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Comparative nutritional composition, physicochemical properties, and sensory attributes of sausages produced from pork, camel, and goat meat (chevon)

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ABSTRACT

The study assessed the quality attributes of sausage products produced from three meat types. Eight kilograms of thigh muscles, each from pork, camel, and chevon, were used for this study and divided into three portions: fresh, fried, and oven-cooked sausage products. Samples from each fresh meat type were analysed for physicochemical and proximate composition, while the final sausage products obtained were analysed to determine the proximate, mineral & vitamin composition, and sensory attributes in a completely randomized design (CRD) 3 × 3 factorial arrangement. The results obtained showed that fresh camel meat had significantly higher ($P < 0.05$) values of crude protein (CP), moisture, ash, minerals (calcium, potassium, and magnesium), and vitamins (B_{12}, B_2, and D) compared to other meat types, but had the lowest ether extract content (2.45 %). The processed (fried and oven-cooked) sausage products generally exhibited higher CP and ether extract than the fresh sausage products across all meat types ($P < 0.05$). Meat type × processing method interaction influenced the nutritional composition of sausage products ($P < 0.05$). Overall, processing sausage products from fresh meat enhances CP content, and oven cooking appears to be the most effective in retaining protein content during processing.

Keywords: pork, camel meat, chevon, sausage, meat processing

INTRODUCTION

Meat and meat products are regarded as a good source of protein in humans' everyday diets, with an appreciable amount of vitamins and minerals such as iron, calcium, magnesium, and other essential nutrients (Pereira & Vicente, 2013). Despite the availability of these nutrients in meat, a growth-enabling medium is provided for microbial activities, resulting in spoilage and/or contamination. Therefore, to prevent the spoilage of meats, various meat processing techniques, including roasting, smoking, and drying, were developed many years ago to process fresh meats into high-value products, thereby extending their shelf life (Dave & Ghaly, 2011). Today, with the advent of technology, the meat processing industry has undergone a significant transformation with the introduction of sophisticated processing techniques, such as high-pressure processing, which transform raw meat into value-added products (Nollet & Toldra, 2006).

Meat processing involves the enhancement of fresh meat through various techniques that add value and alter its characteristics. Processed meat products exhibit distinct flavour, taste, colour, and texture profiles compared to their fresh counterparts (Heinz & Hautzinger, 2007). Sausage is a widely consumed meat product produced from ground meat combined with various ingredients. High-quality cuts of meat, typically sourced from beef, pork, mutton, or poultry, are commonly utilized in sausage production. The most important criterion regarding the choice of meat type to be used should be based on the water-binding capacity (Abdolghafour & Saghir, 2014).

In terms of chemical composition, camel meat exhibits excellent qualities, including higher moisture, protein, and lower fat, particularly intramuscular content. Given this profile, camel meat could serve as an alternative and healthy red meat option for consumers, having approximately 78 % moisture, 19 % protein, 3 % fat, and 1.2 % ash (Kadim et al., 2008). Camels slaughtered at a younger age produce meat with comparable eating qualities (taste and texture) to beef (Babiker & Yousif, 1990; Kadim et al., 2008). Chevon is also an excellent lean meat source with desirable nutritional quality (Webb et al., 2005). Compared with beef, lamb, and pork, chevon is reported to be lower in total fat, saturated fat, and cholesterol, while providing high-quality protein and essential amino acids (Gawat et al., 2023; Ivanović et al., 2020; Mazhangara et al., 2019; Stajic & Pisinov, 2021). Chevon contains approximately 75.42 % moisture, 3.55 % fat, 19.95 % protein, and 1.06 % ash, and exhibits a distinctive flavour and aroma that is species-specific (Ivanović et al., 2016; Webb, 2014). Importantly, chevon's high water retention capacity and lower cooking loss confer on it a superior processing (technological) trait, which makes it a suitable meat for a wide range of traditional and processed products (Babiker et al., 1990; Teixeira et al., 2020). According to F.A.O (2004), a daily protein intake of 56 g per capita is recommended for an adult weighing approximately 63.5 kg, with at least 30 g intake derived from animal sources. Presently, this nutritional target has not yet been achieved in Nigeria and several other developing nations. For instance, in Nigeria, only 3 % and 10 g of protein consumption is sourced from animal origin, and the diet is predominantly plant-based (de Vries-Ten Have et al., 2020; Gavrilova, 2020; Schönfeldt & Hall, 2012). In light of this protein intake deficit, the consumption of processed meat products such as sausages, hamburgers, and bacon presents a promising strategy to help close the gap. Consequently, this present study was designed to evaluate the nutritional, physicochemical, and sensory qualities of sausage produced from commonly used meat (pork) and the rarely used meat types (camel meat and chevon). Furthermore, the study aimed to address the current knowledge gap regarding sausage production in Nigeria and to contribute to the limited body of literature available on this subject within Sub-Saharan Africa.

MATERIALS AND METHODS

Ethical statement

An approval from the Institutional Animal Care and Use Committee was not required for this experiment; meat samples were obtained from commercial carcasses after slaughter, and no treatment was applied to live animals.

Experimental site

This study was conducted at the Meat Science Laboratory, Department of Animal Science, College of Agriculture and Renewable Resources, Osun State University, Ejigbo, Nigeria.

Meat Procurement

The hindquarter of a camel carcass (already deboned) was sourced from a commercial Abattoir in Lagos, Nigeria, and transported in an insulated cooler with ice to the meat laboratory of Osun State University, Ejigbo. In addition, a live boar (Large White breed) and a buck (West African Dwarf breed) were also procured from a commercial farm in Lagos and a livestock market in Oko, Oyo State, respectively. The boar and buck were slaughtered and subsequently deboned by an experienced butcher to obtain the required meat portions for sausage production. Approximately eight (8) kilograms of pork, camel meat, and chevon from the hindquarters were used for this experiment. Samples for proximate and mineral composition and physicochemical analyses were excised from each meat type, weighing approximately 100g.

Chemical analyses

All chemical analyses were conducted following the standard procedures outlined by the Association of Official Analytical Chemists (A.O.A.C., 2005) on a fresh weight basis. Samples of the fresh meats and finished sausage products from the three meat types were analysed to determine their proximate, vitamin (B_2, B_{12}, and D), and mineral contents (Calcium, Potassium, and

Magnesium), with three replicates per treatment for fresh meat samples, and three replicates per processed product samples. The proximate analysis (crude protein, ether extract, moisture, and ash) was carried out following standard AOAC (2005) methods. The methods applied to determine crude protein, fat, and moisture contents were the Kjeldahl method, Soxhlet extraction, and oven drying, respectively, while ash was determined by muffle furnace incineration. The mineral content was first determined by ashing the sample, dissolving the ash in perchloric acid, and then quantifying the minerals using atomic absorption spectrophotometry. Following Adeyeye et al. (2020), vitamins B_2 (riboflavin), B_{12} (cobalamin) were extracted from the samples by grinding with a laboratory mortar and pestle to achieve homogenization, and subsequently, the contents were measured using high-performance liquid chromatography (HPLC) as described by Fuerniss et al., (2024).

Vitamin D was isolated using a mixture of ethanol and petroleum ether, then underwent saponification with alcoholic potassium hydroxide (KOH), and was evaluated on a C18 reverse-phase column (Ekwere et al., 2025). Vitamin D content was subsequently determined using HPLC with UV detection according to the AOAC method 2011.11 (AOAC, 2011; Swing et al., 2021) .

Physicochemical Analyses

i. *Water holding capacity (WHC)* was determined according to Suzuki et al.,(1991). Fresh meat samples were placed between two filter papers using a vice device and pressed for 60 seconds. Following pressing, the area of the filter paper that was moist, in relation to the area of the compressed sample, was utilized to quantify the quantity of water released from each sample. The WHC for each sample was determined using the following mathematical formula:

$$\text{WHC} = \frac{100 - (Aw - Am)}{[(Wm \times Mo)]} \times 9.47$$

Aw = Area of water released from the meat (cm^2)
Am = Area of meat sample (cm^2)
Wm = Weight of meat in mg
Mo = Moisture content of meat (%)
9.47 is a constant factor.

ii. *Cold Shortening of Meat:* Meat samples were placed on a tray and chilled in a cold storage at 4 ^{o}C for 24 hours. After the chilling period, the samples were removed and measured again to determine the percentage change in length, as follows:

$$\text{Cold shortening} = \underline{(IL - FL)} \times 100$$

$$FL$$

IL = Initial length of meat sample (cm)
FL = Final length of meat sample (cm)

iii. *Thermal Shortening:* Meat samples were heated in the oven at 175 °C for 20 minutes and allowed to equilibrate to room temperature before measuring the length. Following Fakolade et al., (2016), the percentage difference in length was calculated to determine the thermal shortening as follows:

$$\text{Thermal shortening} = \frac{(IL - FL)}{FL} \times 100$$

IL = Initial length of meat sample (cm)
FL = Final length of meat sample (cm)

iv. *Thaw Rigour:* Meat samples of known weights and lengths were kept in the refrigerator at 4 °C for 24 hours. After the refrigeration period, the weight change of the samples was measured, and the percentage difference in weight was calculated as follows:

$$\text{Thaw rigour} = \frac{(IW - FW)}{FW} \times 100$$

IW = Initial weight of meat sample (g)
FW = Final weight of frozen meat sample (g)

v. *Cooking loss:* The cooking loss was determined by weighing the meat samples before cooking. Afterwards, the samples were wrapped in airtight polythene bags and cooked in already boiling water (100 °C) on a gas-powered stove for 20 minutes. After cooking, the samples were allowed to cool to room temperature before weighing again. The cooking loss was calculated for each meat type based on the weight difference as follows:

$$\text{Cooking loss} = \frac{(IW - FW)}{FW} \times 100$$

IW = Initial weight of meat sample (g)
FW = Final weight of cooked meat sample (g)

Meat Preparation

The meat samples were thoroughly trimmed to remove external fats, hairs, connective tissues, and ligaments, followed by washing with clean water. The trimmed meats—pork, camel meat, and chevon were cut into uniform chunks. Each meat type was divided into three replicates corresponding to different cooking methods: fresh, oven-cooked, and fried.

Spice and Ingredient

The ingredients used for the spice mixture included salt, seasoning (monosodium glutamate), thyme, curry, onions, white pepper, African nutmeg, ginger, lard, coriander, ice, mustard seed, sugar, onions, red pepper, and cornflour. All ingredients were procured from various local markets within this study area.

Preparation of Casings for Stuffing

Natural casings were prepared from cattle intestines, which were trimmed to remove residual fats and thoroughly washed. The casings were then soaked in water to make them pliable and to facilitate the ease of stuffing.

Formulation of Spice Mixtures

The spice mixtures were formulated in accordance with the basic sausage formulation guidelines provided by (Savic, 1985) as detailed in Table 1.

Preparation of Sausage

The procedures for the preparation of sausage in this study were carried out as follows:

i. *Grinding:* The meat samples were first cut into smaller portions to facilitate the grinding process. Grinding was done using an electronic meat mincer machine (through a 5 mm plate).
ii. *Mixing:* As shown in Table 1, a spice mixture was prepared. The spice mixture consists of all the ingredients, and water was added to the mixture to ensure thorough mixing and dissolution of the curing ingredients, using a mixer.
iii. *Stuffing:* The prepared fresh sausage was then stuffed into pre-soaked casings with the aid of a manual piston stuffer and divided into uniform links by twisting the stuffed casings at regular intervals.
iv. *Oven-Cooking/Frying:* Some portions of each sausage type were kept fresh (uncooked), while the remaining portions were subjected to two different cooking methods: oven cooking and frying. For the oven-cooking method, the sausages were placed in the laboratory oven, Uniscope SM9053 (Surgifriend Medicals, Essex, England), at 85°C for 80 minutes. For the frying method, the sausages were fried in vegetable oil using a large frying pan at 150 ^{o}C for 9 minutes, and turned frequently until a golden-brown colour, indicating the Maillard reaction was obtained.

Sensory Evaluation

A total of fifteen (n =15) semi-trained panellists assessed the palatability of the sausage products. The panel consisted of 70 % males and 30 % females. Sausage samples were served on clean white plates with each sample coded using labels to eliminate bias. To cleanse their palates between tastings, panellists were provided with bread and water. Each panellist evaluated the samples based on the organoleptic attributes, flavour, colour, tenderness, and overall acceptability, using a 9-point hedonic scale, where 1 represented “dislike extremely, and 9 indicated “like extremely”. The scores from the panellists were averaged to indicate each sensory parameter.

Statistical analysis

The study employed a completely randomized design (3 × 3 factorial arrangement). Data obtained from the various analyses were analysed using the IBM SPSS Statistics software (I.B.M.Corp, 2012). Analysis of variance (ANOVA) was used to determine significant differences at a 5 % probability level ($P < 0.05$); one-way ANOVA was employed for proximate, chemical composition, physicochemical analysis of fresh meats and sensory evaluation of sausage products assessing only one factor (meat type), while two-way ANOVA was used for the proximate, mineral and vitamin composition of sausage products analyses, considering the two factors (meat type and processing methods) in triplicates. The obtained mean values were compared using Duncan's Multiple Range Test of the same software.

Table 1. Formulation of spice/ingredients mixtures for sausage preparation (g /100g)

Ingredients	Quantity (g)	Quantity (%)
Red pepper	30.00	6.55
Seasoning	15.00	2.04
African nutmeg	35.00	4.77
Ginger	42.00	5.72
White pepper	20.00	2.72
Curry powder	44.00	6.00
Thyme leaves	23.00	3.13
Common salt	59.00	8.04
Onions	15.00	2.04
Sugar	30.00	4.09
Lard	95.00	12.96
Coriander	75.00	10.23
Mustard seed	80.00	17.46
Ice	50.00	6.82
Total	733.00	100.00

RESULTS AND DISCUSSION

Physicochemical properties of fresh meat samples

The mean values of fresh meat samples (Pork, camel meat, and chevon) are presented in Figure 1, with notable variations observed among the meat types across all evaluated parameters, including cold shortening, thermal shortening, cooking loss, water holding capacity (WHC), and thaw rigour.

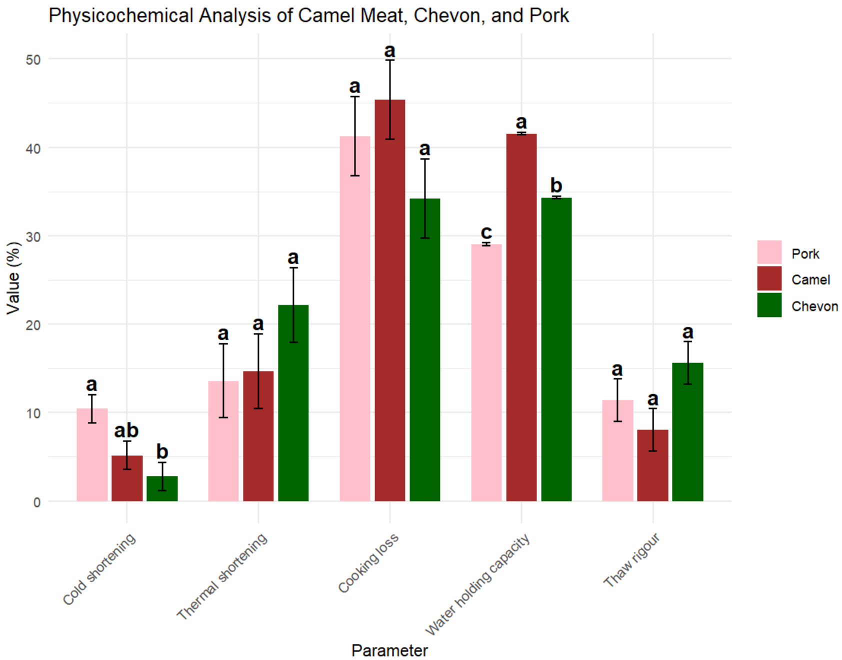

Figure 1. The Physicochemical Analysis of Camel meat, Chevon, and Pork
[abc] Means with different superscripts differ significantly ($P < 0.05$)

Pork exhibited the highest cold shortening, followed by camel meat and chevon ($P < 0.05$); however, camel meat did not differ significantly from pork and chevon. The high cold shortening recorded probably suggests that pork muscle may be more susceptible to contraction under rapid chilling conditions, potentially due to species-specific differences in muscle fibre composition and post-mortem biochemical processes. Scientific studies indicate that pork, particularly the longissimus dorsi muscle, which is mostly made up of fast-twitch glycolytic fibres (Type IIb), is susceptible to cold shortening under certain chilling conditions. Cold shortening occurs when muscle is chilled rapidly to low temperatures before rigour mortis is complete, leading to excessive muscle contraction and increased toughness (Dransfield & Lockyer, 1985; Iversen et al., 1995; Møller & Jensen, 1993; Rees et al., 2003).

The rate of pH decline after death influences the risk of cold shortening. Rapid chilling before a sufficient pH drop increases the risk, while electrical stimulation (which accelerates pH decline) can reduce cold shortening and improve tenderness (Rees et al., 2003).

Thermal shortening and cooking loss did not differ between the three meat types ($P > 0.05$). Although camel meat obtained a very high cooking loss, the value was not significantly higher than other meat types ($P > 0.05$).

The substantial cooking loss observed in camel meat may be attributed to several factors. Previous studies have shown that cooking methods significantly influence the extent of moisture loss, with microwaving yielding higher losses than grilling and frying (Bahwan et al., 2023). Importantly, protein solubility and collagen content are key factors that influence cooking loss (Bahwan et al., 2023). In addition, age and meat cuts largely determine cooking loss; younger camels and certain cuts like ribeye steaks tend to have lower cooking loss and better sensory properties (Dawood, 1995).

In terms of water holding capacity (WHC), camel meat exhibited the highest capacity, followed by chevon and pork. Water holding capacity is an important quality attribute that affects nutritional value, appearance, and eating quality (Kadim & Mahgoub, 2012). From the consumers' and processors' standpoints, WHC largely determines the juiciness of meat cuts. The observed variation in WHC palatability across the meat types likely stems from the varying differences in species-specific physiological differences and the influence of pre- and post-mortem factors, such as muscle pH, muscle, and fibre type. The three meat types also did not differ in thaw rigour ($P > 0.05$).

The Proximate, Mineral, and Vitamin Composition of Fresh Meats

The proximate composition of fresh camel meat, chevon, and pork is shown in Figure 2. Among the three meat types, camel meat had the highest crude protein (CP) content ($P < 0.05$; 21.71 %), followed by chevon and pork; this finding is consistent with previous studies by Nikmaram et al., (2011) and Fakolade et al., (2014) who reported comparable crude protein values (22.14 % and 21.96 %, respectively) in fresh camel muscles. Factors such as breed, diet, and muscle type could be responsible for the observed differences recorded among the meat types.

As expected, pork had the highest ether extract (fat content) ($P < 0.05$) than chevon and camel meat. The low-fat content recorded for camel meat is in agreement with Fakolade et al., (2014), who reported 2.12 %. The ether extract value recorded for chevon in this study (4.55 %) is notably lower than the 10.45 % reported by Enock et al. (2017), likely due to breed differences, the animal's diet, and sampling techniques.

The ash content, which provides an estimate of total mineral concentration, was highest in camel meat ($P < 0.05$; 2.16 %), followed by pork and chevon, respectively. The relatively higher content of ash in camel meat recorded in this study probably indicates the presence of essential dietary minerals. The ash content recorded in camel meat slightly exceeds the range (0.75 - 1.38 %) reported by Babiker & Yousif (1990), while the value of ash content recorded in chevon (1.18 %) agrees with Moawad et al., (2013). The highest moisture content was recorded in camel meat ($P < 0.05$; 71.69 %), followed by chevon, while pork had the least. The camel's moisture content value recorded in this study is lower than the value (76.29 %) reported by Nikmaram et al. (2011) respectively, but agrees with the findings of Kadim et al., (2014), who reported the range 63.0 % - 79.0 %; these varying differences could be traced to the anatomical location of the sampled muscle.

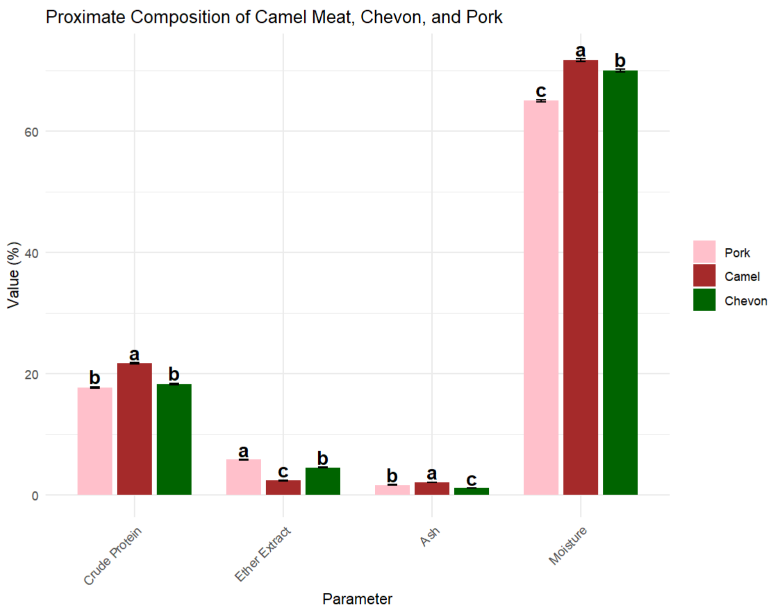

Figure 2. The Proximate Composition of Fresh Camel meat, Chevon, and Pork (Fresh weight basis)

[abc] Means with different superscripts differ significantly ($P < 0.05$)

Figure 3 presents the essential mineral composition of pork, camel meat, and chevon. As shown in the plot, camel meat and chevon obtained similar values for calcium ($P > 0.05$). Camel meat had the highest levels of potassium and magnesium, indicating that camel meat may provide a richer source of essential minerals compared to chevon and pork. Additionally, the high mineral content further substantiates the high ash values observed in camel meat (Figure 2).

In terms of vitamin composition (Figures 4 and 5), camel meat exhibited a markedly higher vitamin B_{12} content than other meat types; a similar trend was noted for vitamin D and Vitamin B_2; camel meat again had the highest values ($P < 0.05$).

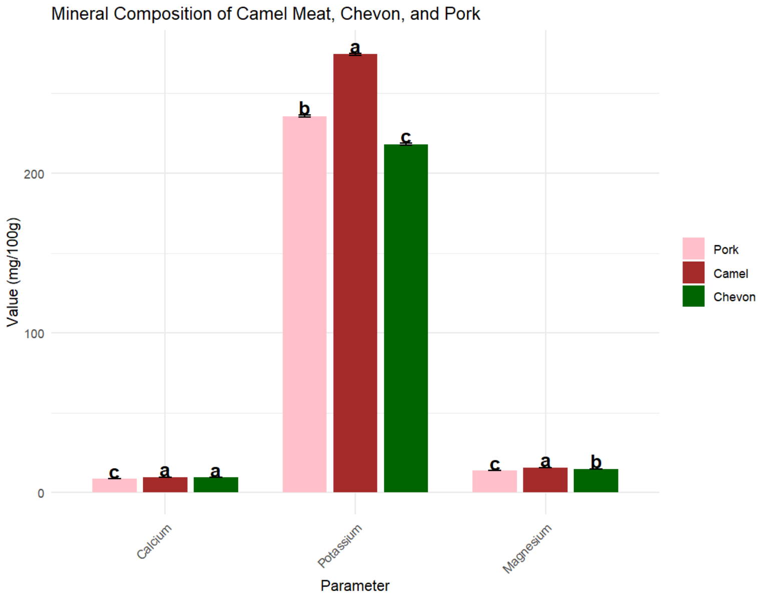

Figure 3. The Mineral Composition of Fresh Camel meat, Chevon, and Pork (Fresh weight basis)
^{abc} Means with different superscripts differ significantly ($P < 0.05$)

In this study, we assessed the levels of selected essential minerals: calcium, potassium, and magnesium in the fresh meats and sausage products, owing to their nutritional and technological benefits. Calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) minerals are regarded as the primary macrominerals of physiological significance (Chekri et al., 2012). From a nutritional standpoint, calcium improves bone health and supports muscle function, while potassium helps maintain electrolyte balance and promotes heart health. Additionally, magnesium is beneficial for enzyme function and supporting muscle/nerve health. In terms of sausage quality, Ca, K, and Mg play functional roles; their addition can influence texture, water retention, color, and sensory properties (Cáceres et al., 2006; Gimeno et al., 1998; Kim et al., 2018; Yang et al., 2021).

Overall, these findings suggest that camel meat exhibits superior nutritional qualities in terms of protein content, micronutrients, particularly vitamin B_2, B_{12}, and D, and essential minerals. The superior nutritional qualities of camel meat probably highlight its potential as a functional meat product relative to more commonly consumed red meats; these findings support Hamed Hammad Mohammed et al., (2020), who reported that camel meat possesses higher moisture, minerals, vitamins, and amino acids content than beef, mutton, and chicken.

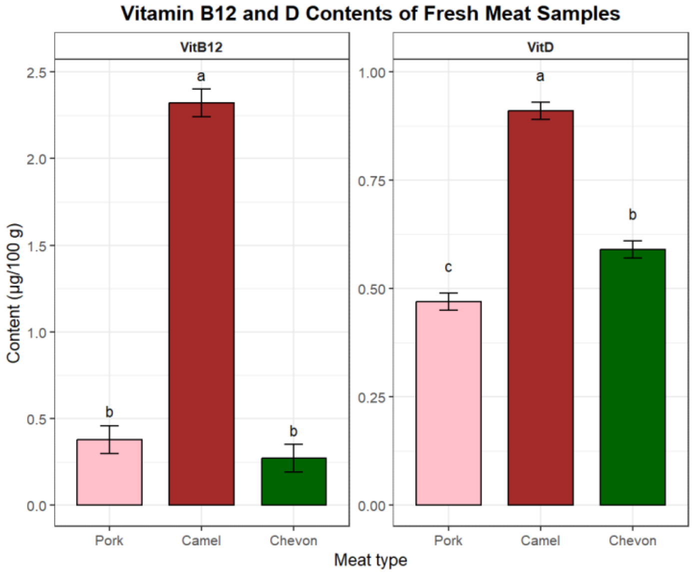

Figure 4. The Vitamin B_{12} and D Composition of Fresh Camel meat, Chevon, and Pork (Fresh weight basis)

abc Means with different superscripts differ significantly ($P < 0.05$)

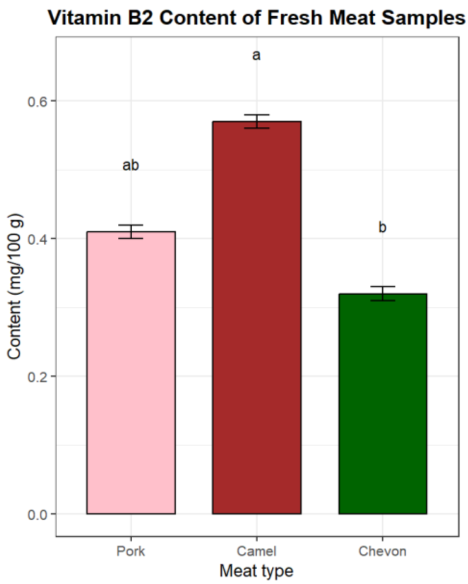

Figure 5. The Vitamin B_2 Composition of Fresh Camel meat, Chevon, and Pork (Fresh weight basis)

abc Means with different superscripts differ significantly ($P < 0.05$)

The Proximate Composition of Sausage Products

As shown in Table 2, the oven-cooked sausages exhibited the highest CP content across all meat types (pork, camel meat, and chevon). For pork sausages, the CP content slightly decreased from fresh to fried but increased from fresh to oven-cooked; however, the CP content of fresh and fried pork sausages did not differ significantly (P > 0.05). In camel meat sausages, CP increased from fresh to fried samples and peaked in oven-cooked samples (17.05 %). A similar trend was observed in chevon sausages, with CP values increasing from fresh to fried and reaching the highest in oven-cooked products. In both camel and chevon sausages, the CP content of both fried and oven-cooked samples did not differ (P > 0.05). The observed increase in CP content with heat processing (fresh < fried < oven-cooked) is consistent across all meat types, except in pork; this trend suggests that thermal processing, particularly oven drying, results in increased protein concentration due to moisture reduction. The higher CP values in oven-cooked products compared to fried samples may be attributed to reduced fat absorption and less protein denaturation during cooking; as a result, the relative proportion of CP in the final products was higher.

Table 2. Proximate composition of sausage products made from pork, camel meat, and chevon (fresh weight basis)

Meat type	**Processing Method**	**Proximate Composition (%)**			
		CP[1]	EE[2]	ASH	MC[3]
Pork	Fresh	15.21^{b}	3.97^{c}	1.14^{b}	63.32^{a}
	Fried	14.11^{b}	5.45^{b}	1.39^{a}	47.09^{c}
	Oven-cooked	17.99^{a}	5.80^{a}	1.19^{b}	51.99^{b}
Camel					
	Fresh	11.85^{b}	3.59^{c}	1.22^{c}	59.74^{a}
	Fried	16.50^{a}	5.00^{a}	1.28^{b}	51.65^{b}
	Oven-cooked	17.05^{a}	4.25^{b}	1.44^{a}	52.11^{b}
Chevon					
	Fresh	13.19^{b}	4.02^{c}	1.18^{c}	63.32^{a}
	Fried	18.29^{a}	4.45^{b}	1.40^{a}	59.98^{b}
	Oven-cooked	20.08^{a}	5.25^{a}	1.31^{b}	52.95^{c}
SEM[4]		0.70	0.13	0.02	0.76

^{abc} means with different superscripts within individual columns differ significantly (P < 0.05)
[1]CP- Crude protein
[2]EE-Ether extract
[3]MC-Moisture content
[4]SEM- Standard error of mean

Compared to previous studies, the CP values obtained in this study are generally similar to those reported by (Siham, 2015) for chevon (18.0 %) and camel sausages (16.0 %), and also comparable with the values reported by Schmid et al. (2009) for pork sausages (16.2 %).

The ether extract (EE) content also varied with processing. In pork sausages, EE increased from fresh to fried and was highest in oven-cooked samples. For camel sausages, EE increased from fresh to fried but was lower in oven-cooked products. Chevon sausages exhibited an increase from fresh to fried and peaked in oven-cooked samples, possibly suggesting that frying generally leads to higher fat content due to oil absorption, although the highest EE ($P < 0.05$) in pork and chevon was observed in oven-cooked samples. The variation in fat content among the meat types and processing methods may be due to differences in fat distribution and the influence of processing methods.

Ash content increased with processing in pork sausages, from fresh to fried, although oven-cooked samples (1.19 %) did not differ from fresh samples ($P > 0.05$; 1.14 %). In camel sausages, the ash content was relatively stable across treatments, with a slight increase in oven-cooked samples. Chevon sausages showed a modest increase in ash content with processing, from fresh to fried and oven-cooked. The general increase in ash content with processing is likely due to moisture loss, which concentrates minerals in the final product.

Table 3. Two-way ANOVA summary for proximate composition of sausage (Effect of meat type, processing method, and their interaction)

Source of variation	DF[1]	Crude protein	Ether Extract	Ash	Moisture
		F-Statistic (P-value)	F-Statistic (P-value)	F-Statistic (P-value)	F-Statistic (P-value)
Intercept	1	4695.78 ($P < 0.001$)	12499.10 ($P < 0.001$)	59075.71 ($P < 0.001$)	842064.60 ($P < 0.001$)
Meat type	2	6.732 ($P < 0.001$)	31.001 ($P < 0.001$)	18.094 ($P < 0.001$)	23.884 ($P < 0.001$)
Processing method	2	37.686 ($P < 0.001$)	89.580 ($P < 0.001$)	101.887 ($P < 0.001$)	172.103 ($P < 0.001$)
Meat type × processing method interaction	4	6.447 ($P = 0.002$)	14.267 ($P < 0.001$)	33.973 ($P < 0.001$)	23.146 ($P < 0.001$)
Error	18	-	-	-	-
Total	27	-	-	-	-

[1]DF = Degree of freedom

Moisture content was highest in fresh sausages for all meat types ($P < 0.05$). Processing reduced the moisture content in both fried sausages and oven-cooked sausages. Among the processed samples, fried sausages appeared to obtain the lowest moisture content, likely due to the intense effect of frying and the simultaneous replacement of water with oil (Krokida et al., 2000; Li & Fan, 2015). Table 3 shows that there was evidence that the interaction of meat type × processing method had significant effects on the nutritional composition of sausage products ($P < 0.05$).

Vitamin Composition of Sausage Products

Table 4 presents the vitamin composition of pork, camel, and chevon sausage products. The pattern for vitamin B_{12} was inconsistent across meat types and processing methods. In pork sausages, the vitamin B_{12} (Cobalamin) content remained unchanged between fresh and fried samples (0.51 µg/100g) but increased to 0.66 µg/100g in oven-cooked products. For camel sausages, vitamin B_{12} increased with frying compared to fresh, but decreased in oven-cooked products. Chevon sausages exhibited a slight decrease with frying but a notable increase in oven-cooked products.

Table 4. Vitamin composition of pork, camel, and chevon sausage (fresh weight basis)

Meat type	Processing Method	Composition		
		Vit B_{12}[1] (µg/100g)	Vit. B_2[2] (mg/100g)	Vit. D[3] (µg/100g)
Pork	Fresh	0.51^{b}	0.03^{c}	1.57^{a}
	Fried	0.51^{b}	0.46^{b}	0.69^{c}
	Oven-cooked	0.66^{a}	0.68^{a}	0.93^{b}
Camel	Fresh	0.51^{b}	0.03^{c}	1.50^{a}
	Fried	0.60^{a}	0.64^{a}	0.83^{b}
	Oven-cooked	0.48^{b}	0.51^{b}	0.59^{c}
Chevon	Fresh	0.50^{b}	0.05^{c}	1.54^{a}
	Fried	0.47^{c}	0.44^{b}	0.63^{c}
	Oven-cooked	0.72^{a}	0.74^{a}	0.97^{b}
SEM[4]		0.02	0.01	0.02

[abc] means with different superscripts within individual columns differ significantly ($P < 0.05$)
[1]Vit B_{12} – Vitamin B_{12}
[2]Vit B_2 – Vitamin B_2
[3]Vit D – Vitamin D
[4]SEM- Standard error of means

In contrast, vitamin B_2 (Riboflavin) content increased significantly with processing intensity. Across all meat types, oven-cooked products exhibited the highest vitamin B_2 concentrations. For instance, the amount of pork sausage vitamins increased from 0.03 mg/100g (fresh) to 0.46 mg/100g (fried) and 0.68 mg/100g (oven-cooked). Camel sausages followed similar trends. The increase in vitamin B_{12} content possibly highlights the heat stability property of riboflavin in processed meat products under appropriate cooking conditions.

A clear and consistent decline in vitamin D was observed across all sausage types, from fresh to fried and oven-cooked products. For example, pork sausage exhibited a marked decrease from fresh to fried and oven-cooked. Similar trends were observed in camel and chevon sausages as well. The reduction of vitamin D is likely due to the thermal degradation of water-soluble vitamins, such as vitamin D, during processing. Both frying and oven-cooking involve high cooking temperatures, which can cause significant losses of temperature-sensitive nutrients.

Our findings agree with previous research, which reported moderate losses in vitamin B_{12} when high-heat treatment methods, such as deep-frying, are applied, resulting in a loss of about 5.5 % in the longissimus beef muscle on a dry basis (Ortigues-Marty et al., 2006), and with Kamel et al., (2024) who also reported a decrease in vitamin D content in fried and oven-cooked shrimp, salmon, and sardine samples, with frying yielding the lowest vitamin D content. This study, however, disagrees with Neill et al., (2022) who reported an increase in vitamin D content of pork meat products post-cooking using various home cooking methods, such as grilling, pan-frying, and roasting. These discrepancies could be traced to the differences in applied cooking methods, cooking time, and temperature settings.

Generally, oven drying causes less vitamin loss than frying, especially for vitamin D. However, oven cooking and grilling are superior in retaining vitamin D content in fish and meat than frying (Kamel et al., 2024). The vitamin B_{12} values observed in pork sausages in this study are comparable to those reported by Schmid et al., (2009), while the vitamin B_2 values in processed pork sausages in this report were higher than the values reported by the same author. Compared to the report of Cunningham et al. (2015), the mean values obtained in this study for vitamin B_{12} appear lower, and the values observed in vitamin D are somewhat comparable.

Table 5 reveals that the interaction of meat type × processing method significantly influences the vitamin contents of pork, camel, and chevon sausage products ($P < 0.05$).

Meat-based products, including sausages, remain excellent dietary sources of vitamins B-complex, particularly B_{12} and B_2, which are either absent or found in negligible quantities in plant-based foods (Titcomb & Tanumihardjo, 2019). The observed preservation and, in some cases, enhancement with processing of these water-soluble vitamins support the recommendation of moderate consumption of sausage, particularly for populations such as infants who are at risk of B-vitamin deficiencies.

Table 5. Two-way ANOVA summary for vitamin composition of sausage (Effect of meat type, processing method, and their interaction)

Source of variation	DF[4]	Vit. B_{12}[1]	Vit. B_2[2]	Vit. D[3]
		F-Statistic (P-value)	F-Statistic (P-value)	F-Statistic (P-value)
Intercept	1	8751.56 ($P < 0.001$)	34253.67 ($P < 0.001$)	38640.85 ($P < 0.001$)
Meat type	2	2.893 ($P = 0.081$)	7.31 ($P = 0.005$)	26.07 ($P < 0.001$)
Processing method	2	34.95 ($P < 0.001$)	7390.14 ($P < 0.001$)	2408.24 ($P < 0.001$)
Meat type × processing method interaction	4	29.69 ($P < 0.001$)	320.11 ($P < 0.001$)	99.37 ($P < 0.001$)
Error	18	-	-	-
Total	27	-	-	-

[1]Vit. B_{12}- Vitamin B12
[2]Vit. B_2- Vitamin B2
[3]Vit. D- Vitamin D
[4]DF = Degree of freedom

Mineral Composition of Sausage Products

Mineral composition of sausage products produced from pork, camel, and chevon is presented in Table 6.

Table 6. Mineral composition of sausage products (fresh weight basis; mg/100g)

Meat type	Processing Method	Composition		
		Ca[1]	K[2]	Mg[3]
Pork	Fresh	12.15^{a}	282.50^{b}	18.59^{a}
	Fried	11.30^{c}	284.00^{b}	17.84^{b}
	Oven-cooked	11.50^{b}	305.00^{a}	18.27^{ab}
Camel	Fresh	11.93^{a}	270.00^{c}	18.59^{a}
	Fried	11.39^{b}	296.50^{a}	18.08^{ab}
	Oven-cooked	11.23^{c}	290.00^{b}	17.89^{b}
Chevon	Fresh	12.27^{a}	280.00^{b}	18.61^{a}
	Fried	11.29^{b}	273.00^{c}	17.75^{b}
	Oven-cooked	11.57^{b}	314.00^{a}	18.39^{ab}
SEM[4]		0.08	1.10	0.18

^{abc} means with different superscripts within individual columns differ significantly ($P < 0.05$)
[1]Ca- Calcium
[2]K- Potassium
[3]Mg- Magnesium
[4]SEM- Standard error of means

For all three sausage types, the calcium content consistently decreased with increased processing intensity. In pork sausages, the highest calcium concentration was measured in fresh samples ($P < 0.05$), with significant reductions observed in both fried and oven-cooked products. Camel sausages exhibited a similar pattern, with fresh samples exhibiting the highest calcium levels ($P < 0.05$), which decreased with frying and oven-cooking. In chevon sausages, the calcium content was highest in the fresh sample ($P < 0.05$), while the fried and oven-cooked products were similar and did not differ significantly ($P > 0.05$).

Generally, fresh samples obtained the lowest potassium levels ($P < 0.05$). In pork sausages, potassium content was lowest in fresh samples and highest in oven-cooked products; however, the fresh and fried pork sausages did not differ significantly ($P > 0.05$). Camel sausages followed a similar trend, with potassium increasing from fresh to oven-cooked but decreasing in fried samples. In chevon sausages, the potassium content decreased from fresh to fried, but an increase was observed in the oven-cooked products.

Table 7. Two-way ANOVA summary for mineral composition of sausage (Effect of meat type, processing method, and their interaction)

Source of variation	**DF[4]**	**Ca[1]**	**K[2]**	**Mg[3]**
		F-Statistic (P-value)	F-Statistic (P-value)	F-Statistic (P-value)
Intercept	1	182884.90 ($P < 0.001$)	621602.30 ($P < 0.001$)	87805.77 ($P < 0.001$)
Meat type	2	4.443 ($P = 0.027$)	16.408 ($P < 0.001$)	0.100 ($P = 0.905$)
Processing method	2	82.71 ($P < 0.001$)	432.623 ($P < 0.001$)	11.086 ($P < 0.001$)
Meat type × processing method interaction	4	2.668 ($P = 0.066$)	128.458 ($P < 0.001$)	1.382 ($P = 0.280$)
Error	18	-	-	-
Total	27	-	-	-

[1]Ca- Calcium
[2]K- Potassium
[3]Mg- Magnesium
[4]DF = Degree of freedom

Magnesium content tended to decrease slightly with the processing of pork and camel sausages. In pork sausages, the fresh samples had the highest magnesium content ($P < 0.05$), with minor reductions in oven-cooked and fried products. For camel sausages, the magnesium content remained relatively stable across all processing methods, with no statistically significant differences observed between fried and oven-cooked products ($P > 0.05$). A similar trend was observed in chevon sausage products, with fresh having the highest value ($P > 0.05$), while fried and oven-cooked products obtained slightly lower values. These results probably suggest that magnesium may be more thermally stable in pork, camel, and chevon, or that losses were negligible under the applied cooking methods.

According to Table 7, meat type × processing method influenced potassium only ($P < 0.05$), but did not influence calcium and magnesium ($P > 0.05$). Overall, the mineral values obtained in this study were higher than those documented by Schmid et al. (2009), and the discrepancy may be due to differences in fresh meat nutritional composition and quality, sausage formulation, and cooking method. Interestingly, despite the impact of processing on mineral composition, sausage products retained a substantial mineral composition and had higher content than their fresh meats (Figure 3). Given the availability of these vital minerals in pork, camel, and chevon sausage products, consuming sausage products can contribute meaningfully to the dietary intake of consumers.

Sensory Evaluation of Sausage Products

Pork sausage received the highest mean score for colour ($P < 0.05$; 6.25), compared to chevon and camel sausages. Colour is a critical parameter in consumer preference and may influence the perceived freshness and quality of meat products. Flavour ratings did not significantly differ ($P > 0.05$) among the sausage products. Tenderness was rated highest in pork, while chevon and camel sausages showed no statistically significant difference ($P > 0.05$). The comparable differences between chevon and camel contrast with expectations, based on the inherent toughness of camel meat traced to its abundant connective tissues. The comparable difference between the camel and chevon sausages for tenderness could be attributed to the effect of thermal processing, at higher cooking temperatures, which enhances tenderness. In addition to thermal processing, the solubilization of intramuscular connective tissues during cooking likely improves the tenderness of camel sausages (Mohamed et al., 2016). Based on the hedonic scale used in this study, the tenderness ratings of the sausage products varied between scores 5 and 6, which represent intermediate and slightly tender, respectively. The moderate tenderness values obtained in this report could be attributed to the comminution of the products, which consequently resulted in the breaking down of muscle fibres, redistribution of the fat content, and reduction of connective tissues, which in turn produced more tender finished products from their raw forms. Interestingly, in this study, pork, camel, and chevon sausages all had similar ratings for juiciness, texture, and overall acceptability ($P > 0.05$); however, overall, pork sausage had relatively higher ratings than camel and chevon sausages.

Table 8. The sensory panel assessment of pork, camel, and chevon sausages

Parameter	Sausage Products			SEM^7
	Pork Sausage	Camel Sausage	Chevon Sausage	
$Colour^1$	6.25^a	2.90^b	3.70^b	0.70
$Flavour^2$	4.90^a	4.55^a	4.35^a	0.46
$Tenderness^3$	6.40^a	5.45^b	5.40^b	0.29
$Juiciness^4$	5.55^a	5.60^a	5.40^a	0.43
$Texture^5$	5.05^a	5.75^a	5.05^a	0.68
Overall $acceptability^6$	6.60^a	5.90^a	6.00^a	0.90

^{abc} means with different superscripts within a row differ significantly (P < 0.05)
[1]Colour: 1=Dark, 9 = Extremely light
[2]Flavour: 1= Not acceptable, 9 = Extremely fine
[3]Tenderness: 1= Extremely tough, 9 = Extremely tender
[4]Juiciness: 1= Extremely dry, extremely juicy
[5]Texture: 1 = Extremely coarse, 9 = Extremely fine
[6]Overall acceptability: 1 = Dislike extremely. 9 = Like extremely
[7]SEM- Standard error of means

CONCLUSION

Meat type, processing method, and the interaction of meat type and processing method significantly influence the nutritional composition of sausage products. This study indicates that thermal processing methods, specifically frying and oven-cooking, significantly improve the nutritional profiles of sausage products, particularly in terms of crude protein and certain B-complex vitamins. However, these methods also lead to reductions in some heat-sensitive vitamins (such as vitamin D) and minerals. Among the sausage types, pork sausage consistently demonstrated a superior sensory appeal compared to other sausage types. These results suggest that camel and chevon exhibit excellent nutritional qualities; however, pork may be more suitable for sausage formulations when consumer acceptability is a primary consideration.

Further, among the processing techniques studied, oven cooking is recommended as the most effective method for preserving the overall nutritional value of sausage products. The oven-cooking method proved particularly beneficial in retaining crude protein and certain minerals while minimizing nutrient degradation compared to frying. For future research, additional cooking methods such as smoking and boiling could be explored as strategies for balancing nutrient retention with desirable sensory attributes.

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