Heliyon 8 (2022) e09376

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Effect of *Teucrium trifidum* powder on some meat quality attributes of chevon under refrigerated storage

Irene Rumbidzai Mazhangara [a], Ishmael Festus Jaja [a,b,*], Eliton Chivandi [c]

[a] Department of Livestock and Pasture Sciences, University of Fort Hare, South Africa
[b] Department of Agriculture and Animal Health, University of South Africa, Roodepoort Johannesburg 1710, South Africa
[c] School of Physiology, University of Witwatersrand, Johannesburg, South Africa

ARTICLE INFO

Keywords:
Consumer health
Antioxidant and antimicrobial activity
Shelf life
Chevon
Teucrium trifidum

ABSTRACT

We investigated the effect of *T. trifidum* on the shelf-life and quality of chevon kept for eight days at 4 ± 1 °C in polyethylene pouches. Different powder levels of *T. trifidum* (0.5 %, 1.0 %, and 2.0 % w/w) and 0.02 % w/w butylated hydroxytoluene (BHT) were used to treat the chevon samples. The *T. trifidum* and BHT treated chevon was compared to untreated chevon (control). Colour, ferric reducing antioxidant power (FRAP), lactic acid bacteria (LAB) counts, oxidative stability, pH and total viable counts (TVC) were all measured while the samples were in storage. Treatment demonstrated a significant ($P < 0.05$) influence on pH with chevon preserved with *T. trifidum* powder (2 %), having a lower pH than the chevon preserved with BHT and the control. The colour of chevon (lightness, redness and yellowness) was shown to differ ($P < 0.05$) across treatments. The redness (a*) and yellowness (b*) reduced as the refrigeration period lengthened ($P < 0.05$).

In contrast, the lightness (L*) of chevon intensified as the storage period lengthened ($P < 0.05$). The TBARS considerably reduced ($P < 0.05$) in samples subjected to *T. trifidum powder* and BHT, with respect to the untreated sample. There was an increase in the FRAP activity as the amount of *T. trifidum* powder ($P < 0.05$) was increased. The FRAP values were shown to be inversely related to the TBARS values, implying that the addition of *T. trifidum* powder could slow lipid oxidation. In comparison with the control, *T. trifidum* powder inhibited bacterial growth during storage as measured by a significant reduction in TVC and LAB counts ($P < 0.05$). It is concluded that, *T. trifidum* powder has potent antioxidant and antimicrobial activity in refrigerated ground chevon thus can be potentially used to preserve the quality of refrigerator stored ground chevon.

1. Introduction

For health conscious people, chevon is a good red meat option. Despite chevon being "despised" by indigenous black South Africans who only prefer to consume it at special traditional ceremonies, its products such as sausages, nuggets and kebabs are becoming more popular [1]. However, meat handling speeds up lipid peroxidation and microbial activity [2]. Augmented lipid peroxidation and microbial activity mediate the loss of meat quality, viz colour, flavour, texture and nutritional content, in addition to compromising life-span of meat [3, 4, 5, 6, 7]. Therefore, it is pertinent that preservatives are used to mitigate against lipid oxidation and microbial-induced quality deterioration and, in the process, protect consumers.

Conventional synthetic antioxidant and antimicrobial substances are used. Nevertheless, there is consumer resistance against the continued use of these substances in the food production chain [8, 9, 10] as they are associated with negative impacts on health [11, 12]. Consumers prefer using natural sources of antioxidants and antimicrobials, which are deemed safe. Plants are known sources of phytochemicals with beneficial health activities, including antioxidant and antimicrobial activity [5, 9, 11, 13].

The possibility of utilizing plant materials in meat and/or meat products opens up and generates scientific prospects to examine the effectiveness of plants like *Teucrium trifidum* Retz., which has been shown to have health-promoting and potentially utilizable bio-activities [14, 15, 16]. This plant belongs to the Lamiaceae family and is found naturally in South Africa [17]. Teucrium species have anti-bacterial, diuretic, anti-feedant, anti-oxidant, anti-pyretic, anti-rheumatic, anti-septic, anti-spasmodic, anti-ulcer, diaphoretic and hypoglycemic bio-activities [15, 16]. Furthermore, species like *T. chamaedrys*, *T. polium* and

* Corresponding author.
E-mail address: IJaja@ufh.ac.za (I.F. Jaja).

https://doi.org/10.1016/j.heliyon.2022.e09376
Received 10 August 2021; Received in revised form 9 December 2021; Accepted 29 April 2022

T. marum have been commercialized due to their multiple health beneficial bioactivities [16, 18]. Despite the abundance of knowledge on *T. trifidum*'s phytochemical composition, antioxidant and antibacterial activities there is a scarcity of data on its effectiveness in meat preservation. In light of this, the research was aimed to investigate the effectiveness of *T. trifidum* powder in preserving ground chevon under refrigerated storage.

2. The materials and methods

2.1. Gathering of plants and meat samples

The shrubs of *T. trifidum* plant used in this study were harvested from the natural veld in the Eastern Cape Mbizana location (South Africa). Verification of the plants was done in Grahamstown (South Africa) in Albany Provincial Museum and a voucher herbarium specimen number was assigned (IMAZ08/2018, Mazhangara *et al.* [17]). (The plants were cleaned in distilled water and left to dry for 7 days in open air. The *T. trifidum* powder was then obtained by blending the dry shrubs (Waring Products Division, Torrington, USA). The powder was then sieved through a 2 mm sieve. Fresh chevon samples were obtained from the carcasses of Boer goats (slaughtered at 6 months old with a slaughter, mass range of 30–40 kg) from a commercial abattoir (Eastern Cape, South Africa). The chevon for sampling was harvested on the *Musculus longissimus* (*Longissimus thoracis et lumborum*, LTL). The slaughter process involved initial electrical stunning at a voltage of 75V at a current of 1A followed by exsanguination. This was followed by flaying then dressing by removing the viscera. Visible fat was then trimmed off the LTL muscle prior to collecting meat samples. The meat was ground into small pieces (22 EL Plus Trespade Meat Grinder, Torino, Italy). Ground chevon portions (100 g) were allotted as follows: control (untreated chevon); BHT (chevon plus 0.02 % w/w BHT); chevon treated with different levels of *T. trifidum* powder: T0.5; T1 and T2 (0.5, 1 and 2 % w/w, respectively). Each treatment had four replicates. The samples (treated chevon and control) were packaged in polyethylene pouches in the presence of oxygen and kept at 4 ± 1 °C. On days 0, 2, 4, 6, and 8, the samples were tested for pH, instrumental colour, lipid oxidation, and FRAP.

2.1.1. Chemicals and Reagents

Chemical and reagent substances of analytical grade were used in this study, including 1,1,3,3-Tetramethoxypropane (TMP), trichloroethanoic acid (TCA), potassium ferricyanide, thiobarbituric acid (TBA) and butylated hydroxytoluene (BHT) (Merck and Sigma-Aldrich, Gauteng, South Africa).

2.2. Determination of pH

With minor adjustments, the pH of chevon was measured according to Falowo *et al.* [2]. A 5g of chevon in 25 mL distilled water (de-ionized) was blended for 60 s (PT Polytron® Stand Dispersion Homogenizer 2500 E, Switzerland). An electrode (standardized) linked to a pH-meter (digital) was then used to measure pH (S.A Crison Equipment, Spain). For all treatments and days of storage, four replicates of pH measurements were taken.

2.3. Determination of colour

The colorimeter (Hunter L, a, b Minolta45/0 BYK-Gardner, U.S.A) () was made use of in determining colour. The CIE colour model (L*, a*, b*) were taken at three separate places after calibrating with the white, black and green standards. The colour readings were calculated using the average of four measurements per treatment on 0, 2, 4, 6 and 8 days.

2.4. Determining the lipid peroxidation status

The status of lipid peroxidation of chevon samples was determined through quantification of TBARS using Mukumbo *et al.* (2018)'s approach with few adjustments. In a 50mL falcon plastic tube, 2 g of sample and equal portions (6.25 mL each) of 2.8 % trichloroethanoic acid () and distilled water were combined. . The mixture was then homogenized for 20 s (PT Polytron® Stand Dispersion Homogenizer 2500 E, Switzerland). Immediately thereafter the slurry was strained using a filter paper (Whatman Number 1). A standard curve was generated in replica using 0.001M 1, 1, 3, 3-Tetramethoxypropane stock solution (TMP), by mixing distilled water (1 mL) with TMP (0, 5, 10, 20 μL). For each sample, three tubes were made. Then filtrate (1 mL) was then added into each tube. Each standard and two sample tubes received 1 mL mL of thiobarbituric acid (TBA) reagent, whereas the third tube (turbidity blank) received 1 mL of distilled water. All tubes were closed, vortexed and kept warm for 1 h inside a water-bath (70 °C). Following that, cooled samples were added to cuvettes using a pipette. A spectrophotometer was made use of in measuring the absorbance at 530 nm for three replicates. The TBARS were measured in mgMDA/kg of chevon.

2.5. Determining ferric ion reducing power

Each sampling point was subjected to FRAP analysis. The assay was performed in triplicate, with few changes, following the method of Arshad *et al.* [20]. In a buffer (phosphate) solution of pH 6.6, 5g of chevon samples were homogenized. A filter paper (Whatman No.1) was used to filter the slurry. Immediately thereafter, 200 μL of sample were added to 500 μL of buffer (phosphate) solution at a concentration of 0.2 M and pH of 6.6, and 500 μL of 1% Potassium hexacyanoferrate (III). The resulting blend was kept for 20 min in an incubator at 50 °C. Subsequently, 2.5 mL of TCA (10 %) was pipetted. The blend was put in centrifuge for 10 min at 2200×g. Equal portions (500 μL) of the supernatant and distilled water were combined together, then 100 μL of iron trichloride (0.1 %) was added. At 700 nm, absorbance was then read. The results were articulated as μmol/Fe^{2+}/per g of chevon.

2.6. Determination of microbial quality of ground chevon

Determination of microbial quality of samples was done soon after the respective treatments and thereafter on day 2, 4, 6 and 8 during refrigeration (at 4 °C) to determine TVC and LAB counts. Meat samples of 5g were homogenized for 2 min at 25 °C in 45 mL of sterile peptone water buffer (0.1 %). Dilution of the homogenate (1 mL) with 0.1 %peptone buffer (9 mL) yielded adequate serial tenfold dilutions for each sample. The bacteria counts were determined by means of the pour-plate method. At the end of the incubation period (48-hour) at 37 °C, the total viable counts were assessed using the CM0463 Oxoid plate count agar. Lactic acid bacteria were determined after 72 h of incubation at 30 °C on de Man Rogosa Sharpe media (Oxoid CM0359). Measurement of colony forming units per gram of sample (log CFU/g) on a base 10 logarithmic function was used to calculate the microbiological counts. Each assay was done in triplicate.

2.7. Statistical methods

Colour, pH, FRAP and lipid oxidation data was analyzed by means of SAS's Generalized Linear Model techniques (9.1.3 version of2007) with varying *T. trifidum* powder treatments and days of storage as the source of variations. The end-results were articulated as mean standard deviation (SD) of the duplicates. The log CFU/g was used to represent microbial results. The Tukey's Studentised Range test technique determined the differences in mean values. Determination of significance was $P < 0.05$. The statistical model employed in this study was as follows:

$$\mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ijk} = Y_{ijk}$$

With Y_{ijk} as the variable (LAB, pH, TVC, colour, TBARS, FRAP) of response

μ = the overall mean

α_i = the i^{th} effect of treatment [T0.5, T1, T2, BHT0.02%, control (meat with no antioxidants)]

β_j = the j^{th} effect of storage day (0, 2, 4, 6 and 8)
$(\alpha \times \beta)_{ij}$ = the interaction between treatment and storage day
ε_{ijk} = random error

3. Results

3.1. T. trifidum powder's effect on ground chevon pH

Table 1 illustrates the pH values of chevon samples for the duration of refrigeration (4 ± 1 °C). There were significant ($P < 0.05$) pH variations across the treatments. On day 0, the pH was ranging between 5.22 ± 0.01 and 5.73 ± 0.03. Generally, the chevon pH increased as number of days in storage increased. However, no effects were observed within *T. trifidum* powder treatments on pH values on days 0 and 2 ($P > 0.05$). Importantly, the pH of chevon subjected to *T. trifidum* powder was generally lower than that of chevon without *T. trifidum* and that of chevon treated with BHT.

3.2. T. trifidum powder's effect on ground chevon colour

The colour of chevon (L*, a*, and b*) treated with *T. trifidum* throughout refrigeration at 4 ± 1 °C is shown in Table 2. The b*, a* and L* of chevon differed significantly ($P < 0.05$) across treatments. The control samples exhibited somewhat higher L* values than the samples exposed to *T. trifidum* powder. Over time, chevon treated with BHT had lower L* values compared to chevon subjected to *T. trifidum* powder. Additionally, the lightness (L*) of the chevon marginally increased across the treatments over storage days. The redness and yellowness of the chevon reduced as the number of days in storage increased across the treatments. Also, the chevon treated with BHT showed higher b* and a* values compared to chevon treated with *T. trifidum powder* ($P < 0.05$).

3.3. The influence of T. trifidum on the ground chevon's lipid oxidation status

Table 3 below shows the antioxidant status of the ground chevon samples with *T. trifidum* powder as measured by TBARS. Treating ground chevon with *T. trifidum* powder at different doses considerably reduced the TBARS values compared to chevon without *T. trifidum* powder ($P < 0.05$), throughout the refrigeration period. The antioxidant status of the differently treated chevon samples differed significantly on day 0. Treatment T2 displayed an antioxidant status of 0.19 ± 0.01 and 0.41 ± 0.02 mg MDA/kg on days 0 and 6 which is as good as that of BHT treatment. The treated chevon (*T. trifidum* powder and BHT) samples' TBARS value did not exceed 0.79 ± 0.01 mg MDA per kilogram throughout the period of storage. The following is the order in which the TBARS levels decreased: control > T0.5% > T1 % > T2 % > BHT.

3.4. The influence of T. trifidum on the ground chevon's ferric reducing antioxidant power

There was an increase ($P < 0.05$) in the antioxidant status of chevon as the dose of *T. trifidum* powder in the chevon samples increased as

Table 1. Effect of *T. trifidum* powder on ground chevon pH during storage.

Storage day	Treatments				
	BHT	Control	T0.5	T1	T2
0	$5.36^{dC} \pm 0.02$	$5.73^{aB} \pm 0.03$	$5.62^{bB} \pm 0.01$	$5.45^{cC} \pm 0.06$	$5.22^{eC} \pm 0.01$
2	$5.39^{dC} \pm 0.03$	$5.74^{aB} \pm 0.03$	$5.64^{bB} \pm 0.04$	$5.47^{cBC} \pm 0.02$	$5.27^{eBC} \pm 0.02$
4	$5.45^{bB} \pm 0.03$	$5.79^{aB} \pm 0.14$	$5.66^{aAB} \pm 0.02$	$5.49^{bBC} \pm 0.02$	$5.28^{cB} \pm 0.03$
6	$5.50^{cB} \pm 0.02$	$5.85^{aB} \pm 0.04$	$5.68^{bAB} \pm 0.06$	$5.53^{cAB} \pm 0.01$	$5.31^{dAB} \pm 0.03$
8	$5.58^{cA} \pm 0.01$	$6.18^{aA} \pm 0.02$	$5.72^{bA} \pm 0.01$	$5.57^{cA} \pm 0.02$	$5.34^{dA} \pm 0.03$

Mean with $^{a-e}$ superscripts within a row indicates significant differences ($P < 0.05$).
Mean with $^{A-E}$ superscripts within a column indicates significant differences ($P < 0.05$).
BHT: 0.02 % Butylated hydroxyltoluene, control: no additive, T0.5, T1 and T2 %: *T. trifidum* powder.

Table 2. Effect of *T. trifidum* powder on colour variables (L*, a*, b*) of ground chevon in storage.

Parameters	Treatments	Days of storage				
		0	2	4	6	8
L*	BHT	$50.80^{cE} \pm 0.12$	$51.09^{cE} \pm 0.03$	$51.97^{bE} \pm 0.25$	$52.74^{aE} \pm 0.66$	$52.98^{aE} \pm 0.04$
	Control	$64.10^{cA} \pm 0.83$	$64.51^{cA} \pm 0.70$	$66.52^{bA} \pm 0.46$	$67.13^{abA} \pm 0.10$	$68.55^{aA} \pm 0.90$
	T0.5	$53.31^{bD} \pm 0.96$	$54.64^{abD} \pm 0.57$	$55.14^{aD} \pm 0.68$	$55.22^{aD} \pm 0.49$	$55.31^{aD} \pm 0.15$
	T1	$56.04^{cC} \pm 0.99$	$56.42^{bcC} \pm 1.43$	$58.36^{abC} \pm 0.92$	$58.71^{aC} \pm 0.43$	$58.95^{aC} \pm 0.04$
	T2	$59.66^{cB} \pm 0.22$	$59.72^{cB} \pm 0.45$	$63.04^{bB} \pm 0.39$	$63.10^{bB} \pm 0.36$	$64.26^{aB} \pm 0.75$
a*	BHT	$13.14^{aA} \pm 0.59$	$11.79^{bA} \pm 0.97$	$11.73^{bA} \pm 0.13$	$9.88^{cA} \pm 0.01$	$9.79^{cA} \pm 0.30$
	Control	$11.91^{aB} \pm 0.08$	$11.06^{bA} \pm 0.74$	$9.64^{cB} \pm 0.04$	$9.13^{cB} \pm 0.05$	$9.10^{cB} \pm 0.04$
	T0.5	$6.56^{aD} \pm 0.03$	$6.45^{aC} \pm 0.05$	$5.96^{bD} \pm 0.03$	$5.67^{bD} \pm 0.35$	$5.19^{cD} \pm 0.10$
	T1	$8.54^{aC} \pm 0.04$	$8.48^{aB} \pm 0.04$	$8.42^{aC} \pm 0.28$	$6.97^{bC} \pm 0.10$	$6.75^{bC} \pm 0.08$
	T2	$5.46^{aE} \pm 0.16$	$4.75^{bD} \pm 0.19$	$3.55^{cE} \pm 0.24$	$3.35^{cdE} \pm 0.03$	$3.08^{dE} \pm 0.02$
b*	BHT	$16.59^{aA} \pm 0.28$	$15.95^{bA} \pm 0.12$	$15.46^{cA} \pm 0.19$	$15.27^{cA} \pm 0.03$	$15.19^{cA} \pm 0.34$
	Control	$15.13^{aB} \pm 0.03$	$15.05^{aB} \pm 0.26$	$14.24^{bB} \pm 0.02$	$13.97^{bB} \pm 0.04$	$13.86^{bB} \pm 0.68$
	T0.5	$13.71^{aC} \pm 0.44$	$13.08^{abC} \pm 0.02$	$12.99^{abC} \pm 0.45$	$12.32^{bC} \pm 0.87$	$12.18^{bC} \pm 0.73$
	T1	$12.06^{aD} \pm 0.43$	$11.06^{bD} \pm 0.03$	$10.8^{bD} \pm 0.13$	$7.48^{cD} \pm 0.17$	$7.25^{cD} \pm 0.06$
	T2	$11.41^{aD} \pm 0.96$	$11.04^{aD} \pm 0.28$	$10.72^{aD} \pm 0.25$	$7.06^{bD} \pm 0.03$	$6.62^{bD} \pm 0.07$

Mean with $^{a-d}$ superscripts within a row indicates significant differences ($P < 0.05$).
Mean with $^{A-E}$ superscripts within a column indicates significant differences ($P < 0.05$).
BHT: 0.02 % Butylated hydroxyltoluene, control: no additive, T0.5, T1 and T2 %: *T. trifidum* powder.

Table 3. Effect of *T. trifidum* powder on lipid oxidation of ground chevon

Storage day	Treatments				
	BHT	Control	T0.5	T1	T2
0	$0.16^{dE} \pm 0.01$	$0.46^{aD} \pm 0.02$	$0.40^{bD} \pm 0.03$	$0.29^{cD} \pm 0.02$	$0.19^{dE} \pm 0.01$
2	$0.23^{dD} \pm 0.02$	$0.52^{aC} \pm 0.03$	$0.49^{aC} \pm 0.01$	$0.32^{bD} \pm 0.01$	$0.27^{cD} \pm 0.01$
4	$0.29^{eC} \pm 0.01$	$0.62^{aB} \pm 0.01$	$0.52^{bC} \pm 0.01$	$0.46^{cC} \pm 0.02$	$0.34^{dC} \pm 0.01$
6	$0.38^{dB} \pm 0.02$	$0.65^{aB} \pm 0.02$	$0.59^{bB} \pm 0.03$	$0.52^{cB} \pm 0.03$	$0.41^{dB} \pm 0.02$
8	$0.43^{eA} \pm 0.01$	$0.79^{aA} \pm 0.01$	$0.68^{bA} \pm 0.02$	$0.63^{cA} \pm 0.02$	$0.51^{dA} \pm 0.02$

Mean with $^{a-e}$ superscripts within a row indicates significant differences ($P < 0.05$).
Mean with $^{A-E}$ superscripts within a column indicates significant differences ($P < 0.05$).
BHT: 0.02 % Butylated hydroxyltoluene, control: no additive, T0.5, T1 and T2 %: *T. trifidum* powder.

shown in Figure 1. During refrigeration, the control had lower FRAP activity ($P < 0.05$) than all of the treatments. In general, the FRAP activity of all the treatments reduced with an increase in the number of days in storage. Treatment T2 showed FRAP activity nearly identical to that of BHT, which was the peak during refrigeration. The following is the order in which FRAP activity decreased: control > T0.5 > T1 > T2 > BHT.

3.5. *T. trifidum's influence on chevon microbial quality*

The influence of *T. trifidum* on the chevon's microbiological quality are shown in Tables 4 and 5. There is an increase in the TVC during refrigeration ($P < 0.05$). On day 0, the TVC throughout the treatments (3.9 ± 0.001 to 4.1 ± 0.005 log CFU/g), while T0.5 and the control had higher bacterial counts. The LAB counts showed a comparable pattern during storage period ($P < 0.05$). Nevertheless, insignificant changes in bacterial counts were found between the BHT and *T. trifidum* powder treated ground chevon on day 2 and day 8 ($P > 0.05$).

4. Discussion

The main reasons of degradation in meat for the duration of storage are lipid peroxidation and microbial activity [3, 21]. However, this endogenous enzyme-induced and microbial-induced deterioration is normally mitigated by using synthetic anti-oxidants and antimicrobials [22, 23]. Plant extract phytochemicals have anti-microbial and anti-oxidant properties [10, 24]. The pH of the control and treated chevon samples (*T. trifidum* powder and BHT) were found to be significantly different in the current investigation, with the treated chevon samples having a lower pH than the control. Falowo *et al.* [2] found similar findings in fresh ground beef mixed with *Moringa oleifera* and *Bidens pilosa* extracts. Salah *et al.* [25] also found similar results in fresh beef mixed with leaf extract of olives. The lower pH exhibited by the chevon treated with *T. trifidum* powder suggests that the anti-microbial constituents of the *T. trifidum* powder inhibited the growth of spoilage microbes. Also, the pH increased across the treatments with increasing refrigeration period which could be due to the accumulation of ammonia caused by microbial load on meat protein and amino acids over storage [26, 27, 28]. On the other hand, no significant effects were observed within *T. trifidum* powder treatments on the increase in pH values on days 0 and 2 of storage. However, an increase in pH could be attributed to the releasing of ammonium hydroxide composites by proteolytic bacteria in meat [29, 30].

The results from the current study showed a steady decrease in the redness and yellowness of the chevon preserved with *T. trifidum* powder during refrigeration period. The change in colour caused by the oxidation

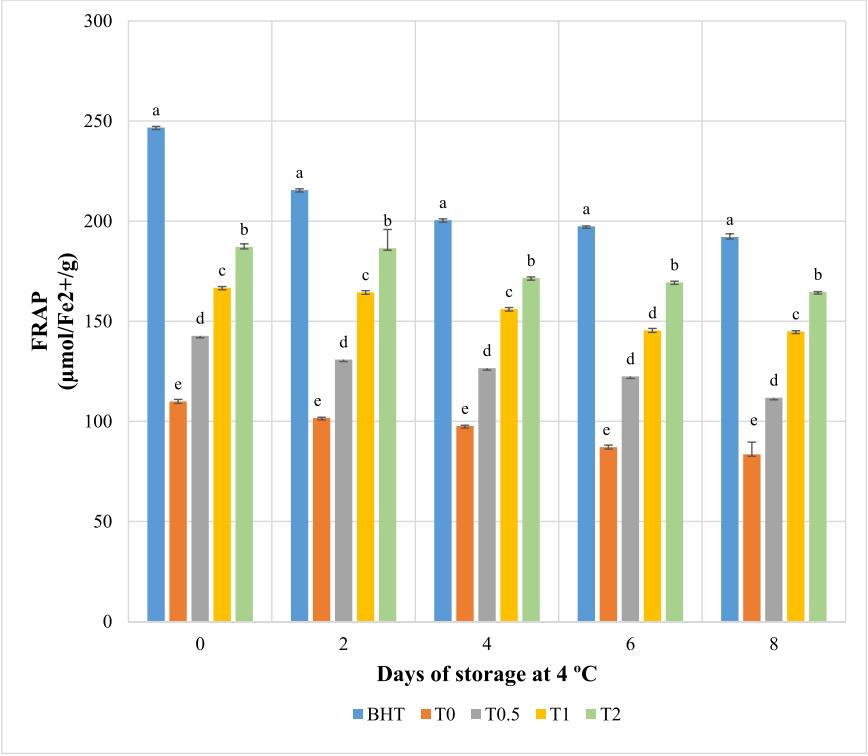

Figure 1. FRAP of ground chevon treated with *T. trifidum*. $^{a-e}$ Means that are different on the same storage day indicate significant differences ($P < 0.05$). BHT: 0.02 % Butylated hydroxyltoluene, T0: control without any additive, T0.5, T1 and T2 %: *T. trifidum* powder.

Table 4. Effect of *T. trifidum* powder on total viable bacteria counts of ground chevon

Storage day	Treatments				
	BHT	Control	T0.5	T1	T2
0	$3.9^{cE} \pm 0.002$	$4.1^{aE} \pm 0.005$	$4.1^{aE} \pm 0.006$	$4.0^{bE} \pm 0.004$	$3.9^{cE} \pm 0.001$
2	$4.2^{dD} \pm 0.003$	$4.4^{abD} \pm 0.004$	$4.4^{aD} \pm 0.001$	$4.3^{bD} \pm 0.002$	$4.2^{cD} \pm 0.010$
4	$4.3^{cC} \pm 0.014$	$4.6^{aC} \pm 0.004$	$4.5^{aC} \pm 0.001$	$4.4^{bC} \pm 0.011$	$4.4^{bC} \pm 0.008$
6	$4.3^{dB} \pm 0.000$	$4.8^{aB} \pm 0.004$	$4.8^{aB} \pm 0.002$	$4.7^{bB} \pm 0.005$	$4.6^{cB} \pm 0.000$
8	$4.5^{dA} \pm 0.003$	$4.9^{aA} \pm 0.000$	$4.9^{aA} \pm 0.001$	$4.8^{bA} \pm 0.001$	$4.7^{cA} \pm 0.001$

Mean with $^{a-d}$ superscripts within a row indicates significant differences ($P < 0.05$).
Mean with $^{A-D}$ superscripts within a column indicates significant differences ($P < 0.05$).
BHT: 0.02 % Butylated hydroxyltoluene, control: no additive, T0.5, T1 and T2 %: *T. trifidum* powder.

Table 5. Effect of *T. trifidum* powder on lactic acid bacteria counts of ground chevon

Storage day	Treatments				
	BHT	Control	T0.5	T1	T2
0	$3.2^{eE} \pm 0.000$	$3.6^{aE} \pm 0.006$	$3.5^{bC} \pm 0.004$	$3.4^{cC} \pm 0.037$	$3.3^{dE} \pm 0.006$
2	$3.3^{dD} \pm 0.000$	$3.7^{aD} \pm 0.008$	$3.6^{abC} \pm 0.045$	$3.5^{bcC} \pm 0.057$	$3.5^{cdD} \pm 0.000$
4	$3.5^{cC} \pm 0.003$	$3.9^{aC} \pm 0.004$	$3.9^{aB} \pm 0.004$	$3.8^{bB} \pm 0.024$	$3.7^{bC} \pm 0.003$
6	$3.9^{dB} \pm 0.004$	$4.3^{aB} \pm 0.001$	$4.3^{aA} \pm 0.003$	$4.2^{bA} \pm 0.008$	$4.0^{cB} \pm 0.006$
8	$4.1^{cA} \pm 0.001$	$4.4^{aA} \pm 0.001$	$4.4^{aA} \pm 0.001$	$4.2^{bA} \pm 0.009$	$4.1^{cA} \pm 0.003$

Mean with $^{a-d}$ superscripts within a row indicates significant differences ($P < 0.05$).
Mean with $^{A-D}$ superscripts within a column indicates significant differences ($P < 0.05$).
BHT: 0.02 % Butylated hydroxyltoluene, control: no additive, T0.5, T1 and T2 %: *T. trifidum* powder.

of myoglobin can be seen in the decrease in redness of the meat. This agrees with Yin and Cheng [31], who discovered that minced beef without antioxidants had higher metmyoglobin than beef combined with garlic-derived substances.

The L* values of chevon treated with *T. trifidum* powder were low when contrasted with the control. These findings could be explained by the dark colour from inherent plant pigment substances such as chlorophylls contained in *T. trifidum* powder [32]. These findings proved that chevon treated with BHT had lower lightness than chevon subjected to *T. trifidum* powder during refrigeration. This shows the *T. trifidum* powder's protective effect on colour lightness.

It is worth noting that as *T. trifidum* powder was added to ground chevon, there was a significant decrease in the TBARS in comparison with the control. It can, therefore, be inferred that *T. trifidum* powder delayed oxidation of lipids in the chevon samples. Considering the phytochemical composition and *in vitro* anti-oxidant activities of *T. trifidum* extracts in previous studies (Mazhangara *et al.*, 2020), *T. trifidum* powder reduced oxidation in meat lipids due to its intrinsic phytochemicals that can quench free radicals. Importantly, the TBARS recorded in this study were lower than the permissible range of 1–2 mg MDA/kg [33], showing that *T. trifidum* powder in chevon has good anti-oxidant activity. Moreover, as the period of storage increased, the TBARS values increased. During refrigerated storage, the breakdown of lipids, oxidative off-flavours and the accumulation of secondary metabolic products may all contribute to an increase in TBARS [34].

The ability of *T. trifidum* powder to lower TBARS could be ascribed to the high concentration of phytochemicals that can donate electrons to free radicals changing them to constant compounds and therefore ending free-radical reactions [35]. Interestingly, in their evaluation of plant-derived anti-oxidants, Devatkal *et al.* [36] found a favourable association between phenolic contents and reduced TBARS in cooked chevon patties. On the other hand, the results of the current revealed a decreasing trend of FRAP as the storage period increased, with an inverse relationship to TBARS. As a result, it may be deduced that the addition of *T. trifidum* powder during storage is critical in retarding lipid oxidation.

The chevon samples treated with BHT and *T. trifidum* powder showed a slow increase and lower microbial counts than the control. This means that *T. trifidum* powder may help in delaying microbial growth in the meat. The acceptable meat's maximum microbiological limit is determined to be 7 log colony-forming units per gram TVC [37]. The TVC of chevon samples treated with *T. trifidum* powder did not exceed this limit in our investigation, demonstrating that the *T. trifidum* powder inhibited the growth of microorganisms. The anti-microbial action observed in our investigation can be caused by the polyphenols' capacity to impair the cell-wall as well as the plasma membrane of microbes, thus limiting their growth [38, 39]. In chevon treated with *T. trifidum* powder, the lactic acid bacteria levels were likewise lower than the control. The outcomes thereof are noteworthy in the light of the fact that LAB have extreme resistance against the anti-microbial effects of phytochemicals [40].

According to our understanding, no research has investigated the preservative ability of *T. trifidum* powder in meat. The addition of *T. trifidum* powder to ground chevon improved colour, pH, and lipid oxidation stability during refrigerated storage. . However, the effects of 2 % *T. trifidum* powder (T2 treatment) were lower than BHT treatments. This warrants further study to determine the effect of adding higher doses of *T. trifidum* powder to validate its use in meat preservation. Additional studies are required to assess the toxicity of *T. trifidum* powder to identify the best clear-cut level of addition to meat.

5. Conclusion

The current findings revealed that the inclusion of *T. trifidum* powder improved oxidative stability and microbiological quality of chevon throughout the refrigeration period. It can be inferred that *T. trifidum* powder, by increasing acidity and antioxidant activity of the meat, can potentially increase the meat's shelf- life. *T. trifidum* powder can, therefore, could employed in preserving chevon.

Declarations

Author contribution statement

Irene Rumbidzai Mazhangara, Eliton Chivandi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Ishmael Festus Jaja: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This work was supported by the National Research Foundation Collaborative Postgraduate Training Programme, South Africa (Grant Number 105289).

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

We acknowledge the support given by the Govan Mbeki Research & Development Center (University of Fort Hare).

References

[1] N.S. Jagtap, R.V. Wagh, M.K. Chatli, P. Kumar, O.P. Malav, N. Mehta, Optimisation of extraction protocol for Carica papaya L. to obtain phenolic rich phyto-extract with prospective application in chevon emulsion system, J. Food Sci. Technol. 56 (2019) 71–82.

[2] A.B. Falowo, V. Muchenje, A. Hugo, O.A. Aiyegoro, P.O. Fayemi, Antioxidant activities of *Moringa oleifera* L. and *Bidens pilosa* L. leaf extracts and their effects on oxidative stability of ground raw beef during refrigeration storage, CyTA - J. Food 15 (2017) 249–256.

[3] S. Noor, Z.F. Bhat, S. Kumar, R.J. Mudiyanselage, Preservative effect of Asparagus racemosus: a novel additive for bioactive edible films for improved lipid oxidative stability and storage quality of meat products, Meat Sci. 139 (2018) 207–212.

[4] I.N. Prado, M.M. Campo, E. Muela, M. V Valero, O. Catalan, J.L. Olleta, C. Sañudo, Effects of castration age, protein level and lysine/methionine ratio in the diet on colour, lipid oxidation and meat acceptability of intensively reared Friesian steers, Animal 9 (2015) 1423–1430.

[5] A.C.P. Vital, A. Guerrero, J.D.O. Monteschio, M.V. Valero, C.B. Carvalho, B.A. De Abreu Filho, G.S. Madrona, I.N. Do Prado, Effect of edible and active coating (with rosemary and oregano essential oils) on beef characteristics and consumer acceptability, PLoS One 11 (2016).

[6] P. Meena, A. Pandey, A. Saini, A.S. Gurjar, Cost economics of chevon nuggets incorporated with green coffee and grape seed extracts, Int. J. Chem. Stud. 7 (2019) 2707–2710.

[7] I.K. Kalem, Z.F. Bhat, S. Kumar, S. Noor, A. Desai, The effects of bioactive edible film containing Terminalia arjuna on the stability of some quality attributes of chevon sausages, Meat Sci. 140 (2018) 38–43.

[8] H. Zhang, J. Wu, X. Guo, Effects of antimicrobial and antioxidant activities of spice extracts on raw chicken meat quality, Food Sci. Hum. Wellness 5 (2016) 39–48.

[9] D. Mhalla, A. Bouaziz, K. Ennouri, R. Chawech, S. Smaoui, R. Jarraya, S. Tounsi, M. Trigui, Antimicrobial activity and bioguided fractionation of Rumex tingitanus extracts for meat preservation, Meat Sci. 125 (2017) 22–29.

[10] I.K. Kalem, Z.F. Bhat, S. Kumar, R.M. Jayawardena, Preservative potential of Tinospora cordifolia, a novel natural ingredient for improved lipid oxidative stability and storage quality of chevon sausages, Nutr. Food Sci. 48 (2018) 605–620.

[11] G. Mahapatra, S. Biswas, G. Patra, A.K. Vidyarthi, Enhancement of storage stability , textural profile , physico-chemical parameters and sensory attributes of chevon meatballs by guava powder incorporation, Int. J. Bio-Resource Stress Manag. 10 (2019) 346–352.

[12] M. Rathour, G. Angad, D. Veterinary, N. Mehta, G. Angad, D. Veterinary, P. Kumar, G. Angad, D. Veterinary, O.P. Malav, G. Angad, D. Veterinary, Functional chevon rolls fortified with cinnamon bark and Aloe vera powder extracts, Haryana Vet. 58 (2019) 1–5.

[13] J. Jiang, Y.L. Xiong, Natural antioxidants as food and feed additives to promote health benefits and quality of meat products: a review, Meat Sci. 120 (2016) 107–117.

[14] V. Maphosa, P.J. Masika, Ethnoveterinary uses of medicinal plants: a survey of plants used in the ethnoveterinary control of gastro-intestinal parasites of goats in the Eastern Cape Province, South Africa, Pharm. Biol. 48 (2010) 697–702.

[15] F. Menichini, F. Conforti, D. Rigano, C. Formisano, F. Piozzi, F. Senatore, Phytochemical composition, anti-inflammatory and antitumour activities of four Teucrium essential oils from Greece, Food Chem. 115 (2009) 679–686.

[16] A.K. Ruiters, P.M. Tilney, S.F. Van Vuuren, A.M. Viljoen, G.P.P. Kamatou, B.-E. Van Wyk, The anatomy, ethnobotany, antimicrobial activity and essential oil composition of southern African species of Teucrium (Lamiaceae), South Afr. J. Bot. 102 (2016) 175–185.

[17] I.R. Mazhangara, E.M. Idamokoro, E. Chivandi, A.J. Afolayan, Phytochemical screening and in vitro evaluation of antioxidant and antibacterial activities of Teucrium trifidum crude extracts, Heliyon 6 (2020), e04395.

[18] E. Darabpour, H. Motamedi, S.M.S. Nejad, Antimicrobial properties of Teucrium polium against some clinical pathogens, Asian Pac. J. Trop. Med. 3 (2010) 124–127.

[20] M.S. Arshad, M. Anjum, M.I. Khan, M. Shahid, S. Akhtar, M. Sohaib, Wheat germ oil enrichment in broiler feed with α-lipoic acid to enhance the antioxidant potential and lipid stability of meat, Lipids Health Dis. 12 (2013) 164.

[21] V.J. Ajaykumar, P.K. Mandal, Modern concept and detection of spoilage in meat and meat products, in: Meat Qual. Anal., Academic Press, 2020, pp. 335–349.

[22] A.B. Falowo, P.O. Fayemi, V. Muchenje, Natural antioxidants against lipid-protein oxidative deterioration in meat and meat products: a review, Food Res. Int. 64 (2014) 171–181.

[23] M. Kozłowska, I. Ścibisz, D. Zaręba, M. Ziarno, Antioxidant properties and effect on lactic acid bacterial growth of spice extracts, CyTA - J. Food 13 (2015) 573–577.

[24] F. Vizzarri, M. Palazzo, A.G. D'Alessandro, D. Casamassima, Productive performance and meat quality traits in growing rabbit following the dietary supplementation of Lippia citriodora, Raphanus sativus and Solanum lycopersicum extracts, Livest. Sci. 200 (2017) 53–59.

[25] E. Saleh, A.E. Morshdy, E. El-Manakhly, S. Al-Rashed, H.F. Hetta, P. Jeandet, R. Yahia, G. El-Saber Batiha, E. Ali, Effects of olive leaf extracts as natural preservative on retailed poultry meat quality, Foods 9 (2020) 1017.

[26] M.L. Hernández- Macedo, G.V. Barancelli, C.J. Contreras-Castillo, Microbial deterioration of vacuum-packaged chilled beef cuts and techniques for microbiota detection and characterization: a review, Braz. J. Microbiol. 42 (2011) 1–11.

[27] M.A. Shah, S.J.D. Bosco, S.A. Mir, Effect of Moringa oleifera leaf extract on the physicochemical properties of modified atmosphere packaged raw beef, Food Packag. Shelf Life 3 (2015) 31–38.

[28] Y. Zhang, I. Han, W.C. Bridges, P.L. Dawson, Peach skin powder inhibits oxidation in cooked Turkey meat, Poultry Sci. 95 (2016) 2435–2440.

[29] S. Mokhtar, G. Mostafa, R. Taha, G.S.S. Eldeep, Effect of different starter cultures on the biogenic amines production as a critical control point in fresh fermented sausages, Eur. Food Res. Technol. 235 (2012) 527–535.

[30] M.A. Zahid, J.K. Seo, J.Y. Park, J.Y. Jeong, S.K. Jin, T.S. Park, H.S. Yang, The effects of natural antioxidants on protein oxidation, lipid oxidation, color, and sensory attributes of beef patties during cold storage at4°C, Korean J. Food Sci. Anim. Resour. 38 (2018) 1029.

[31] M.C. Yin, W.S. Cheng, Antioxidant and antimicrobial effects of four garlic-derived organosulfur compounds in ground beef, Meat Sci. 63 (2003) 23–28.

[32] N.S. Lungu, A.J. Afolayan, R.S. Thomas, E.M. Idamokoro, Quality and oxidative changes of minced cooked pork incorporated with Moringa oleifera leaf and root powder, Sustain. Times 13 (2021) 10126.

[33] R. Banerjee, A.K. Verma, A.K. Das, V. Rajkumar, A.A. Shewalkar, H.P. Narkhede, Antioxidant effects of broccoli powder extract in goat meat nuggets, Meat Sci. 91 (2012) 179–184.

[34] A.A. Bhat, A. Kumar, S. Dua, Storage quality and oxidative stability attributes of Almond (Prunus dulcis) fortified chevon nuggets, J. Anim. Res. 6 (2016) 747–755.

[35] A.K. Das, V. Rajkumar, A.K. Verma, D. Swarup, Moringa oleiferia leaves extract: a natural antioxidant for retarding lipid peroxidation in cooked goat meat patties, Int. J. Food Sci. Technol. 47 (2012) 585–591.

[36] S.K. Devatkal, K. Narsaiah, A. Borah, Anti-oxidant effect of extracts of kinnow rind, pomegranate rind and seed powders in cooked goat meat patties, Meat Sci. 85 (2010) 155–159.

[37] I. Karabagias, A. Badeka, M.G. Kontominas, Shelf life extension of lamb meat using thyme or oregano essential oils and modified atmosphere packaging, Meat Sci. 88 (2011) 109–116.

[38] R.K. Krishnan, S. Babuskin, P. Azhagu Saravana Babu, M. Sasikala, K. Sabina, G. Archana, M. Sivarajan, M. Sukumar, Antimicrobial and antioxidant effects of spice extracts on the shelf life extension of raw chicken meat, Int. J. Food Microbiol. 171 (2014) 32–40.

[39] M. Aminzare, M. Hashemi, H. Hassanzad Azar, J. Hejazi, The use of herbal extracts and essential oils as a potential antimicrobial in meat and meat products: a review, J. Human, Environ. Heal. Promot. 1 (2016) 63–74.

[40] M. Kostaki, V. Giatrakou, I.N. Savvaidis, M.G. Kontominas, Combined effect of MAP and thyme essential oil on the microbiological, chemical and sensory attributes of organically aquacultured sea bass (Dicentrarchus labrax) fillets, Food Microbiol. 26 (2009) 475–482.