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ORIGINAL ARTICLE

Crude essential oil from roots of white's ginger (*Mondia whitei*) as natural minced beef preservative

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Abstract

Potentials of crude essential oil from the roots of white's ginger (EOWG) as a natural preservative in minced beef were investigated. EOWG was produced using 1% (T1), 1.5% (T2), and 2% (T3) n-hexane, and their antibacterial and in vitro antioxidant activities were assessed. pH, thiobarbituric acid reactive substances (TBARs), total volatile basic nitrogen (TVBN) values, total plate count (TPC), and bacterial count (BC) of EOWG-treated meat were determined and compared with those of BHA-treated (T4) and untreated samples (T0) for 12 days (3 days interval) at 2°C. Meat color change was determined. The pH, TBARs, TVBN, TPC, and BC significantly ($p \leq .05$) reduced in EOWG-treated beef and reduction was higher with an increase in concentration. Total color difference (TCD) of refrigerated EOWG-treated minced beef varied and was concentration dependent. Meat treated with 1.5% and 2% EOWG compared most favorably with BHA-treated sample and could be considered as natural means of meat preservation.

Novelty impact statements

Crude essential oil from roots of white's ginger preserved the quality and shelf life of minced beef during refrigeration.

Minced beef treated with 1.5%–2% crude essential oil from roots of white's ginger yielded comparable quality attributes with butylated hydroxyl anisole (BHA)-treated beef.

Natural antioxidants and antimicrobial could give impetus to novel meat products development with enhanced health benefits, prolonged shelf life, and improved safety and quality.

1 | INTRODUCTION

Convenience-driven lifestyles, occupational demands, and dietary habits have all culminated into increased production and consumption of minced meat globally (Reham & Shimaa, 2017). Arising from its rich nutrient matrix, animal meat is universally recognized as a veritable option for a protein of high biological value (Shaltout et al., 2017). Paradoxically, the shelf life of meat is short, usually a day or less at ambient temperature and a few days even at refrigerated temperature. Naturally, meat is low in antioxidants and during refrigeration, ground meat is susceptible to microbial growth together with oxidative stress resulting in lipid oxidation (Ansorena & Astiasarán, 2004; Reham & Shimaa, 2017); in the process, the protein structure is damaged, sensory attributes and nutritive values are hampered, and hence, decrease in its shelf life, affecting the quality and acceptability of meat products (Dave & Ghaly, 2011). Intuitively, lipid oxidation could be influenced by many factors, such as the chemical structure of meat, entrance of oxygen and light, storage temperature, and some technological procedures during processing (Rather et al., 2016). Besides, as a consequence of continued dependent on meat as a protein source by both elite and the masses, the price of meat is turning sky rocketed and unaffordable to the latter

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group. Hence, meat preservation continues to be a sine qua non. Although various preservation techniques have been developed in a bid to counteract both lipid oxidation and microbial spoilage, the two main meat deterioration mechanisms, synthetic antimicrobial and antioxidants, are endemic, such as butylated hydroxyl anisole (BHA). These synthetic chemicals are lately associated with toxicity, carcinogenicity, and potential health hazards (Gbadamosi & Erinoso, 2015; Reham & Shimaa, 2017; Salem, 2013). Thus, extending the shelf life of meat by natural antioxidant and antimicrobial alternatives, usually from plant origin, is considered novel and safer technique. Various extracts, powder or essential oil, from different parts of some plants have been employed with huge successes (Hernández-Ochoa et al., 2014; Phimolsiripol et al., 2021; Shaltout et al., 2017). Essential oils, volatile or ethereal oils as they are so called, are situated in 10% of the plant kingdom. They are stored in plants in special brittle secretory structures, such as glands, secretory hairs, secretory ducts, secretory cavities, or resin ducts (Bozin et al., 2006). Potentials of essential oil in the preventions of oxidative rancidity and microbial spoilage of foods have been documented (Al-Hajj et al., 2014). In the food industry, essential oils do not preserve meat against spoilage alone but are also used as flavoring additives. Nowadays, the import of essential oils from peppermint, lavender, geranium, eucalyptus, rose, bergamot, sandalwood, and chamomile is rampant. Most of them are foreign to sub-Sahara Africa and could be too expensive with the possibility of adulterations. Therefore, the use of indigenous but neglected materials like roots of *Mondia whitei* in the production of essential oil and its subsequent application as natural food preservatives constitute a healthier alternative. *Mondia whitei*, also known as Apocynaceae, or white's ginger is traditionally known as *Isirigun* in some western states of Nigeria. It is a rich source of essential oil with little or no awareness. Its roots' extract was reportedly rich in antioxidant vitamins C and E (Amaechi & Egesi, 2017) and several secondary metabolites (phytochemicals: carotenoids, phenols, flavonoids, saponin, etc.) which are antimicrobial (Amani et al., 2017; Gbadamosi & Erinoso, 2015). The crude essential oil derived from the roots of white's ginger has been found to possess great antioxidant and antimicrobial activities too (Solorzano-Santos & Miranda-Novales, 2012). Given the paucity of information on quality attributes and shelf life of minced beef treated with crude essential oil from roots of white's ginger, its potential as a beef preservative was investigated.

2 | MATERIALS AND METHODS

2.1 | Sources of materials

Weighted amount (1.5 kg) of beef was purchased immediately after slaughter from a butcher's shop inside Dr. Abubakar Saraki Memorial Abattoir, Sobi Road, Ilorin. The meat was minced with a portable mincer and packed in clean polythene bags. It was then transported with aids of insulated and iced containers to the Microbiology Laboratory of Kwara State University (KWASU). Mature roots (10 kg) of *Mondia whitei* were obtained from Bode market, Ibadan. Chemicals and reagents used are of good analytical grades, obtained from Laboratories of Chemistry, Food Science and Technology, and Microbiology Departments, KWASU.

2.2 | Extraction of crude essential oil from roots of white's ginger (EOWG)

Soxhlet extraction technique was adopted according to a modified method of Alhassan et al. (2018). This was done by setting up a medium-size Soxhlet apparatus containing 30 g of the pulverized sample in a thimble and 300 ml of solvent (n-hexane) in a round bottom flask to obtain 1% extract. The procedure was repeated by dissolving 45 and 60 g of the pulverized sample in 300 ml of solvent (n-hexane) to obtain 1.5% and 2% extracts, respectively. The n-hexane was gently heated at 65°C with the aid of a heating mantle. The condenser cooled down the vapor passing through the vapor tube, and thereafter, the condensed hot solvent dropped into the thimble containing the sample. After reaching the top of the tube, it was siphoned over into the flask. The process was not stopped until complete extraction had been done. The solvent was separated from the oil sample using a rotary evaporator; it was then bottled in a sterile container before use.

2.3 | Assessments of the in vitro antioxidant activities of crude essential oil from roots of white's ginger

2.3.1 | Determination of total phenolic content

Folin–Ciocalteu reagent was used for total phenolic content determination as reported by Miguel et al. (2010) with slight modification. Fifty microliters of each oil dissolved in methanol (500 μg/ml) was combined with 250 μl of the Folin–Ciocalteu reagent and 0.750 ml of sodium carbonate (20%). This was followed by shaking of the mixture, which was then made up to 5 ml using distilled water and allowed for a 2 hr standing. Thereafter, the absorbance was measured at 765 nm against a blank with distilled water. Gallic acid serves as a standard and the results were expressed as milligram gallic acid equivalent per gram dry weight extract (mg GAE/g extract). The results were presented as the averages of triplicate analyses done.

2.3.2 | DPPH radical scavenging activity

The procedures described by Liu et al. (2008) were used for the DPPH radical scavenging activity determination. Different concentrations of the extracted essential oil were added to 2 ml of a solution of DPPH in methanol (0.1 mmol L − 1). Incubation was done for 30 min at 37°C in the dark and the absorbance, at 517 nm, was recorded. All experiments were carried out in triplicate and ascorbic acid and vitamin E

were used as standards. A decrease in the DPPH solution absorbance is an indication of an increase in the DPPH radical scavenging activity. The DPPH scavenging activity of the extracts was calculated and the concentration of sample required to scavenge 50% of DPPH radicals (SC50) value was determined from Equation (1):

$$\text{Scavenging activity } \% = \left[\frac{\text{Acontrol} - \text{Asample}}{\text{Acontrol}}\right] \times 100, \quad (1)$$

Where Asample is the absorbance of a sample solution, and Acontrol is the absorbance of the control solution. The control solution contains all of the reagents except the test sample.

2.3.3 | Determination of the reducing power

The method of Oyaizu (1986) was used to evaluate the reducing power of the extract. Precisely, 200 μg/ml of each sample dissolved in 1 ml methanol was mixed with 2.5 ml of sodium phosphate buffer (0.2 M, pH 6.6) and 2.5 ml of 1% K3Fe (CN)6. Thereafter, incubation of the mixture was done at 50°C for 20 min. Then, the addition of 2.5 ml of trichloroacetic acid (TCA) was done and the mixture was centrifuged at 3,000 rpm for 10 min. The (2.5 ml) supernatant solution was taken out and immediately mixed with 2.5 ml of methanol and 0.5 ml of 0.1% ferric chloride. The absorbance against blank was measured at 700 nm after incubation for 10 min at room temperature. An increase in absorbance of the reaction mixture is an indication of increased reducing power. Ascorbic acid and vitamin E standards were used for comparison. All the tests were carried out in triplicates.

2.4 | Treatment of minced beef

Minced meat was divided into five groups (300 g each). The first four samples were treated with 0%, 1%, 1.5%, and 2% EOWG, respectively, while the fifth sample was treated with butylated hydroxyl anisole (BHA). Samples were coded as T0, T1. T2, T3, and T4, respectively, stored at 2°C, and examined every 3 days for chemical, microbiological, and physical (color) changes. The experiment was conducted in triplicate for 12 days of storage, according to a modified method of Reham and Shimaa (2017).

2.5 | Quality attributes assessment

2.5.1 | pH determination

The pH values of minced beef in all samples were determined with a digital pH meter (HAANA, hI902 meter, Germany) every 3 days using 10 g of the sample. The sample was homogenized in a blender with 50 ml of distilled water for 1 min before pH measurement (Ibrahim et al., 2012).

2.5.2 | Thiobarbituric acid reactive substances (TBARS) measurement

Two grams of homogenized sample was measured and TBARS extracted twice with 10 ml of 0.4 M perchloric acid. The extract was made up to 25 ml with 0.4 M perchloric acid and centrifuged for 5 min at 1,790 *g*. Thereafter, 1 ml of the extract was poured into a glass stoppered test tube. Then, exactly 5 ml of TBARS reagent was added and the extract was heated for 35 min in a boiling water bath, followed by cooling under tap water. The absorbance of the sample was then measured against the blank solution at 538 nm. Preparation of a standard curve was done by using 1,1,3,3-tetraethoxy propane (TEP). The TBARS value was expressed as milligram of malonaldehyde/kg of the minced beef sample (Ibrahim et al., 2012).

2.5.3 | Measurement of total volatile nitrogen (TVBN)

The total volatile basic nitrogen (TVBN) measurement was carried out according to the procedure of FAO (1980) (FAO, 1991), as reported by Shaltout et al. (2017).

2.5.4 | Microbiological analysis

Total plate count was determined by the method described by APHA (1984). Readymade media (HImedia) (a commercial media) were used for the analysis. Spread plate techniques were used as described by HImedia laboratories (FLOO6, NOV, 2008). Enterobacteriaceae count (EBC) was done according to ICMSF (1996).

2.5.5 | Antimicrobial assay

One milliliter of each of the oil was screened using an agar well diffusion assay (Hood et al., 2003). Precisely, 19 ml of nutrient agar was inoculated with 1 ml of overnight cultures (10^1 to 10^6 cfu/ml) of the test organisms. The agar that has been inoculated was then poured into Petri dishes and allowed to set. Four wells were bored in the agar from each of the plates, using 6-mm sterile cork-borer; 100 μl of essence was introduced into each of the wells using a micropipette. The plates were left at room temperature, allowing for a time long enough for the diffusion of the oil into the agar. The plates were subsequently incubated at 35 ± 2°C for 18–36 hr. Zones of inhibition were then recorded in millimeters. Each experiment was carried out in triplicates for all the organisms.

2.5.6 | Color measurement

The color of each sample was instrumentally measured by L^*, a^*, and b^* system using Minolta CR400 (Tokyo, Japan) colorimeter according

to Zengin and Baysal (2015) method. Standardization of the instrument was first carried out against a white reference plate. Then, five measurements were taken for each sample and direct measurement of three color features of L^* (lightness), a^* (red–green component), and b^*(yellow–blue component) was done by the colorimeter. Total color difference (TCD) represented as $\blacktriangle E$ was determined using Equation (2).

$$\blacktriangle E = \left[(\blacktriangle L)2 + (\blacktriangle a)2 + (\blacktriangle b2)\right] 1/2. \quad (2)$$

2.6 | Statistical analysis

All data, in triplicates, were statistically analyzed by one-way analysis of variance (ANOVA) using the SPSS package (SPSS 23.0, Chicago, IL, USA). Significant ($p < .05$) differences between treatments were determined using Duncan's multiple-range test. Data were expressed as means ± standard deviation (*SD*).

3 | RESULTS AND DISCUSSIONS

3.1 | In vitro antioxidant activities of crude essential oil from roots of white's ginger

In vitro antioxidant activities of various concentrations of crude essential oil from roots of white's ginger (EOWG) were presented in Table 1. Total polyphenols (mg GAE/g), percent inhibition of $DPPH^+$, and reducing capacity IC_{50} (μg/mL) of EOWG ranged between (254.50 and 393.17, 46.21 and 49.22, and 14.56 and 15.79, respectively, and rose with increase in concentration. With exceptions of 1.0% and 1.5% for percent inhibition of $DPPH^+$ and 1.5% and 2.0% for reducing capacity, significant differences exist among the antioxidant activities of various concentrations of crude essential oil from roots of white's ginger (EOWG). The result was slightly lowered than 416.67–573.33 mg GAE/g. The range of values of total phenol obtained in this study (254.50–393.17 GAE/g) was slightly lower than (416.67–573.33 GAE/g) earlier reported by Gbadamosi and Erinoso (2015). However, reducing capacity in the present study was generally higher than 5.7 μg/m recorded by Esievo et al. (2018), and increases as the concentration increases. Effects of concentration on antioxidant activities of essential oil have been diversely reported (Fankam et al., 2011; Mayunzu et al., 2011; Gbadamosi & Erinoso, 2015 and Esievo et al., 2018). It was clearly shown that crude essential oil from roots of white's ginger (EOWG) possesses antioxidant activities, which is dependent on concentration.

3.2 | Influence of concentration of crude essential oils from roots of white's ginger (EOWG) and BHA on P^H values of minced beef during refrigerated storage

The pH values of minced beef samples as influenced by concentration of essential oil obtained from roots of white's ginger (EOWG) and BHA during refrigerated storage are shown in Figure 1. Initial pH values 7 steadily increased between the 3rd and 12th days of storage, for all samples, depending on the treatments. The pH value ranged between 7.20 and 7.55 at day 3, with T4 (sample treated with BHA) and T0 (untreated meat) samples being the lowest and highest, respectively. In samples T1 to T3 (treated with 1%, 1.5%, and 2% essential oil of white's ginger), pH value reduces with an increase in the concentration of crude essential oil. Similar trends were observed for days 6, 9, and 12 with pH values ranging between 7.14 and 7.70, 7.00 and 7.60, and 7.25 and 7.55, respectively. A similar result has been documented by earlier researchers (Salem-Amany et al., 2010; Kassem et al., 2011; and Kesavan et al., 2014). Specifically, Salem-Amany et al. (2010) reported lowering of pH values of refrigerated minced beef treated with different concentrations of essential oil of thyme compared with untreated ones. Kassem et al. (2011) documented lowering of pH values of burger samples treated with a high concentration of natural extract oil (1.2%) compared with control samples after 4 days of storage at refrigeration temperature. Kesavan et al. (2014) also reported lower pH values in raw beef meat samples treated with crude essential oil than untreated counterparts during storage at 4 ± 1°C for 15 days. These researchers opined that the presence of phenolic acid and the consequential antimicrobial effect of phenolic compounds in herb oil might have been responsible for this observation. Reduction in pH is desirable, since an increase in pH reflects the degree of meat spoilage through protein breakdown for the production of free amino acids, leading to the formation of NH_3 and amines, compounds of alkaline reactions.

TABLE 1 In vitro antioxidant properties of various concentrations of crude essential oil from roots of white's ginger (EOWG)

Concentrations of EOWG in %	Polyphenols (mg GAE/g)	% Inhibition of $DPPH^+$	Reducing capacity IC_{50} (μg/mL)
1.0%	254.50 ± 0.02^c	46.21 ± 0.17^b	14.56 ± 0.18^b
1.5%	317.34 ± 0.13^b	46.52 ± 0.14^b	15.77 ± 0.02^a
2.0%	393.17 ± 0.21^a	49.22 ± 0.14^a	15.79 ± 0.03^a

Note: Superscripts a, b, c, d, and e show significant difference (along the rows); n = number of observation (3); and $p \leq .05$ (99.05% confidence level).

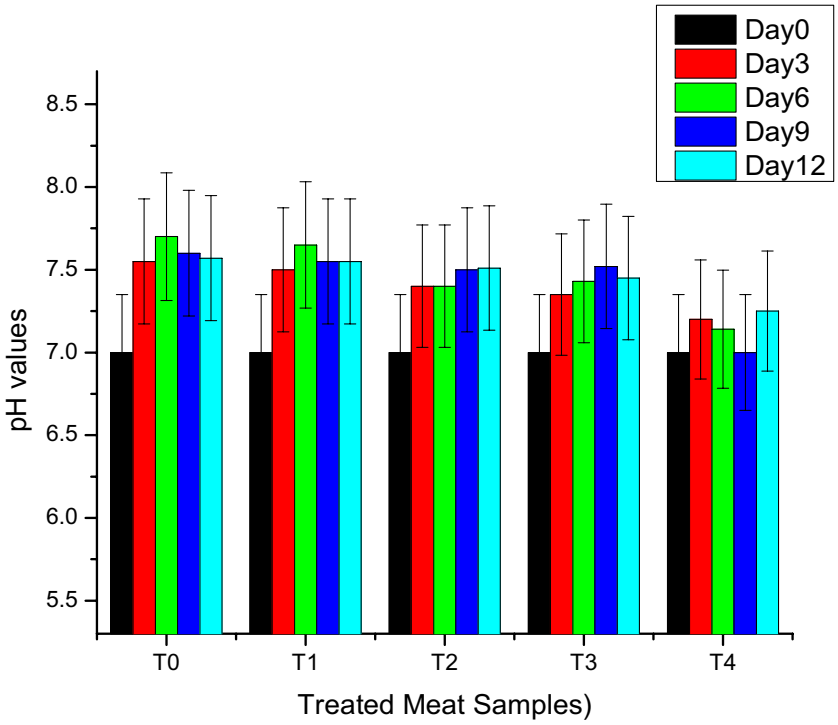


FIGURE 1 Mean P^H of untreated, white's ginger oil and BHA treated minced beef during refrigerated storage. (Mean ± SE)

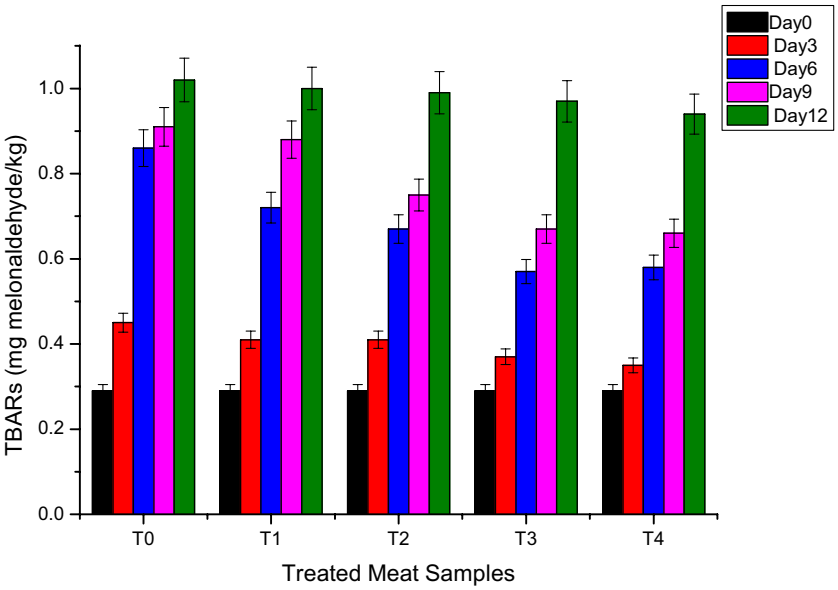


FIGURE 2 Thiobarbituric Acid Reactive Substances (TBARs) values of untreated, white's ginger oil and BHA treated beef during refrigerated storage

3.3 | Thiobarbituric acid reactive substances (TBARs) values of minced beef as influenced by the concentration of crude essential oils from roots of white's ginger and BHA during refrigerated storage

A commonly used index of lipid oxidation in stored meat products is TBARs values. When TBARs reaches a value of 0.9, the rancid flavor is initially detected (EOS, 2005). The initial value of TBARs value of minced beef in this study was 0.29 mg malonaldehyde/kg as shown in Figure 2. However, there was a gradual increase in this value between days 3 and 12 for all samples. Variations exist among the samples depending on the concentration of crude essential oil of white's ginger used. TBARs values ranged from 0.35 to 0.45, 0.58 to 0.86, 0.66 to 0.91, and 0.94 to 1.02 for the 3rd, 6th, 9th, and 12th day, respectively, with samples T0 and T4 being the highest and lowest in each case, respectively. Noticeably, no significant differences exist between samples T3 and T4, except on day 3 of storage. Sample T0 had a TBARs value of 0.91 on the 9th day, while every other sample reaches 0.9 and above on the 12th day. This implied that untreated and treated minced meat started producing rancid flavor on days 9 and 12, respectively, and therefore, crude oil extracted from white's ginger may prevent this rancidity for 9 days under refrigerated storage. Sample T3 was especially compared favorably with T4 (BHA-treated sample). This also indicated that 2% of this oil will suffice to do this preservation. Such findings may be attributed to the high antioxidant effect of crude essential oil, which

is related to the scavenging potentials of its flavonoids and phenolic contents. A similar result was documented by Kassem et al. (2011) in a study on the effect of different concentrations of essential oil on lipid oxidation of beef under refrigeration. This finding also agreed with Irfiana et al. (2017), who reported a decrease in TBARs values of vacuum-packed ground beef during refrigerated storage (at 0, 4, 8, 12, and 16 days) when compared with TBARs values of control samples. Likewise, fresh pork treated with the ultrasonicated extracts of Ceylon spinach at 100 and 120 mg/ml had lower values of thiobarbituric acid reactive substances ($TBAR_S$) than the control (Phimolsiripol et al., 2021). Crude essential oils are known to contain active compounds which are antioxidants and can curtail the incidence of autoxidation in meat and its products (Homayounpour et al., 2021; Irfiana et al., 2017).

3.4 | Total volatile basic nitrogen (TVBN) values of minced beef as influenced by the concentration of crude essential oils from roots of white's ginger and BHA during refrigerated storage

Total volatile basic nitrogen can be regarded as an index of raw minced meat spoilage, especially at 20 mg/100 mg raw minced meat (EOS, 2005). In this study, the initial TVBN values in mg/100 mg raw minced meat were 10.47 (Figure 3). This was steadily increased with duration of storage, but significantly influenced by the concentration of treatment for days 3, 6, 9, and 12, which ranged between 9.81 and 13.57, 10.20 and 14.07, 12.11 and 16.20, and 20.40 and 24.65, respectively. Although in each day, an increase in TVBN was observed, the sample without treatment had the highest values while the sample treated with BHA had the lowest. Statistically there were no significant differences between samples treated with 2% crude essential oil (T3) and BHA (T4). A similar trend was observed for samples treated with 1.5% (T2) and BHA (T4), except on day 9. It implies that both samples T2 and T3 can compete favorably with T4 in preserving the minced meat under refrigerated storage. Treatment of meat with between 1.5% and 2% crude essential oil of white's ginger roots could be considered as a natural means of meat preservation as against utilization of BHA, a synthetic antioxidant with track records of TVBN lowering. The degree of autolysis and bacterial proteolysis in meat can be measured by TVBN, which determines the proportions of amino acids, that is, tyrosine, and tryptophan present in an extract of meat (Shaltout et al., 2017). This finding agreed with Salem-Amany et al. (2010), who reported similar results on minced beef stored at 4°C. These researchers also confirmed that 1.5% natural extract oil concentration was more effective in decreasing TVBN values than samples treated with 1% natural extracted oil at 6th and 12th day of storage period due to the role of naturally extracted oil on microbial population and bacterial growth as antimicrobial agents.

3.5 | Total plate count of minced beef treated with different concentrations of crude essential oil from white's ginger during refrigerated storage

Total plate counts (log cfu/g) significantly varied, both with storage period and concentration of crude essential oil from white's ginger (Table 2). Total plate counts (log cfu/g) increase with an increase in storage period (0–12 days) and range between 1.88 and 5.11,

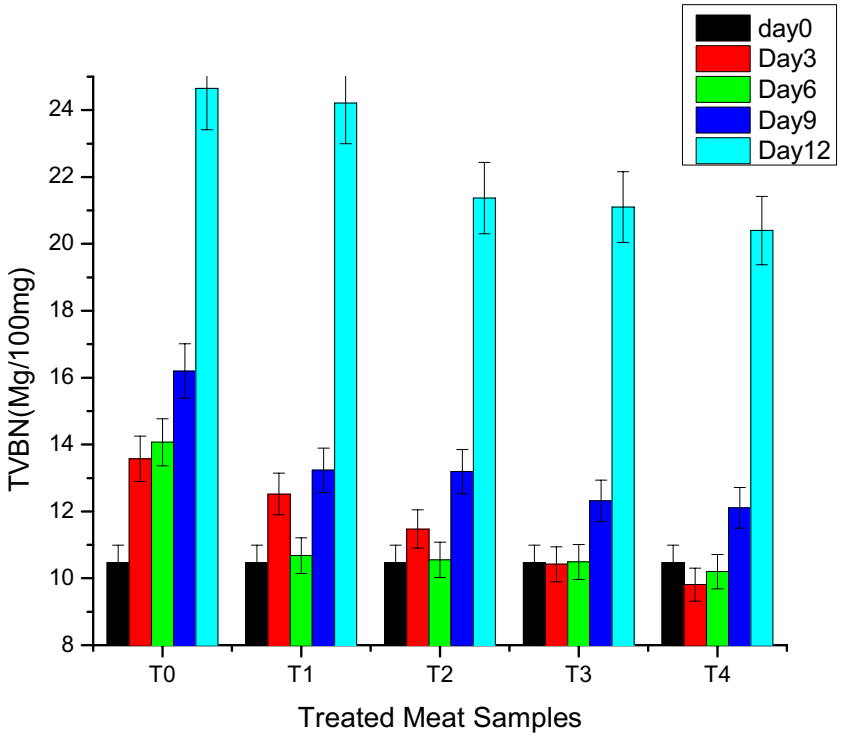


FIGURE 3 Effect of different concentrations of crude essential oil from the root of white ginger and BHA on Total Volatile Basic Nitrogen(TVBN) values of minced meat during refrigerated storage

TABLE 2 Total plate counts (log cfu/g) of minced beef treated with different concentrations of crude essential oil from white's ginger during refrigerated storage

Treatment	Day 0	Day 3	Day 6	Day 9	Day 12
T0	1.88 ± 0.01^{ew}	2.13 ± 0.01^{dw}	3.34 ± 0.12^{cw}	4.56 ± 0.02^{bw}	5.11 ± 0.10^{aw}
T1	1.84 ± 0.21^{ex}	2.03 ± 0.04^{dx}	2.78 ± 0.02^{cx}	3.24 ± 0.02^{bx}	3.83 ± 0.11^{ax}
T2	1.81 ± 0.01^{ey}	2.00 ± 0.01^{dy}	2.34 ± 0.00^{cy}	2.68 ± 0.03^{by}	3.11 ± 0.14^{ay}
T3	1.79 ± 0.02^{ez}	1.97 ± 0.02^{dz}	2.23 ± 0.01^{cz}	2.45 ± 0.01^{bz}	2.55 ± 0.01^{az}

Note: Superscripts a, b, c, d, and e show significant difference along the rows and w, x, y, and z showed significant difference along the column; n = number of observation (3); and $p \leq .05$ (99.05% confidence level). T0 (untreated raw meat serving as control); T1 (meat treated with 1% essential oil); T2 (meat treated with 1.5% essential oil); and T3 (meat treated with 2% essential oil).

TABLE 3 *Escherichia coli* (log cfu/g) counts of minced beef treated with different concentrations of crude essential oil from white's ginger during refrigerated storage

Treatment	Day 0	Day 3	Day 6	Day 9	Day 12
T0	0.96 ± 0.01^{ew}	1.75 ± 0.02^{dw}	2.23 ± 0.01^{cw}	$3.71 \pm 0.01w^{bw}$	4.55 ± 0.01^{aw}
T1	0.88 ± 0.01^{ex}	1.44 ± 0.01^{dx}	1.78 ± 0.01^{cx}	2.33 ± 0.01^{bx}	2.84 ± 0.14^{ax}
T2	0.80 ± 0.01^{ey}	1.13 ± 0.01^{dy}	1.25 ± 0.01^{cy}	1.47 ± 0.01^{by}	1.90 ± 0.01^{ay}
T3	0.67 ± 0.00^{dz}	0.94 ± 0.02^{cz}	1.03 ± 0.01^{bz}	1.06 ± 0.01^{bz}	1.02 ± 0.01^{az}

Note: Superscripts a, b, c, d, and e show significant difference along the rows and w, x, y, and z showed significant difference along the column; n = number of observation (3); and $p \leq .05$ (99.05% confidence level). T0 (untreated raw meat serving as control); T1 (meat treated with 1% essential oil); T2 (meat treated with 1.5% essential oil); and T3 (meat treated with 2% essential oil).

TABLE 4 Salmonella/Shigella (log cfu/g) counts of minced beef treated with different concentrations of crude essential oil from white's ginger during refrigerated storage

Treatment	Day 0	Day 3	Day 6	Day 9	Day 12
T0	0.75 ± 0.02^{ew}	1.15 ± 0.02^{dw}	1.63 ± 0.01^{cw}	2.72 ± 0.01^{bw}	3.75 ± 0.02^{aw}
T1	0.70 ± 0.01^{ex}	0.95 ± 0.02^{dx}	1.32 ± 0.01^{cx}	2.64 ± 0.01^{bx}	2.81 ± 0.02^{ax}
T2	0.59 ± 0.00^{ey}	0.75 ± 0.01^{dy}	1.13 ± 0.02^{cy}	1.78 ± 0.02^{by}	1.19 ± 0.01^{ay}
T3	0.46 ± 0.02^{ez}	0.52 ± 0.02^{dz}	0.81 ± 0.01^{cz}	1.04 ± 0.00^{bz}	1.20 ± 0.26^{az}

Note: Superscripts a, b, c, d, and e show significant difference along the rows and w, x, y, and z showed significant difference along the column; n = number of observation (3); and $p \leq .05$ (99.05% confidence level). T0 (untreated raw meat serving as control); T1 (meat treated with 1% essential oil); T2 (meat treated with 1.5% essential oil); and T3 (meat treated with 2% essential oil).

1.84 and 3.83, 1.81 and 3.81, and 1.79 and 2.55, but decrease with increase in the concentration of crude essential oil from white's ginger and ranged between 1.88 and 1.79, 2.13 and 1.97, 3.34 and 2.23, 4.56 and 2.45, and 5.11 and 2.55. It can be inferred from this result that crude essential oil of white's ginger has the potentials to inhibit the growth of microorganisms and also that higher concentrations of the oil possess the greater power of microbial inhibition. This is consistent with Irfiana et al. (2017), who recorded that the total plate count of microorganisms in vacuum-packed ground beef treated with natural essential oil from thyme was lesser than the untreated sample in the same package during refrigerated storage (at 0, 4, 8, 12, and 16 day). The observation was associated with high content and wide spectrum of phenolic compounds, variety of flavonoids, including apigenin, naringenin, luteolin, and thymonin, and antimicrobial and antioxidant properties of thyme. Bark and leaves of cinnamon were reported to possess similar characteristics. The major compounds in the essential oil of cinnamon are cinnamaldehyde, benzaldehyde, limonene, linalool, and eugenol (Irfiana et al., 2017).

3.6 | Effect of different concentrations of crude essential oil from white's ginger on different species of bacteria during refrigerated storage

Salmonella, *Listeria*, and *Staphylococcus aureus* comprised of the most pathogenic genus of mesophilic bacteria. For instance, *Salmonella* spp. is a common cause of food poisoning. *Listeria monocytogenes* is frequently distributed through contaminated foods like raw meats (Valenzuela et al., 2021). In this study, counts of *Escherichia coli* (log cfu/g) and *Salmonella/ Shigella* (log cfu/g) significantly varied across the storage duration and with increase in the concentration of essential oil from white's ginger (Tables 3 and 4). From Table 3, *E. coli* counts (log cfu/g) increased with the increase in storage duration

(0–12 days) and ranged between 0.96 and 4.55, 0.88 and 2.84, 0.80 and 1.90, and 0.67 and 1.02, but decreased with increase in the concentration of crude essential oil from white's ginger and ranged between 0.96 and 0.67, 1.75 and 0.94, 2.23 and 1.03, 3.71 and 1.06, and 4.55 and 1.02. A similar trend was observed in Table 4 for *Salmonella/Shigella* counts (log cfu/g) which increased with increase in storage period (0–12 days) and ranged between 0.75 and 3.75, 0.70 and 2.81, 0.59 and 1.19, and 0.46 and 1.20, but decreased with increase in the concentration of crude essential oil from white's ginger and ranged between 0.75 and 0.46, 1.15 and 0.52, 1.63 and 0.81, 2.72 and 1.04, and 3.75 and 1.20. This result justified the fact that crude essential oil of white's ginger has capability of preventing the growth of bacteria and a higher concentration of the oil performed better than lower concentrations. Antibacterial properties of essential oil from plants with similar characteristics (garlic, thyme, and lemongrass) on minced beef at 4°C storage were documented (Salem-Amany et al., 2010; Solomakos et al., 2008). High counts of Enterobacteriaceae in untreated minced beef in comparison with those treated with different concentrations of plant essential oils had also been reported and were attributed to the presence of bioactive compounds in the oil (Shaltout et al., 2017). Additionally, results of antimicrobial activities of various concentrations of crude essential oil from roots of white's ginger were presented in Table 5. The zones of inhibition in millimeter (mm) for *E. coli*, *Staphylococcus aureus*, and *Salmonella typhi* were 19.12–25.30, 9.79–13.54, and 17.11–23.10, respectively. There was a significant difference among organisms treated with different concentrations of EOWG. The zones of inhibition in mm increase with the increase in the concentration of the EOWG. This further revealed that crude essential oil of white's ginger possesses antibacterial activities, which could be associated with the presence of bioactive compounds in the root, such as alkaloids, flavonoids, saponins, tannins, and polyphenols, in varying quantities (Esievo et al., 2018). Similar results have been documented (Fankam et al., 2011; Mayunzu et al., 2011; and Gbadamosi & Erinoso, 2015).

3.7 | Effect of different concentrations of crude essential oil from white's ginger on color (L, a, and b values) of minced beef during refrigerated storage

Table 6 presented the color of the treated and untreated meat at a storage temperature of 2°C. Accordingly, lightness (L), redness (a), and yellowness (b) were reported for each day. On day 3, the color values of the control sample (T0) for L, a, and b were insignificantly different from T4 (treated with BHA). This was closely followed by T1 (treatment with 1% essential oil from white's ginger). Redness of control (T4) and other treated samples (T1, T2, and T2) decreases as the concentration of the essential oil increases, with T1 closely compared with T0 and T4. The reverse was the cases with lightness (L) and yellowness (b) values, which increased with a higher concentration of treatment. The (L, a, and b) values ranged between 26.40 and 42.55, 16.49 and 25.87, and 6.61 and 4.02, respectively, at day 3. The trends were very similar in day 6 with ranges 18.07–26.74, 13.66–24.82, and 3.71–4.64; day 9 with ranges 17.94–20.90, 11.95–18.38, and 2.93–4.51; and day 12 with ranges 16.78–19.09, 9.50–12.53, 2.26–3.11, respectively. Redness is an important attribute being sought by consumers and it appears that lower concentrations of the essential oil of white's ginger might be better for adequate protection of redness in refrigerated minced beef. All the color values (lightness, redness, and yellowness) diminish with storage duration, regardless of the treatment type and proportion. This result agrees with Fernández-López et al. (2005), who studied the effects of different antioxidants on the color of meat and meat products and reported that meat oxidation decreases a^* values. This finding corroborated with Borella et al. (2019), who observed variations in L^* and a^* values when commercial antioxidants of rosemary in different concentrations in mixed hamburger processing were used. Borella et al. (2019) also confirmed that lower variations were those with higher antioxidant concentrations. The decrease in redness value could be attributed to the influence of pH on the myoglobin proportion. The a^* values of treated minced meat were decreased due to low pH which formatted metmyoglobin during storage. The presence of oxygen resulted in the oxidation of myoglobin to oxymyoglobin and consequently, the color change with storage time (Shalaby et al., 2018).

3.8 | Total color difference of minced beef treated with different concentrations of crude essential oil from white's ginger during refrigerated storage

Total color difference (TCD) of minced beef significantly ($p \leq .05$) varied across storage durations and with an increase in concentrations of essential oil from white's ginger (Table 7). TCD ranged between 6.00 and 8.19, 6.23 and 7.69, 4.86 and 13.15, 3.99 and 16.18, and 5.76 and 7.33 for samples T0, T1, T2, T3, and T4,

TABLE 5 Inhibitory effects of various concentrations of crude essential oil from roots of white's ginger (EOWG) against some pathogens organisms

Concentrations of EOWG in %	Escherichia coli (10^5 cfu/ml)/Zone of inhibition (mm)	Staphylococcus aureus (10^5 cfu/ml)/Zone of inhibition (mm)	Salmonella typhi (10^5 cfu/ml)/Zone of inhibition (mm)
1.0%	19.12 ± 1.51^c	9.79 ± 1.21^c	17.11 ± 1.15^c
1.5%	21.13 ± 1.25^b	10.54 ± 2.11^b	18.12 ± 1.20^b
2.0%	25.30 ± 1.35^a	13.54 ± 5.11^a	23.10 ± 1.00^a

Note: Superscripts a, b, c, d, and e show significant difference along the rows; n = number of observation (3); and $p \leq .05$ (99.05% confidence level).

TABLE 6 Effect of different concentrations of crude essential oil from white's ginger on Hunter's (*L*, *a*, and *b*) color values of minced beef during refrigerated storage

Samples/storage days	*L* values	*a* values	*b* values
Day 3			
T0	26.18 ± 3.58^{d}	25.87 ± 5.72^{a}	4.02 ± 0.54^{d}
T1	29.95 ± 0.74^{c}	24.04 ± 1.69^{b}	4.54 ± 1.09^{c}
T2	35.90 ± 5.23^{b}	18.06 ± 2.26^{c}	5.69 ± 0.69^{b}
T3	42.55 ± 4.93^{a}	16.49 ± 0.71^{d}	6.61 ± 2.21^{a}
T4	26.40 ± 2.40^{d}	24.60 ± 0.15^{ab}	4.13 ± 0.43^{cd}
Day 6			
T0	18.07 ± 1.22^{cd}	24.82 ± 5.84^{a}	3.77 ± 1.05^{c}
T1	22.31 ± 5.76^{bc}	24.14 ± 0.91^{a}	3.75 ± 0.09^{c}
T2	22.87 ± 3.56^{b}	17.56 ± 2.68^{b}	4.02 ± 1.07^{b}
T3	26.74 ± 0.61^{a}	13.66 ± 0.61^{c}	4.64 ± 0.91^{a}
T4	19.71 ± 0.24^{c}	24.01 ± 1.23^{a}	3.71 ± 0.38^{c}
Day 9			
T0	17.94 ± 1.60^{c}	18.38 ± 2.57^{a}	2.93 ± 1.31^{d}
T1	20.28 ± 0.84^{ab}	18.25 ± 1.58^{a}	3.19 ± 1.66^{c}
T2	20.10 ± 1.08^{ab}	14.73 ± 0.45^{b}	3.40 ± 0.41^{b}
T3	21.90 ± 1.25^{a}	11.95 ± 2.07^{c}	4.51 ± 0.47^{a}
T4	18.75 ± 0.98^{b}	18.38 ± 2.57^{a}	2.97 ± 0.09^{d}
Day 12			
T0	16.78 ± 0.47^{c}	12.53 ± 0.52^{a}	2.26 ± 1.82^{c}
T1	18.34 ± 1.71^{ab}	12.17 ± 0.41^{ab}	2.48 ± 0.60^{b}
T2	18.52 ± 1.49^{ab}	10.12 ± 0.48^{b}	2.92 ± 1.51^{ab}
T3	19.09 ± 1.85^{a}	9.50 ± 0.92^{bc}	3.11 ± 0.34^{a}
T4	17.33 ± 1.09^{b}	12.52 ± 0.56^{a}	2.27 ± 0.23^{c}

Note: T (untreated raw meat); T1 (meat treated with 1% essential oil); T2 (meat treated with 1.5% essential oil); T3 (meat treated with 2% essential oil); and T4 (meat treated with BHA).

TABLE 7 Effect of different concentrations of crude essential oil from white's ginger on total color difference in minced beef during refrigerated storage

Storage intervals	T0	T1	T2	T3	T4
3–6 days	8.19 ± 0.12^{av}	7.69 ± 0.02^{aw}	13.15 ± 0.03^{ax}	16.18 ± 0.02^{ay}	7.33 ± 0.03^{az}
6–9 days	6.48 ± 0.01^{bv}	6.23 ± 0.01^{cw}	7.24 ± 0.02^{bx}	5.14 ± 0.01^{by}	5.76 ± 0.02^{cz}
9–12 days	6.00 ± 0.02^{cv}	6.43 ± 0.11^{bw}	4.86 ± 0.01^{cx}	3.99 ± 0.15^{cy}	6.07 ± 0.05^{bz}

Note: Superscripts v, w, x, y, and z showed significant difference along the rows and a, b, and c significant difference along the column; n = number of observation (3); and $p \leq .05$ (99.05% confidence level). T0 (untreated raw meat serving as control); T1 (meat treated with 1% essential oil); T2 (meat treated with 1.5% essential oil); T3 (meat treated with 2% essential oil); and T4 (meat treated with BHA).

respectively, within 12 days of storage. However, between 3 and 6 days, the range of color change was 7.33–16.18, with samples T4 and T1 being the highest and lowest, respectively. Samples T1 and T0 closely followed T4 and indicted that low concentration of the essential oil from white's ginger resulted in little color change relative to others, and similar to that of T4 (commercial preservative). Color changes between 6 and 9 days and 9 and 12 days followed a similar trend, with few exceptions. The result is consistent with those of earlier researchers (Falowo et al., 2019; Karabagias et al., 2011; Shalaby et al., 2018; Unal et al., 2014) in related studies. In their works, meat treated with essential oils from oregano, sage, rosemary, and thyme compared with the control group throughout the storage period, perhaps as a result of protective effect of essential oil treatment on color lightness. These researchers also reported progressive decrease across the days of storage within the treatments. However, the concentration remains an important guiding factor. One of the most essential parameters governing a consumer's decision in purchasing, selecting, and acceptability of meat and meat products during display is meat color (Grunert et al., 2004). Caution must be exercised concerning concentration when utilizing these essential oils as meat preservatives. In the present study, utilization of between 1% and 1.5% of crude

essential oil from white's ginger for protection of color change could be regarded as best.

4 | CONCLUSIONS

Crude essential oil from the roots of white's ginger (EOWG) possesses antioxidant and antimicrobial activities, which are dependent on concentration. Minced beef samples treated with EOWG had significantly lower values of pH, TBARS, TVBN, TPC, and BC than those of control (untreated meat) and comparable ranges of values with BHA-treated samples during refrigerated storage. The L, a, and b color values and total color difference of refrigerated minced beef were not markedly influenced by the treatment. The efficiency of EOWG depended on concentration and 1.5%–2% compared favorably with BHA. EOWG offered a satisfactory preservative effect against lipid oxidation and microbial spoilage and may be a suitable alternative to the synthetic antioxidant BHA. Therefore, EOWG could be used as both natural antioxidant and antibacterial agents during refrigerated storage of minced beef. In the meat industry, natural antioxidants may give impetus to novel meat products development with enhanced health benefits, prolonged shelf life, and improved safety and quality. Further studies on isolation of major spoilage organisms, impacts of EOWG on major spoilage organisms, sensory analysis of minced beef during refrigeration, and the analysis of the shelf life of minced beef treated with EOWG when stored at room temperature are recommended.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTION

Kazeem Koledoye Olatoye: Data curation; Formal analysis; Methodology; Project administration; Supervision; Writing – original draft; Writing – review & editing.

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REFERENCES

Al-Hajj, N. Q. M., Wang, H. X., Chaoyang, M., Lou, Z., Bashari, M., & Thabit, R. (2014). Antimicrobial and antioxidant activities of the essential oils of some aromatic medicinal plants (*Pulicaria inuloides*-Asteraceae and *Ocimum forskolei-Lamiaceae*). *Tropical Journal of Pharmaceutical Research*, *13*(8), 1287–1293. https://doi.org/10.4314/tjpr.v13i8.13

Alhassan, M., Lawal, A., Nasiru, Y., Suleiman, M., Safiya, A. M., & Bello, N. (2018). Extraction and formulation of perfume from locally available lemon grass leaves. *ChemSearch Journal*, *9*(2), 40–44.

Amaechi, N. C., & Egesi, N. M. (2017). Nutritional evaluation of a wild edible fruit *Mondia whitei* (Hook. f.) Skeels consumed by some human populations in Izzi Clan, isolated from mondia whytei (hook.f.) root. *Asian Journal of Pharmaceutical Science & Technology*, *2*(1), 39–45.

Amani, M. S., Zakaria, E. M., & Abd El -Raheem, K. A. (2017). Efficiency of some essential oils in control of methicillin resistant *Staphylococcus aureus* (MRSA) in Minced Beef. *Faculty of Veterinary Medicine, Benha University, Egypt, Animal Health Research Institute, Dokki, Egypt (BVM) Journal*, *32*(1), 177–183.

Ansorena, D., & Astiasarán, I. (2004). Effect of storage and packaging on fatty acid composition and oxidation in dry fermented sausages made with added olive oil and antioxidants. *Meat Science*, *67*(2), 237–244. https://doi.org/10.1016/j.meatsci.2003.10.011

APHA. (1984). *Compendium of methods for the microbiological examinations of foods* (6th ed., pp. 919–927). American Public Health Association.

Borella, T. G., Peccin, M. M., Mazon, J. M., Roman, S. S., Cansian, R. L., & Soares, M. B. A. (2019). Effect of rosemary (*Rosmarinus officinalis*) antioxidant in industrial processing of frozen-mixed hamburger during shelf life. *Journal of Food Processing and Preservation*, *42*(11), 1–9. https://doi.org/10.1111/jfpp.14092

Bozin, B., Mimica-Dukic, N., Simin, N., & Anackov, G. (2006). Characterization of the volatile composition of essential oils of some Lamiaceae spices and the antimicrobial and antioxidant activities of the entire oils. *Journal of Agriculture and Food Chemistry*, *54*(5), 1822–1828. https://doi.org/10.1021/jf051922u

Dave, D., & Ghaly, A. E. (2011). Meat spoilage mechanisms and preservation techniques: A critical review. *American Journal of Agricultural and Biological Sciences*, *6*, 486–510. https://doi.org/10.3844/ajabssp.2011.486.510

EOS (Egyption Organization for Standardization and Quality). (2005). Egyption Standard, ES.

Esievo, K. B., Fatokun, O. T., Adamu, A., & Egharevba, H. O. (2018). HPLC analysis, anti-oxidant and antiproliferative evaluation of methanol extracts of leaves and roots of *Mondia whitei* (Hook. f) skeels. *Journal of Chemical and Pharmaceutical Research*, *10*(4), 81–87.

Falowo, A. B., Mukumbo, F. E., Idamokoro, E. M., Afolayan, A. J., & Muchenje, V. (2019). Phytochemical constituents and antioxidant activity of sweet basil (*Ocimum basilicum* L.) essential oil on ground beef from Boran and Nguni cattle. *Hindawi International Journal of Food Science*, *2019*(1), 1–8. https://doi.org/10.1155/2019/2628747

Fankam, A. G., Kuete, V., Voukeng, I. K., Kuiate, J. R., & Pages, J.-M. (2011). Antibacterial activities of selected Cameroonian spices and their synergistic effects with antibiotics against multidrugresistant phenotypes. *BMC Complementary and Alternative Medicine*, *11*(1), 104–114. https://doi.org/10.1186/1472-6882-11-104

FAO (Food and Agriculture Organization of the United Nations) (1980). *Manual of food quality control, 3- commodities*. United Nations.

FAO (1991). Guidelines for slaughtering, meat cutting and further processing. FAO animal production and health paper 91.

Fernández-López, J., Zhi, N., Aleson-Carbonell, L., Pérez-Alvarez, J. A., & Kuri, V. (2005). Antioxidant and antibacterial activities of natural extracts: Application in beef meat balls. *Meat Science*, *69*(3), 371–380. https://doi.org/10.1016/j.meatsci.2004.08.004

Gbadamosi, I. T., & Erinoso, S. M. (2015). In vitro antioxidant and antimicrobial activities of *Mondia whitei* (Hook. f.) skeels. *Journal of Basic and Applied Sciences*, *11*(1), 428–433. https://doi.org/10.6000/1927-5129.2015.11.60

Grunert, K. G., Bredahl, L., & Brunsø, K. (2004). Consumer perception of meat quality and implications for product development in the meat sector - A review. *Meat Science*, *66*(2), 259–272. https://doi.org/10.1016/S0309-1740(03)00130-X

Hernández-Ochoa, L., Aguirre-Prieto, Y. B., Nevárez-Moorillón, G. V., Gutierrez-Mendez, N., & Salas-Muñoz, E. (2014). Use of essential oils and extracts from spices in meat protection. *Journal of Food Science and Technology*, *51*(5), 957–963. https://doi.org/10.1007/s13197-011-0598-3

Homayounpour, P., Sani, M. A., & Shariatifar, N. (2021). Application of nano-encapsulated *Allium sativum* L. essential oil to increase the shelf life of hamburger at refrigerated temperature with analysis

of microbial and physical properties. *Journal of Food Processing and Preservation*, *45*(11), 1–10. https://doi.org/10.1111/jfpp.15907

Hood, J. R., Wilkinson, J. M., & Cavanagh, H. M. A. (2003). Evaluation of common antibacterial screening methods utilized in essential oil research. *Journal of Essential Oil Research*, *15*(6), 428–433. https://doi.org/10.1080/10412905.2003.9698631

Ibrahim, H. M., Robiel, K. M., & Wafaa, H. E. (2012). Antioxidant effect of pomegranate rind, seed extracts and pomegranate juice on lipid oxidation and some quality properties of cooked beef patties. *Journal of Applied Sciences Research*, *8*(8), 4023–4032.

ICMSF (International Commission on Microbiological Specifications for Foods). (1996). *Microorganisms in foods*. Black Academic and Professional.

Irfiana, D., Utami, R., Khasanah, L. U., & Manuhara, G. J. (2017). Preservation effect of two stage cinnamon bark (*Cinnamomum Burmanii*) oleoresin microcapsules on vacuum packed ground beef during refrigerated storage. *Food Science and Technology, Universitas Sebelas Maret, Surakarta*, https://doi.org/10.1088/1757-899X/193/1/012026

Karabagias, I., Badeka, A., & Kontominas, M. G. (2011). Shelf-life extension of lamb meat using thyme or oregano essential oils and modified atmosphere packaging. *Meat Science*, *88*(1), 109–116.

Kassem, G. M., Atta-Alla, O. A., & Ali, F. H. M. (2011). Improving the quality of beef burger by adding thyme essential oil and jojoba oil. *Archivos de Zootecnia*, *60*(231), 787–795. Egypt. https://doi.org/10.4321/S0004-05922011000300066

Liu, X., Mouming, Z., Jinshui, W., Bao, Y., & Yueming, J. (2008). Antioxidant activity of methanolic extract of emblica fruit (*Phyllanthus emblica* L.) from six regions in China. *Journal of Food Composition and Analysis*, *21*(1), 219–228. https://doi.org/10.1016/j.jfca.2007.10.001

Mayunzu, O., Shitanda, D., Okalebo, F., & Simiyu, L. (2011). Evaluation of antimicrobial and antioxidant properties of *M. whitei* root extracts. *The Annals of University Dunarea De Jos of Galati, Fascicle VI: Food Technology*, *35*(2), 27–32.

Miguel, M. G., Nunes, S. A., Dandlen, A. M., Cavaco, M. D., & Antunes, M. D. (2010). Phenols and antioxidant activity of hydro-alcoholic extracts of propolis from Algarve, South of Portugal. *Food and Chemical Toxicology*, *481*(2), 3418–3423. https://doi.org/10.1016/j.fct.2010.09.014

Oyaizu, M. (1986). Studies on the product of browning reaction prepared from glucose amine. *Japanese Journal of Nutrition*, *44*(1), 307–315.

Phimolsiripol, Y., Buadoktoom, S., Leelapornpisid, P., Jantanasakulwong, K., Seesuriyachan, P., Chaiyaso, T., Leksawasdi, N., Rachtanapun, P., Chaiwong, N., Sommano, S. R., Brennan, C. S., & Regenstein, J. M. (2021). Shelf life extension of chilled pork by optimal ultrasonicated Ceylon spinach (*Basella alba*) extracts: Physicochemical and microbial properties. *Foods*, *10*, 1241. https://doi.org/10.3390/foods10061241

Radha krishnan, K., Babuskin, S., Babu, P. A. S., Fayidh, M. A., Sabina, K., Archana, G., Sivarajan, M., & Sukumar, M. (2014). Bio-protection and preservation of raw beef meat using pungent aromatic plant substances. *Journal of the Science of Food and Agriculture*, *94*, 2456–2463. https://doi.org/10.1002/jsfa.6580

Rather, S. A., Masoodi, F. A., Akhter, R., Gani, A., Wani, S. M., & Malik, A. H. (2016). Effects of sugar as fat replacer on some quality parameters of mutton goshtaba, a traditional Indian meat product. *Small Ruminant Research*, *137*(1), 169–176. https://doi.org/10.1016/j.smallrumres.03.013

Reham, A., & Shimaa, N. E. (2017). Grape seed extract as natural antioxidant and antibacterial in minced beef. *PSM Biological Research*, *2*(2), 89–96.

Salem, R. H. (2013). Quality characteristics of beef sausages with tomato peel as a colour and functional additive during frozen storage. *World Applied Sciences Journal*, *22*(8), 1085–1093.

Salem-Amany, M., Amine-Reham, A., & Afifi, G. S. (2010). Studies on antimicrobial and antioxidant efficiency of some essential oils in minced beef. *Journal of American Science*, *6*(12), 691–700.

Shalaby, A. R., Anwar, M. M., & Sallam, E. M. (2018). Improving quality and shelf-life of minced beef using irradiated olive leaf extract. *Journal of Food Processing and Preservation*, *42*(11), 1–10. https://doi.org/10.1111/jfpp.13789

Shaltout, F. A., Thabet, M. G., & Koura, H. A. (2017). Impact of some essential oils on the quality aspect and shelf life of meat. *Journal of Nutrition and Food Sciences*, *7*(6), 351–364. https://doi.org/10.4172/2155-9600.1000647

Solomakos, N., Govaris, A., Koidis, P., & Botsoglou, N. (2008). The antimicrobial effect of thyme essential oil, nisin and their combination against *Escherichia coli* O157:H7 in minced beef during refrigerated storage. *Meat Science*, *80*, 159–166.

Solorzano-Santos, F., & Miranda-Novales, M. G. (2012). Essential oils from aromatic herbs as antimicrobial agents. *Current Opinion in Biotechnology*, *23*(2), 136–141.

Unal, K., Babaoglu, A. S., & Karakaya, M. (2014). Effect of oregano, sage and rosemary essential oils on lipid oxidation and color properties of minced beef during refrigerated storage. *Journal of Essential Oil-Bearing Plants*, *17*(5), 797–805.

Valenzuela, C., Garcia-Galicia, I. A., Paniwnyk, L., & Alarcon-Rojo, A. D. (2021). Physicochemical characteristics and shelf life of beef treated with high-intensity ultrasound. *Journal of Food Processing and Preservation*, *45*(4), 1–11. https://doi.org/10.1111/jfpp.15350

Zengin, H., & Baysal, A. H. (2015). Antioxidant and antimicrobial activities of thyme and clove essential oils and application in minced beef. *Journal of Food Processing and Preservation*, *39*, 1261–1271. https://doi.org/10.1111/jfpp.12344

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