calculated from measured moisture at day 5 and weight recordings. Error bars represent standard errors (n=6)

Table 2 Physico-chemical composition of beef and pork droëwors during processing and storage (LSMeans $\pm$ standard errors; $n = 6$)

Physico- chemical characteristics	Day 0	Day 5	Day 12	Day 21	Day 28
Moisture					
Beef	62.6 ^a $\pm$ 0.19	18.3 ^c $\pm$ 0.83	9.2 ^e $\pm$ 0.30	6.9 ^f $\pm$ 0.12	6.8 ^f $\pm$ 0.05
Pork	63.2 ^a $\pm$ 0.56	23.6 ^b $\pm$ 0.56	10.5 ^d $\pm$ 0.32	7.7 ^f $\pm$ 0.33	7.1 ^f $\pm$ 0.09
Protein					
Beef	18.7 ^b $\pm$ 0.33	42.4 ^a $\pm$ 0.42	–	–	–
Pork	18.3 ^b $\pm$ 0.28	41.0 ^a $\pm$ 1.22	–	–	–
Fat ^S					
Beef	15.9 ^c $\pm$ 0.39	32.8 ^a $\pm$ 1.02	–	–	–
Pork	15.7 ^c $\pm$ 0.78	29.5 ^b $\pm$ 1.31	–	–	–
Ash					
Beef	2.8 ^c $\pm$ 0.03	6.5 ^a $\pm$ 0.28	–	–	–
Pork	3.0 ^c $\pm$ 0.06	5.9 ^b $\pm$ 0.18	–	–	–
Salt					
Beef	2.0 ^b $\pm$ 0.01	4.4 ^a $\pm$ 0.10	–	–	–
Pork	2.0 ^b $\pm$ 0.05	4.2 ^a $\pm$ 0.08	–	–	–
a _w					
Beef	0.98 ^a $\pm$ 0.001	0.72 ^c $\pm$ 0.014	0.55 ^e $\pm$ 0.007	0.49 ^{fg} $\pm$ 0.005	0.48 ^g $\pm$ 0.003
Pork	0.98 ^a $\pm$ 0.001	0.81 ^b $\pm$ 0.009	0.60 ^d $\pm$ 0.005	0.54 ^e $\pm$ 0.009	0.50 ^f $\pm$ 0.004
pH					
Beef	5.21 ^e $\pm$ 0.037	5.22 ^e $\pm$ 0.012	5.46 ^{cd} $\pm$ 0.039	5.23 ^e $\pm$ 0.012	5.43 ^d $\pm$ 0.013
Pork	5.68 ^a $\pm$ 0.034	5.61 ^b $\pm$ 0.053	5.63 ^{ab} $\pm$ 0.039	5.53 ^c $\pm$ 0.038	5.68 ^a $\pm$ 0.039

Moisture, protein, fat, ash and salt contents are expressed in g/100 g; a_w: Water activity

^{a–g}For each characteristic, means with different superscripts are significantly different ($P \leq 0.05$)

‘–’ Not measured

^SCalculated from $100 - (\text{moisture} + \text{protein} + \text{ash contents})$

ultimate pH values; and likely contributed to the higher moisture content of pork droëwors from day 5, as higher pH increases water holding capacity (Fernández-Martín et al. 2002). The pH of droëwors was fairly stable throughout the storage period.

The TBARS of beef and pork droëwors during processing and storage are presented in Fig. 2, expressed on the basis of dry matter content due to continual loss of moisture during drying and storage. Before drying, the TBARS were similar ($P > 0.05$) in both beef and pork droëwors. In pork droëwors, TBARS increased ($P \leq 0.05$) from day 0 to day 5 (after drying and 3 days of storage) and then decreased. The TBARS in beef droëwors did not change significantly from day 0 to day 12 and significantly decreased ($P \leq 0.05$) on days 21 and 28. Although they did not test the significance of the increase of TBARS in droëwors made with 55% game meat, 35% lean beef and 10% beef fat during 60 h of drying; the significant effect of the addition of a natural antioxidant extract in the study of Jones et al. (2015a) shows that droëwors are expected to undergo oxidation during drying as a result of exposure to pro-oxidants. In pork droëwors, the initial increase in TBARS value with time can be explained by the depletion

of endogenous antioxidants and the continued exposure to aerobic conditions. Thereafter TBARS seemed to react with other compounds to form complexes; which rendered a lower total TBARS number on days 12, 21 and 28. Other studies have attributed the decline in TBARS to the degradation of MDA; or to further reactions between the aldehydes and/or free amino acids released from muscle proteins during processing (Antequera et al. 1992).

At day 5, TBARS were higher ($P \leq 0.05$) in pork droëwors (3.83 mg MDA equivalents/kg DM) than in beef droëwors (0.99 mg MDA equivalents/kg DM) and continued to be consistently higher up to day 28. This occurred in spite of the fact that the beef and pork droëwors had a similar fat content before drying and pork droëwors had a lower fat content than beef after drying. The significantly lower TBARS in beef droëwors compared to pork droëwors may be attributed to the use of beef fat, which may have a more saturated fat profile making it less susceptible to oxidation. The higher level of oxidation in pork is consistent with reports that pork is susceptible to rancidity because of its polyunsaturated fat profile (Wood et al. 2003). Increasing the concentration of $n - 3$ PUFA in muscles can result in a significant increase in TBARS

Fig. 2 TBARS of beef and pork droëwors during processing and storage. (a–f) Means with different superscripts are significantly different ($P \leq 0.05$). Error bars represent standard errors ($n=6$)

(Pouzo et al. 2016). Jones et al. (2015b) reported TBARS ranging from 0.7 to 0.9 mg MDA equivalents/kg meat in game droëwors made with 33.3% sheep fat. In another study in which beef fat was used, TBARS ranged from 1.0 to 1.5 mg MDA equivalents/kg meat after drying and 1.2–2.8 mg MDA equivalents/kg meat after 2 weeks of storage (Jones et al. 2015a). Hoffman et al. (2014) reported TBARS values indicating the progression of oxidation in ostrich droëwors made with 25% pork fat, after a 15 days drying period (1.4 mg MDA equivalents/kg meat before drying vs 8.0 mg MDA equivalents/kg meat after drying). The TBARS in this study did not reach that extent, however comparison is difficult as different methods have been used for TBARS determination between the studies. This also highlights the significant effects of meat (and fat) species and drying time on lipid oxidation during droëwors processing. There is no other data on unfermented salted dry sausages made without nitrites/nitrates in the literature. Literature on lipid oxidation of other beef salted/dried meat products in which use of nitrites/nitrates were not mentioned include kilishi with TBARS increasing from 1.5 to 2 mg MDA equivalents/kg meat during 60 weeks of storage (Igene et al. 1990), beef charqui reaching 4.5 mg MDA equivalents/kg meat after drying (Torres et al. 1994). On pork dry fermented sausages, which have a closer fat content to droëwors, TBARS values often less than 1 mg MDA equivalents/kg meat, sometimes up to 2 mg MDA equivalents/kg, are reported (Liaros et al. 2009; Baka et al. 2011; Lorenzo et al. 2013). These lower values could be

explained by the use of nitrites/nitrates and/or lower temperatures during drying and storage compared to dry sausages in this study. There is little data on lipid oxidation of fermented dry sausages made without nitrites/nitrates or other compounds with antioxidant activity, as the studies conducted on these have mostly focused on microbiological concerns. Schivazappa et al. (2012) showed that when no nitrites/nitrates were used in fermented dry sausages, TBARS increased more rapidly and reached values up to 1.5 mg MDA equivalents/kg which is much lower than values reported on pork droëwors in this study. According to Campo et al. (2006), rancidity is detectable when TBARS values are higher than or equal to 2 mg MDA equivalents/kg on fresh meat. As the TBARS values of pork droëwors were higher than this, it verifies the unpublished claims that pork is not usually used in droëwors production because it is prone to rancidity. On the basis of these results, if droëwors are to be produced using pork, further research on the efficacy of antioxidants to inhibit the rate of lipid oxidation in pork unfermented dry sausages without nitrites/nitrates is warranted. Another alternative could be to lower the salt and fat content of pork sausage batters, which may have sensorial implications on flavour and texture and requires further study.

Conclusion

The proximate, salt content, a_w and pH of commercial droëwors made from beef, game and ostrich meat were consistent with the recommended values for product stability at ambient temperatures during storage. Comparison of lipid oxidative stability in similarly produced beef and pork droëwors showed that dry pork sausages made without nitrites/nitrates underwent significant oxidation during drying and storage; to a greater extent than dry beef sausages. Since both types of droëwors had similar fat content; the higher level of oxidation in pork is consistent with reports that the higher PUFA content of pork makes it more susceptible to rancidity. The fatty acid profiles of the droëwors were not analysed in this study and further investigations on this are recommended. What would also be of particular interest is the effect that drying has on oxidation of the lipids and the effect thereof on sensory and consumer acceptance. Additionally, as no antioxidants were added to the sausage batter in this study, further research on the addition of less fat and salt or the use of antioxidants to reduce the extent of oxidative deterioration in dry pork sausages is also recommended.

Acknowledgements The authors acknowledge the financial support of the South African Research Chairs Initiative (SARChI) of the Department of Science and Technology (DST) and National Research

Foundation (NRF) of South Africa, under the framework of the DST-NRF SA-France Protea Project (95139). Any opinion, finding and conclusion or recommendation expressed in this material is that of the author(s) and the NRF does not accept any liability in this regard.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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