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Properties of cheese and ground beef in the presence of staghorn sumac

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Abstract

Cost-effective and under-exploited plant species as functional food ingredients represent alternatives to chemicals with safety concerns and potent toxicity. Staghorn sumac (*Rhus typhina*) is considered a good source of natural polyphenols, which can be introduced into food products to carry out some specific technological functions (e.g., antioxidation and preservation). However, sumac fruit as a spice is under-explored for its diversified uses in various food products as a novel functional ingredient. This study explored the technological feasibility and sensory acceptability of two representative sumac-fortified food systems, namely Cheddar cheese and ground beef. Extracts of sumac (0.5%−5%) dose-dependently increased the total phenolic and anthocyanin contents, while reducing thiobarbituric acid reactive substance (up to 46%), total plate counts of bacteria (up to 4.5 log colony-forming units [CFU]/g) and pH of the cheese. In fresh ground beef, sumac extract at concentrations of 1%−5% was effective in reducing the total aerobic counts of *Escherichia coli* inoculated fresh ground beef by 0.16−1.14 log CFU/g, while improving meat color and oxidative stability during a storage period of 7 days at 4°C. Phytochemical profiling by high-performance liquid chromatography showed the presence of gallic acid, caffeic acid, ellagic acid, quercetin and anthocyanins in the sumac extracts. These compounds were possibly responsible for the antimicrobial and antioxidant activities in the evaluated food systems. Sensory acceptability of Cheddar cheese or cooked beef meatballs with sumac extract addition (0.5%−3%) were similar to their respective controls. This study provides a feasible approach to satisfy health-conscious consumers who favor a natural multifunctional ingredient to preserve food products.

KEYWORDS

anthocyanin, Cheddar cheese, ground beef, natural preservative, phenolic compound, *Rhus typhina*, sensory quality

1 | INTRODUCTION

Cheese consumption has grown globally with increased awareness of flavor appeals, nutritional value and health potentials of cheeses. Cheese quality and flavor are attributes related to its various chemical and bioactive constitutions, such as bioactive peptides, γ-aminobutyric acid, conjugated linoleic acid, fat-soluble vitamins, and minerals (i.e., Ca, Zn, P, and Mg) and organic acids (Santiago-López et al., 2018). Common reasons for cheese quality degradation mostly include lipid oxidation and microbiological spoilage (Riddet et al., 1961; Vrdoljak et al., 2016). Lipid oxidation results in rancidity and flavor deterioration of cheese. Bacterial spoilage negatively influences the sensory attributes (color, texture, flavor, and appearance) of the cheeses. Generic

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Escherichia coli, coagulase-positive *Staphylococci*, and *Enterobacteriaceae* represent sanitation and hygiene indicator microorganisms in the cheese production (Astegiano et al., 2014). *Salmonella* spp., *Staphylococcus aureus*, *Listeria monocytogenes*, and enteropathogenic strains of *E. coli* represent the principal pathogenic organisms associated with food poisoning outbreaks linked to cheese (Choi et al., 2016; Kim et al., 2014).

Food-grade natural and synthetic additives (antioxidants or preservatives) have been used to prolong the shelf life of cheese products. Addition of natural preservatives become more favored by consumers, due to the health concerns of consumption of synthetic additives. Some plant extracts possess antioxidant and antimicrobial activities (Cai et al., 2006; Carocho et al., 2018; Proestos et al., 2005; Shan et al., 2011). One of the active ingredients in these plant-based ingredients is polyphenols. The biological activities of diverse polyphenols vary, depending on the types of polyphenols and food systems (Cai et al., 2006; Carocho et al., 2018). Selected spice and herb extracts as natural food preservatives have been used to inhibit lipid oxidation and microbial growth, and therefore extending the shelf-life of dairy products (Shan et al., 2011). However, it is emphasized that the addition should not modify the sensory profile of cheese products for commercial applications.

Ground beef products are susceptible to spoilage bacteria (i.e., *Pseudomonas* spp., *Lactobacillus* spp.) and pathogenic bacteria (i.e., *E. coli* O157:H7, *Salmonella* spp.) (Cevallos-Cevallos et al., 2011; Fang et al., 2022; Valerio et al., 2020). Regulation and safe practices, physical and chemical interventions and biocontrol have been well-established/well-studied to mitigate risk of pathogens contaminating finished raw ground beef products (Puligundla & Lim, 2022; Schilling et al., 2009; Scott-Bullard et al., 2017). Growth of spoilage bacteria during the refrigerated storage decreased shelf life and developed off-odors of ground beef products (Fang et al., 2022). Incorporation of edible natural antimicrobials (i.e., phenolic-rich spices) has demonstrated promising results in preventing microbial contamination or degradation of perishable food including ground beef (Chibane et al., 2019; Sagdic et al., 2011). Antibacterial spices that were effective in vitro may not be effective in a complex food matrix, such as a ground beef model (Uhart et al., 2006). Demand for natural food preservatives continues with a focus on their abilities to extend shelf life, maintain (or improve) quality attributes, as well as satisfy consumer perception of freshness (flavor and color stability) of ground beef products.

Native to North America, staghorn sumac (*Rhus typhina*) shrub (or tree) grows well in Southern Ontario, the Appalachian Mountains, and the Northeastern and Midwestern United States. Staghorn sumac has been adapted to other parts of the world, mostly as an ornamental plant (Wang & Zhu, 2017). Global and regional geographic distribution of staghorn sumac promotes its accessibility to international markets. Since ancient time, staghorn sumac fruit has acquired a reputation among indigenous peoples of the North America as traditional medicinal herb for reducing gastrointestinal disorders and diabetic complications (Wang & Zhu, 2017). Recently, researchers have shown that staghorn sumac and its bioactive constituents possess multiple bioactivities, including antioxidative, antimicrobial, antidiabetic, anticancer, anthelmintic, and anti-inflammatory properties. Staghorn sumac is a good source of polyphenolic compounds. In particular, major anthocyanins of staghorn sumac are different from that of common fruits and vegetables, such as raspberry. Staghorn sumac derived ingredients have great potentials for practical applications in different fields of science and technology (Wang & Zhu, 2017). In medical and health sciences, sumac-enriched products may help to cope with the rising occurrence of chronic diseases, such as diabetes, cancer and obesity. Health benefits associated with the intake of natural polyphenols have been well-established (Del Rio et al., 2013). Sumac derived food products could be functional food alternatives in niche food market for consumers who are health conscious. Within food science and technology, reddish-purple fruit with lemony taste (mainly comes from organic acids and tannins) is typical seasoning and flavoring ingredients for salad and meat. In addition, staghorn sumac extract has been introduced to only few food products to carry out specific technologic functions. Sumac extract fortified wheat breads had extended shelf life and enhanced phenolic content along with unique textural and sensory properties (Wang & Zhu, 2018). Sumac inhibited microbial growth and lipid oxidation of ground sheep meat during refrigerated storage (Aliakbarlu & Mohammadi, 2015). Koobideh Kebab with sumac water extracts had extended shelf life and improved overall acceptability (Yadolahi-Baghloei et al., 2017). Extending the usage of sumac to other types of meat products, such as ground beef, would benefit validation of previous findings. To maximize antioxidant and antibacterial potentials of staghorn sumac, food applications of sumac remain to be diversified (Wang & Zhu, 2017, 2018). No studies have been conducted on the inhibitory effects of sumac extract (as a potentially attractive natural food preservative) against microbial spoilage and deterioration in physicochemical and sensory attributes in cheese.

In this study, Cheddar cheese (a dairy product) and ground beef (a meat product) were selected as food models. Reddish-purple sumac fruit powders possibly simulate the desired hues for ground meat products (red color of unprocessed meat or the brown color of cooked meat) and Cheddar cheeses with yellowish-orange color. This study was to investigate the potentials of staghorn sumac extract for retarding lipid oxidation and microbial spoilage (using *E. coli* as a model bacterium) in Cheddar cheese and ground beef during storage conditions.

E. coli represents one biological hazard during manufacture and storage of cheese and raw ground beef (Freitas et al., 2013; Ombarak et al., 2016; Scott-Bullard et al., 2017). The physicochemical and microbiological, and sensory characteristics were evaluated. High-performance liquid chromatography (HPLC)-based profiling of potential antimicrobial and antioxidant phytochemicals for sumac extracts was performed. The results of this study expand the food applications of staghorn sumac with enhanced functional performance, while considering sustainable use of staghorn sumac plants as natural food preservatives. The resulting food products with sumac would satisfy consumers' demands toward more natural food products, which would limit use of permitted synthetic antioxidants and antimicrobial agents in foods.

2 | MATERIALS AND METHODS

2.1 | Materials

Sliced Cheddar cheese (yellowish-orange color) and ground beef were purchased from a local grocery store (Countdown Supermarket, Auckland, New Zealand) in the period from August 2021 to October 2021. Staghorn sumac fruit powder was from The Spice House (Illinois, USA). Tryptic soy broth (TSB), tryptic soy agar (TSA), ×10 phosphate buffer saline (PBS) were purchased from Thermo Fisher Scientific. All the chemicals were of analytical grade from Sigma-Aldrich.

2.2 | HPLC analysis of staghorn sumac extract

An HPLC system (Agilent Technology 1100 Series) equipped with a quaternary pump, an inline degasser, a thermostatic auto-sampler, and a diode array detector (DAD) was used for the quantification of phytochemicals in the sumac extract. The separation was carried out on a Phenomenex Luna 5 μm column (250 × 4.60 mm) with a C18 guard column. The binary mobile phases were consisted of acetonitrile (solvent A) and 6% acetic acid (solvent B). A gradient program was used as follows: 100% B was kept for 5 min; 5−8 min, 100%−85% B; 85% B were kept for 30 min; 30−35 min, 85%−80% B; 35−50 min, 80% to 50% B; 50−55 min, 50%−20% B; 55−60 min, 20%−100% B. The flow rate was 1.0 mL/min and the injection volume was 10 μL for all the standards and samples. The DAD collected data from 190−900 nm, and absorbance at 254, 280, 320, 360, 520 nm were used to monitor the phytochemicals. Compounds were identified by congruent retention time and UV spectrum, and by LC-MS^n, as described previously (Wu et al., 2013). A calibration curve was prepared using standards to determine the relationship between the peak areas and concentrations of phytochemicals (Safarov, 2020; Wu et al., 2013).

2.3 | Preparation of sumac extracts

Sumac fruit powder was extracted in deionized water at 90°C for 5 min. The selection of the infusion conditions was based on our preliminary studies, in which the effects of different infusion parameters such as time (3 min, 5 min, 8 min, and 10 min) and temperature (25°C, 50°C, 60°C, 70°C, 80°C, 90°C, and 100°C) on total phenolic contents (TPC) were considered.

Acid hydrolysis was performed (Hough et al., 1999) by incubating a well mixture of 5 mL of the crude extract and 5 mL of 4 M HCl in a water bath at 90°C for 2 h to hydrolyze the glycosides. After cooling down at room temperature (~23°C), the resultant hydrolysate was filtered through a PTFE 0.2 μm membrane filter (Thermo Fisher Scientific). The filtrate was subjected to further phytochemical analysis.

2.4 | Culture preparation and growth conditions

E. coli cultures were prepared by following a modification of the method described previously (Shan et al., 2009). Specifically, frozen stock *E. coli* K12 cultures from the American Type Culture Collection (ATCC) was rehydrated by transferring aseptically thawed culture to 5 ml of fresh TSB and then was incubated at 37°C for 24 h. The overnight culture was streaked onto TSA and stored at refrigerating temperature as stock culture. Before each experiment, a single colony of *E. coli* was selected from the stock agar plates and transferred into 5 mL of TSB solution, followed by growth grow at 37°C and 250 rpm in a shaking incubator for 24 h. The optical densities (OD) of the *E. coli* at 600 nm (OD600) reached 1.5 and 1.2. The overnight *E. coli* culture was then centrifuged at 3500*g*, followed by washing with sterile ×1 phosphate-buffered saline (PBS 0.1 mol/L, pH 7.2) three times. The resulting pellets were resuspended in sterile PBS to achieve a bacterial suspension with an approximately 10^6 colony-forming units (CFU)/mL for inoculation in ground meat and cheese samples.

2.5 | TPC and total anthocyanin content

TPC was determined by the Folin-Ciocalteu method described previously (Slinkard & Singleton, 1977). A gallic acid standard curve was prepared with a concentration range from 50 to 250 μg/mL. The TPC was expressed as micrograms of gallic acid equivalent (GAE) per gram of sample. All tests were done in triplicate.

Total anthocyanin content was based on the pH differential method (Revilla et al., 1998). The total anthocyanin content was expressed as milligrams of cyanidin-3-glucoside equivalent, on the basis of the molar absorptivity at 535 nm and the molecular weight of cyanidin 3-glucoside (molar extinction coefficient $\varepsilon = 26900\ cm^{-1}M^{-1}$, molecular weight [MW] = 449.2 g/mol).

2.6 | Color measurement

Color changes (occurring on the surface of meat or cheese samples) during storage were monitored by a portable Minolta CR-300 (Minolta, Japan). Lightness (L^*, 100 = white and 0 = black), redness/greenness (a^*, positive = red) and yellowness/blueness (b^*, positive = yellow) of CIELAB color space were analyzed.

2.7 | Lipid oxidation measurement

Lipid oxidation determined by thiobarbituric acid reactive substance (TBARS) assay (Reitznerová et al., 2017; Turgut et al., 2016) with some modifications. The TBARS assay measures malonaldehyde (MDA) produced during cheese and ground meat storage. Each sample (2*g*) was weighed into 50 mL centrifuge tube. Cold 10% trichloroacetic acid (TCA) (10 mL) was added to the tube, followed by vortex mixture for 1 min. Hexane (10 mL) was then added and the mixture was vortexed for another 1 min. The resulting mixture was centrifuged at 4500 rpm for 5 min, before the removal of hexane layer with Pasteur pipette. The resulting aqueous extracts were filtered. The filtrate (2.0 mL) was then well mixed with TBA reagent (0.5 mL). The mixture was heated in a boiling water bath for 30 min. After cooling using tap water to ambient temperature (~20°C), the absorbance was measured spectrophotometrically at 532 nm. The concentration of MDA in the analyzed samples was calculated using a standard curve obtained using serial dilutions of a solution of 1,1,3,3 tetraethoxypropane. The TBARS value was expressed as μmol MDA per g sample.

2.8 | Quality attributes and sensory characteristics

2.8.1 | Cheddar cheese model

Samples of Cheddar cheese were randomly divided into seven groups: (1) Sumac_0% (control, dipped in 75% ethanol), (2) Sumac_0.5%, (3) Sumac_1%, (4) Sumac_2%, (5) Sumac_ 3%, (6) Sumac_4% and (7) Sumac_5%. Cheese slice (20 g) was placed into a zip-lock bag and completely coated with the 100 mL 75% ethanol and extracts with different concentrations (0.5%, 1%, 2%, 3%, 4% and 5%, respectively) for 5 min at room temperature. This was to coat the slices completely. After the treatment, the cheese slices in the same bag were drained. The treated cheese samples were placed in a biological safety cabinet for 20 min before being inoculated. For microbiological analysis, the treated cheese samples were inoculated by dipping into 100 mL of cell suspensions containing about 10^6 CFU/ml of *E. coli*. All cheese samples were aseptically held in biological safety cabinet for 15 days at room temperature (~23°C). The selection of storage conditions was based on our preliminary studies and other previous publications (Shan et al., 2011).

Chemical attributes (pH, water activity, total phenolic and total anthocyanin contents, TBARS) and microbiological attribute (total plate count) of Cheddar cheese were measured Day 14. Day 0 in the test is the day of sample preparation. All samples were measured triplicate. Water activity and pH of the cheese samples were determined by a dew point water activity meter 4TE (AQUALAB) and a potable pH meter, respectively. Total phenolic and anthocyanin contents of samples were determined based on the Folin-Ciocalteu and pH-differential methods, respectively (Revilla et al., 1998; Slinkard & Singleton, 1977). The oxidative stability of cheese samples was assessed by extraction method with trichloroacetic acid (14%), followed by hexane. The cheese extracts were then mixed with thiobarbituric acid (0.8%) (Botsoglou et al., 1994). The levels of TBARs were expressed as micromolar MAD per g cheese. The content of MDA derived by lipid oxidation has been used as marker of oxidative damage in cheese (Papastergiadis et al., 2012; Shan et al., 2011).

The microbiological spoilage was determined by the total aerobic count during storage (Hough et al., 1999; MFHPB-18, 2015). Specially, each cheese sample (20 g) was aseptically mixed with 180 mL of 2% sterile sodium citrate (prewarmed at 45°C) and homogenized (300 rpm, 5 min) using the Seward Stomacher 400 Lab Blender (Seward). The homogenate was decimally diluted. Each diluted homogeneous suspension (0.1 mL) was spread plated onto duplicate Petri plates. All plates were then incubated at 35°C for 24 h. All samples were assayed in triplicate. Results were expressed as log CFU/g.

The sensory characteristics (appearance, flavor, and texture) of cheese determine their eating quality. Sensory evaluation of cheese is necessary to determine the influence of these sensory characteristics on the eating quality of cheese and its consumer acceptability (Hough et al., 1999). In this study, sensory characteristics including color, appearance, texture, flavor, and total acceptability were evaluated by a difference-from-control test, with a 7-point structured scale anchored as follows: 0 = no difference, 1 = very slight, 2 = slight, 3 = moderate, 4 = moderately big, 5 = big, and 6 = very big (Hough et al., 1999). Trained panelists of 10 volunteers participated in the evaluation of sensory attributes of cheese

sample at Day 0. A difference-from-control test is commonly used in shelf-life studies, in which trained panelists focus on unexpected sensory changes rather than detect a specific off-odor or flavor (Hough et al., 1999).

2.8.2 | Ground beef model

Ground beef samples were randomly divided into seven groups: (1) Sumac_ 0% (control, without sumac extract), (2) Sumac_0.5%, (3) Sumac_1%, (4) Sumac_2%, (5) Sumac_3%, (6) Sumac_4%, and (7) Sumac_5%. In a low-density polyethylene bag, each representative sample (25 g of ground beef) was aseptically mixed with the 100 mL sterile water (control) or sumac extracts at different concentrations (0.5%, 1%, 2%, 3%, 4% and 5%, respectively) for 2 min at room temperature. Each bag was sealed and well mixed before removal of excess solution. The ground beef treated with sterile water was used as control according to previous studies (Fang et al., 2022; Zhang et al., 2016). The treated meat samples (25 g each sample) were then inoculated by mixing with 100 mL *E. coli* cell suspensions (10^6 CFU/mL). All treated ground beef samples were aseptically stored in refrigerator at 4°C for 7 days. For bacterial enumeration, each ground meat sample (25 g) was aseptically mixed with 225 mL of 1% sterile peptone water and homogenized (300 rpm, 5 min) using the Seward Stomacher 400 Lab Blender (Seward). The homogenate was decimally diluted. Each diluted homogeneous suspension (0.1 ml) was spread-plated onto duplicate Petri plates. All plates were then incubated at 35°C for 24 h. Results were expressed as log CFU/g ground beef.

Ground beef samples (25 g each sample) to be used for determining pH, water activity, total phenolic and total anthocyanin contents and TBARs were not inoculated. All aerobically packed samples were tested according to previous reports (Botsoglou et al., 1994; Kim et al., 2018; MFHPB-18, 2015; Revilla et al., 1998; Slinkard & Singleton, 1977; Turgut et al., 2016). All experiments were carried out in triplicates.

Trained panelists of 11 volunteers (6 females and 5 males, 19–29 years) participated in the evaluation of sensory attributes of cooked meatballs at Day 0 using a discrimination sensory testing method. Meatballs were made with ground beef without/with sumac at different concentrations (0.5%, 1%, 2%, 3%, 4% and 5%, respectively). Each mixture was kneaded by hand for about 5 min. The meatballs were cooked at 400°F for around 25 min (until the meatballs reach an internal temperature of 71°C). cooked meatballs were served in randomized order to the panelists. Panelists scored for color, tenderness, juiciness, flavor, and total acceptability using a 7-point hedonic scale. Tenderness, juiciness and flavor represent the most influential sensory attributes affecting the eating quality of meat (Robbins et al., 2003; Zhang et al., 2016). The total acceptability was used to determine the optimal concentration of sumac addition. The objective of this difference-from-control test was to determine the overall quality difference caused by sumac additions.

2.9 | Experimental design and statistical analysis

Preparations of solutions and treatments were performed according to previous studies (Fang et al., 2022; Shan et al., 2009, 2011; Turgut et al., 2016; Zhang et al., 2016). The selection of the storage conditions and sumac concentrations for ground beef (Fang et al., 2022; Shan et al., 2009; Turgut et al., 2016) and cheese (Shan et al., 2011) were based on either previous studies or our preliminary studies. All the tests were performed in independent triplicate. Statistical analysis was performed by SPSS software (IBM Corporation). One-way analysis of variance determined the treatment effects, and Fisher's protected LSD post hoc test separated the means with a significance level at $p < 0.05$.

3 | RESULTS AND DISCUSSION

3.1 | Polyphenol composition of sumac extracts

Figure 1 shows a representative HPLC chromatogram of sumac extract (A) and acid hydrolyzed extract (B). The phytochemical profile of sumac extracts was dominated by polyphenols (Figure 1A, Table 1). Many of these phytochemical compounds may have different glycosides of the same aglycone. To simplify the spectrum, acid hydrolyzed extracts were used for quantification (Table 1). Hydrolyzed sumac extract showed high concentrations of caffeic acid, gallic acid, ellagic acid, quercetin, and anthocyanins (peonidin, petunidin, and an unidentified anthocyanidin) based on retention time and coinjection of standards (Figure 1C). HPLC-DAD-MS results showed that caffeic acid 3-*O*-hexose (8.35 mg/g, dry weight) was the most abundant nonanthocyanin phenolics, followed by gallic acid, ellagic acid, quercetin-3-rhamnoside, and quercetin (Kirby et al., 2013). Fruit of staghorn sumac was reported to possess six major anthocyanins, including two cyanidin derivatives and four 7-O-methyl anthocyanins and their galloylated derivatives (Kossah et al., 2011). 7-O-methyl-cyanidin-3- O-(2″galloyl)-galactoside ($C_{29}H_{27}O_{15}$, 7Me-Cy-G-g) and 7-O-methyl-cyanidin-3-O-(2‴galloyl)-galactoside-4-vinylcatechol-3″-O-glucoside ($C_{43}H_{41}O_{22}$, Py-7Me-Cy-G-g) were the two major anthocyanins identified from sumac fruit. Their relative abundance were 45.3% and 14.9%, respectively, as measured by integrated peak areas at 520 nm (Kossah et al., 2011). These results of previous reports largely agreed with the results of this

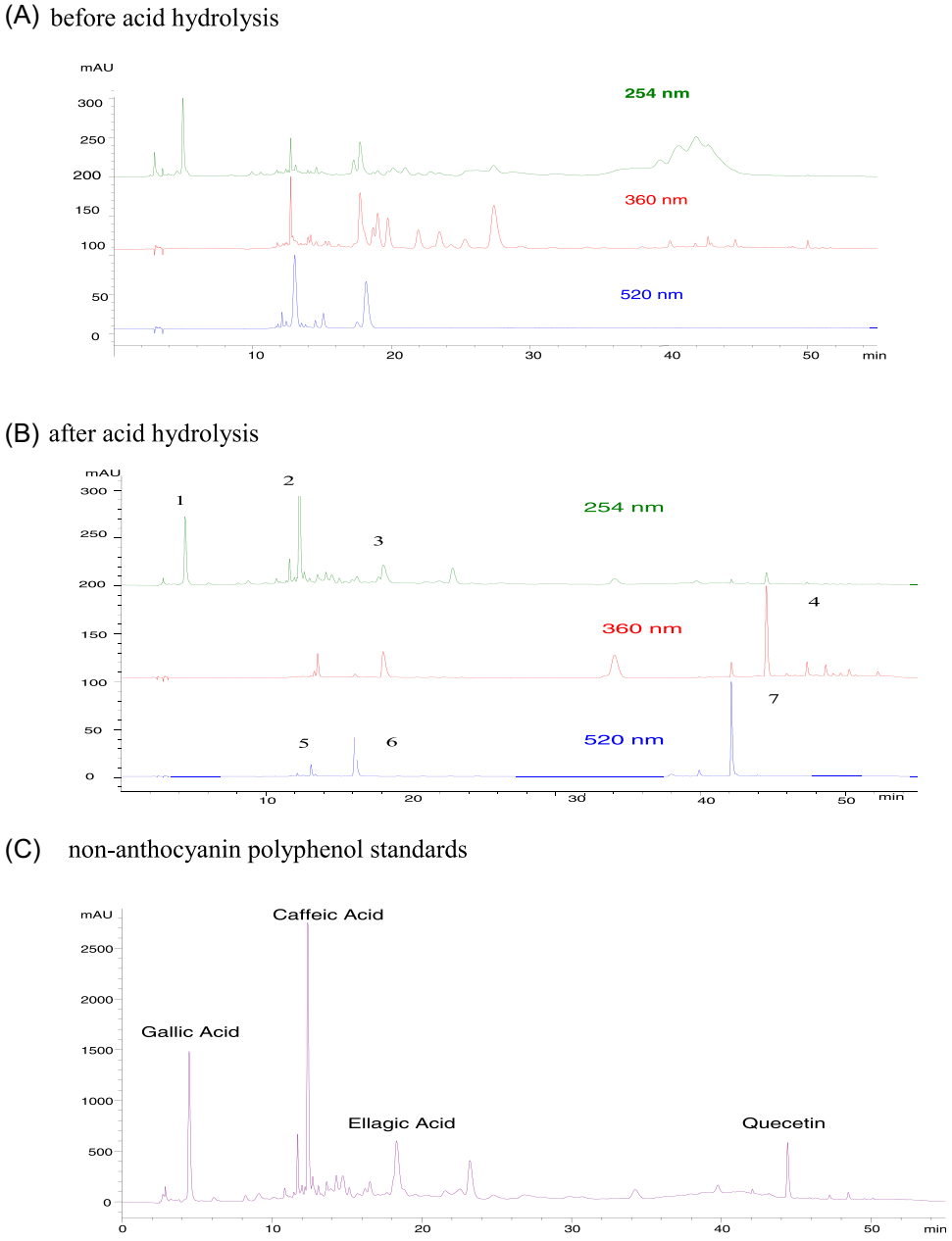


FIGURE 1 HPLC profiles of staghorn sumac crude extract. (A): Before acid hydrolysis; (B): After acid hydrolysis.1, Gallic acid; 2, Caffeic acid; 3, Ellagic acid; 4, Quercetin; 5, Petunidin, 6, Peonidin, 7, unknown aglycone (443 Da). (C): Non-anthocyanin polyphenol stardards. HPLC, high-performance liquid chromatography.

report (Table 1, Figure 1). Early studies have shown differences in anthocyanin composition between sumac and commonly consumed berries and their potential as natural chemotherapeutic agents, or food additives in wheat bread for quality improvement (Kirby et al., 2013; Ombarak et al., 2016; Wang and Zhu, 2018). These chemicals are associated with various bioactivities of sumac, including antioxidant and antimicrobial capacities (Wang & Zhu, 2017). In this study, the possible antioxidant and antimicrobial activities of sumac extracts were extended to cheese and beef products as described in the following sections.

3.2 | The impacts of sumac on cheddar cheese

3.2.1 | pH and water activity of cheese

A significant difference ($p < 0.05$) in pH values was observed between the control cheese and cheese with sumac extracts (Figure 2A). The pH values of cheese samples with sumac extracts at different concentrations were similar, while being significantly lower than the control (Figure 2A). During ambient storage, cheese treated with extracts of cinnamon stick, oregano, clove, and pomegranate peels had lower pH values of cheese by

TABLE 1 Major polyphenols detected in the sumac extracts.

Peak number	Retention time (min)	Tentative identity	Concentration (DW)
Nonanthocyanin polyphenols			
1	4.46	Gallic acid	3.68 mg/g
2	13.26	Caffeic acid	5.18 mg/g
3	17.63	Ellagic acid	1.93 mg/g
4	43.71	Quercetin	1.31 mg/g
Anthocyanin aglycones			
5	14.85	Petunidin	10.63 μg CGE/g
6	16.98	Peonidin	29.38 μg CGE/g
7	42.15	Unknown aglycone (443 Da)	61.37 μg CGE/g

Abbreviations: CGE, cyanidin 3-glucoside equivalent; DW, dry weight.

3.6−6.0% as compared to the control cheese (Shan et al., 2011). Similar pH decreasing trend was also observed in low fat Kalari cheese treated with 2.5% and 5.0% of pine needles (*Cedrus deodara* (Roxb.) Loud.) extract during refrigerated storage within low density polyethylene pouches (Mahajan et al., 2016). The decreased pH could be attributed to the presence of organic acids (e.g., malic, citric and fumaric acids) and phenolic acids (e.g., caffeic acid and gallic acid) in sumac samples as shown in the above section. The pH of cheese control time-dependently increased during a 9-days storage at room temperature. Selected plant extract was able to stabilize the pH of cheese during the storage period due to the presence of antioxidant components such as phenolic acids (Kossah et al., 2011; Mahajan et al., 2016; Shan et al., 2011). Maintaining pH at certain levels may also control possible microbial growth.

No significant difference in water activity was observed among the control and cheese with sumac extracts (Figure 2B). Controlling acidity level (pH) and/or the level of water activity of cheese could effectively increase the shelf life of cheese products as shown in the following sections.

3.2.2 | Oxidative stability of cheese

Oxidative stability of cheese products reflects the susceptibility to lipid oxidation (Papastergiadis et al., 2012). Figure 2C shows the effect of sumac extract addition on TBARs of cheese samples. Addition of sumac extracts dose-dependently decreased the TBARS values. The lowered TBARS of cheese samples with the addition of sumac extracts (2%−5%) indicated the potential of sumac in preventing cheese from getting rancid. Staghorn sumac is rich in phenolic compounds as shown in a section above. The strong antioxidant activity is mainly associated with flavonoids, anthocyanins, pyranoanthocyanins, hydrolyzed tannins, and gallic acid in sumac (Peng et al., 2016; Wang & Zhu, 2017). These phenolic compounds are free-radical scavengers and transition metal chelators (Brown et al., 1998). Similar results were found on the inhibitory effect of selected spice and herb extracts (cinnamon stick, oregano, clove, pomegranate peel, and grape seed) on the lipid oxidation of cheese products to certain extents (Shan et al., 2011).

3.2.3 | Microbiological stability of cheese

Staghorn sumac derived compounds may have antimicrobial capacity, which may be independent of their antioxidant properties (Shan et al., 2011). Adding sumac extract increased microbiological stability of cheese samples. Total aerobic contents of cheese samples were decreased by increasing sumac extract addition in a dose-dependently manner (Figure 2D). Addition of sumac extracts (2%−5%) resulted in 2.3−5.4log reductions in total aerobic content of cheeses, indicating the potential of sumac to prevent cheese from spoilage. Staghorn sumac-based materials have been reported for their in vitro antimicrobial activities against diverse bacteria including *Pseudomonas aeruginosa, Candida albicans, E. coli, S. aureus, Bacillus cereus, L. monocytogenes, Salmonella typhimurium, Helicobacter pylori, Saccharomyces cerevisiae, Pichia pastoris*, and *Kluyveromyces lactis* (Borchardt et al., 2008; Kossah et al., 2011; Vandal et al., 2015). Optimizing the antimicrobial efficacy of staghorn sumac in food products deserves future investigation. The antibacterial mechanism of plant extracts may be, at least partially, attributed to their phenolic compounds. Gallic acid, caffeic acid, quercetin, rutin, and tannins of sumac were demonstrated to be antibacterial (Borchardt et al., 2008; Kossah et al., 2011; Vandal et al., 2015). The phenolic compounds of plant extracts induced bacterial cell death by degrading the bacterial cell walls and/or inducing rigidity of bacteria membranes (Wang & Zhu, 2017). The copresence of organic acids in sumac extracts reduced the pH levels of cheese samples with sumac (Figure 2A). Organic acids, such as lactic acid and acetic acid, were effective antibacterial agents in food industry (Pattison et al., 2003). The reduced pH of cheese samples may also contribute to the microbial inhibition during storage. It should be noted that cheese was stored at room temperature, *E. coli* population may first increase then decrease during 14 day-storage.

3.2.4 | Total phenolic and anthocyanin contents of cheese

Adding sumac extracts dose-dependently increased the total phenolic and anthocyanin contents of cheese

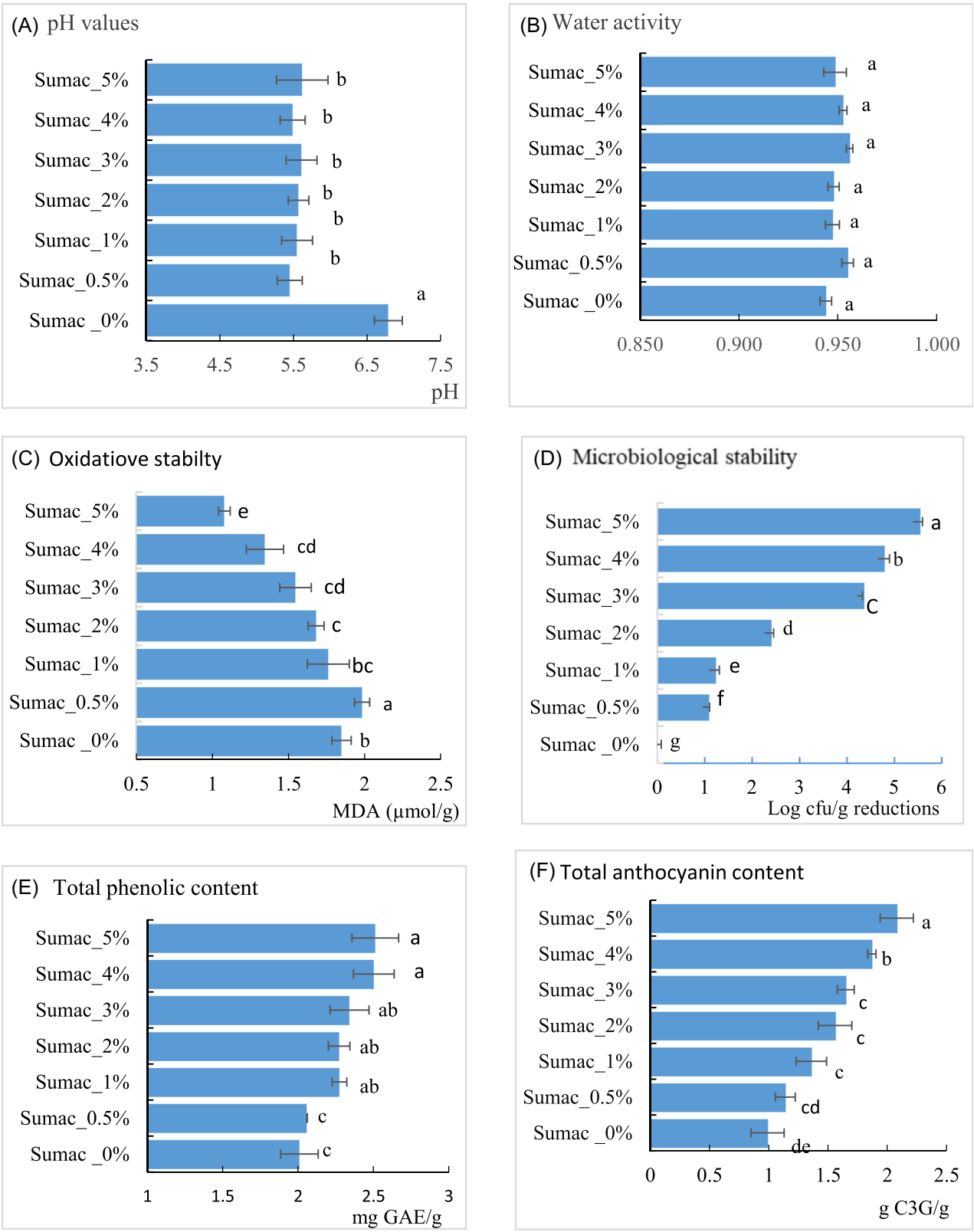


FIGURE 2 Physicochemical and microbiological attributes of Cheddar cheese (stored at 23 ± 2°C) measured on day 14. (A) pH; (B) water activity; (C) oxidative stability; (D) microbiological stability; (E) total phenolic content; (F) total anthocyanin content. Oxidative stability assayed by thiobarbituric acid reactive substances (TBARS) assay. Microbiological stability assayed by total plant count. C3G, cyanidin-3- glucoside equivalent; CFU, colony forming unit; GAE, gallic acid equivalent; MDA, malondialdehyde. Different letters in each figure indicate significant differences between treatments ($p < 0.05$).

samples (Figures 2E and 2F). The increased TPC of cheese products with sumac addition could contribute to the reduced TBARS values (Figure 2C) and total aerobic count (Figure 2D). Staghorn sumac has been proved to be a good source of bioactive components, such as polyphenols, as shown in a section above with antioxidative, antimicrobial, and anticancer potential according to in vitro and in vivo assays (Wang & Zhu, 2017). Therefore, cheese products fortified with sumac extract not only have enhanced the shelf life, but also have increased nutritional benefits. The optimization of incorporating, stabilizing and delivering these diverse bioactive components of staghorn sumac remains to be studied in other food formulations.

3.2.5 | Sensory characteristics of cheese

Sensory acceptance of cheeses with 0.5%−3% sumac addition was slightly different from the control except for the color (Figure 4A). The increased total anthocyanin content could partially explain the difference in color between the control cheese and the cheeses with sumac addition. The color, appearance, texture, flavor, and total acceptability of cheese were more significantly different from those of the control when sumac addition increased from 4% to 5%. Cheddar cheese is valued for their unique complex odor and taste (Singh et al. 2003; Drake et al. 2007; Andersen et al. 2010). The main taste-active compounds of Cheddar cheese consist of glutamic acid, mineral salts, and organic acids (Andersen et al., 2010). Glutamic acid and mineral salts drive the umami taste of Cheddar cheese (Andersen et al., 2010). The flavor components of staghorn sumac fruits, such as organic acids and polyphenols, contribute the astringent and acidic taste (Wang & Zhu, 2017). The interaction between the main tastants of Cheddar cheese and the constituents of sumac extract remains to be studied. Promisingly, these constituents minimally influenced the flavor of the Cheddar cheese with sumac extracts at the concentrations of 0.5%−3% (Figure 4A).

3.3 | The impacts of sumac on ground beef

3.3.1 | Color and pH stability and water activity of ground beef

Consumers perceive meat color to be an indicator of freshness. Beef color has a tendency to change from red to brown after grinding and in the period of refrigeration. Ground beef with sumac (2%−5%) displayed stable color. Increased anthocyanin contents of ground beef from the sumac additions could be responsible for the color stability of beef samples. Previously, improved color stability was reported for fresh ground beef mixed with noni puree (*Morinda citrifolia*) (2%, 4%, and 6%). Vitamin C and antioxidant-properties of the phytochemicals in noni puree synergistically improved color stability of resulting ground beef (Tapp et al., 2012).

Increasing amount of sumac addition dose-dependently decreased the pH values of ground beef samples (Figure 3A). Organic acids (malic, citric, and fumaric acids) in sumac could lower the pH of meat (Kossah et al., 2011).

There was no significant difference in water activity between sumac-treated samples and control samples (Figure 3B). Controlling microbiology stability of food products was achieved not only by manipulating the pH or water activity alone, by possible through other factors or a combination of pH or water activity and other factors.

3.3.2 | Oxidative stability of ground beef

Ground beef is rich in protein, lipids, and heme iron, and is susceptible to chemical deterioration. Degradation of lipids and development of oxidative rancidity in meat result in reducing sensory and nutritional quality and consumer acceptance of meat products (Amaral et al., 2018). Lipid oxidation indicator (TBARS values) was considered one of key determinants of the shelf-life of ground meat (Valerio et al., 2020). Oxidative stability of meat depends on intrinsic (meat composition) and extrinsic factors (processing, storage conditions, preservatives) (Domínguez et al., 2019). Meat oxidative stability decreased during storage. Synthetic antioxidants such as butylated hydroxyanisole and butylated hydroxytoluene are less popular today. There is a growing demand to use natural antioxidants.

As shown in Figure 3C, the TBARS values in ground beef with sumac (3%, 4%, and 5%) were significantly lower ($p < 0.05$) than that of control sample and treated samples (containing 0.5%, 1%, and 2% sumac) at the end of storage (on Day 7). No significant differences in the initial concentrations of TBARS between the control and treated ground beef samples were obtained. These results were consistent with a previous publication (Shan et al., 2009), which reported that cinnamon stick, oregano, clove, pomegranate peel, and grape seed extracts were effective in reducing TBARS of fresh pork during 9 days of storage at 20°C. There were no significant differences in TBARS values between treated and control pork samples during storage less than 3 days (Shan et al., 2009). Compared to the control, the sumac treated ground beef had a lower TBARS value, suggesting that sumac extract (3%−5%) effectively protected ground beef against lipid oxidation during storage. Some plant extracts possess antioxidant activity. One type of the active ingredients in these plants is phenolic compounds. Phenolic compounds are free-radical scavengers and transition metal chelators. Selected plant-based ingredients incorporated into meat product formulations were capable of preventing lipid oxidation. The TBARS values of beef meat meatballs containing

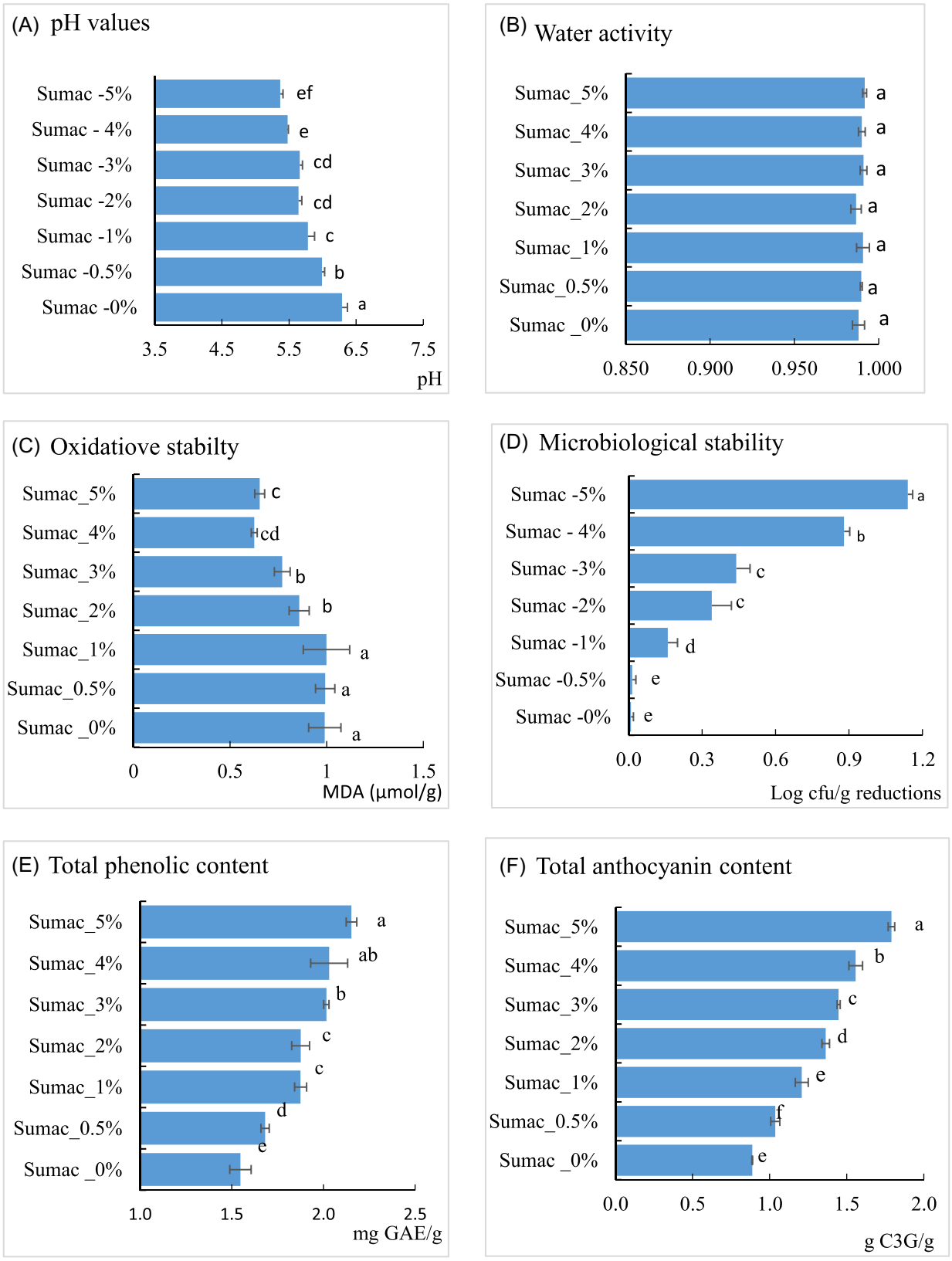


FIGURE 3 Physicochemical and microbiological attributes of ground beef (stored at 4°C) measured on Day 7. (A) pH; (B) water activity; (C) oxidative stability; (D) microbiological stability; (E) total phenolic content; (F) total anthocyanin content. Oxidative stability assayed by thiobarbituric acid reactive substances (TBARS) assay, microbiological stability assayed by total plant count. C3G, cyanidin-3-glucoside equivalent; CFU, colony forming unit; GAE, gallic acid equivalent; MDA, malondialdehyde. Different letters in each figure indicate significant differences between treatments ($p < 0.05$).

pomegranate peel (0.5% and 1%) was lower than that of control after 8 days of storage in the dark at 4°C (Turgut et al., 2016). TBARS values of Swedish-style meatballs containing rosemary, orange or lemon extracts were lower than those of the control after 12 days of storage in the dark at 8°C (Fernández-López et al., 2005).

Antioxidant activity of sumac could be attributed to compounds containing phenolic hydroxyl groups and double bonds (i.e., gallic acid, hydrolysable tannins and flavonoids). Phenolics inhibited lipid oxidation via scavenging the active radicals to block radical chain reaction or chelating transition metal ions in the oxidation process (Shan et al., 2009; Wang & Zhu, 2017). Staghorn sumac fruits are rich in multiple antioxidant compounds, including phenolic acids, flavonoids, anthocyanins and pyranoanthocyanins (Wang & Zhu, 2017). The ascorbic acid (vitamin C) and phenolic compounds acted synergistically to inhibit lipid oxidation in the ground beef (Tapp et al., 2012).

3.3.3 | Microbiological quality of ground beef

Microbiological contamination status of ground beef samples were evaluated by total aerobic plate count (TAPC), which is one of important microorganism indicators to ensure the quality and safety of raw beef (Valerio et al., 2020). TAPC of all ground beef samples remained stable on Day 1. Ground beef with 1% and 5% sumac resulted in a reduction in microbial populations by 0.16 and 1.84 log CFU/g, respectively (Figure 3D), as compared with the control. The concentration of sumac below 1% had a negligible effect in reducing *E. coli* and other aerobic bacteria on ground beef. Antimicrobial activity of leaves and fruits of staghorn sumac on selected food spoilage and pathogenic bacteria have been reported previously (Wang & Zhu, 2017). Gallic acid, caffeic acid, quercetin, rutin and tannins are antibacterial (Borchardt et al., 2008; Kossah et al., 2011; Vandal et al., 2015). Antibacterial activity relies on hydrogen bonding interactions between polyphenols and surface of bacterial cells. Sumac polyphenols may interact with bacteria through inducing rigidity of bacteria membranes, inhibiting extracellular microbial enzymes, depriving the substrates required for microbial growth, or disrupting microbial metabolism through inhibiting oxidative phosphorylation (Borchardt et al., 2008; Kossah et al., 2011; Vandal et al., 2015). These results suggested that sumac derived ingredients can be a barrier for preventing or eliminating undesirable bacterial contaminations.

3.3.4 | Total phenolic and total anthocyanin contents of ground beef

As shown in the Figures 3E and 3F the contents of total phenolics and total anthocyanins of sumac treated ground beef samples increased with increasing concentration of sumac. The increased contents possibly contributed to the microbiological and oxidative stability, as well as the sensory quality of treated ground beef samples under experimental storage conditions. The TPC of staghorn sumac fruits ranged 46−151 mg GAE/g dry weight, depending on the country of origin and extraction conditions (Wang & Zhu, 2017). Sumac derived polyphenols are highly diverse and had diverse mechanisms behind antimicrobial and antioxidant activities. Such antimicrobial mechanisms including phenolic induced cell surface hydrophobicity, charge, and K^+ leakage of bacterial cell constituents. Polyphenol stability is important for its applications in food systems as preservatives. The stability of polyphenols depends on several factors, such as pH, interactions between phenolics or with other constituents and hydrophilic or hydrophobic natures of food model systems (Chibane et al., 2019).

3.3.5 | Sensory characteristics of cooked ground beef meatballs

Color, flavor, tenderness, juiciness and total acceptability of cooked meatballs (Supporting Information & Materials) with sumac (0.5%, 1%, 2%, 3%, 4% and 5 %) were comparable to those of control (Figure 4B). Flavor, tenderness, and juiciness are believed to be the most important eating quality attributes of beef, influencing consumer acceptance (or rejection) of meat products (Santos et al., 2021). Sumac concentration below 4% had minimal negative impacts on the sensory acceptance of cooked beef meatballs. These finding suggested sumac incorporated ground beef would be attractive due to their sensory characteristics.

The optimal amount of sumac extract treatment for ground beef is 3% for improved antioxidant and antimicrobial, while minimally influencing consumer overall acceptability of cooked beef meatballs. Interactions between sumac derived flavor compounds and ground beef derived flavor compounds possibly influence on flavor perception of sumac treated ground beef samples. Perceived rancidity of lemon extract treated cooked Swedish-style meatballs have been attributed to the presence of off flavors in lemon extracts (Fernández-López et al., 2005).

In this study, properly trained panelists were able to describe quality attributes and stability with a high degree of repeatability with minimal personal bias or preference and cost. Consumer panels (50 or more panelists) are expected for evaluating acceptance and satisfaction, indicating purchasing decisions of commercial novel food products in further study.

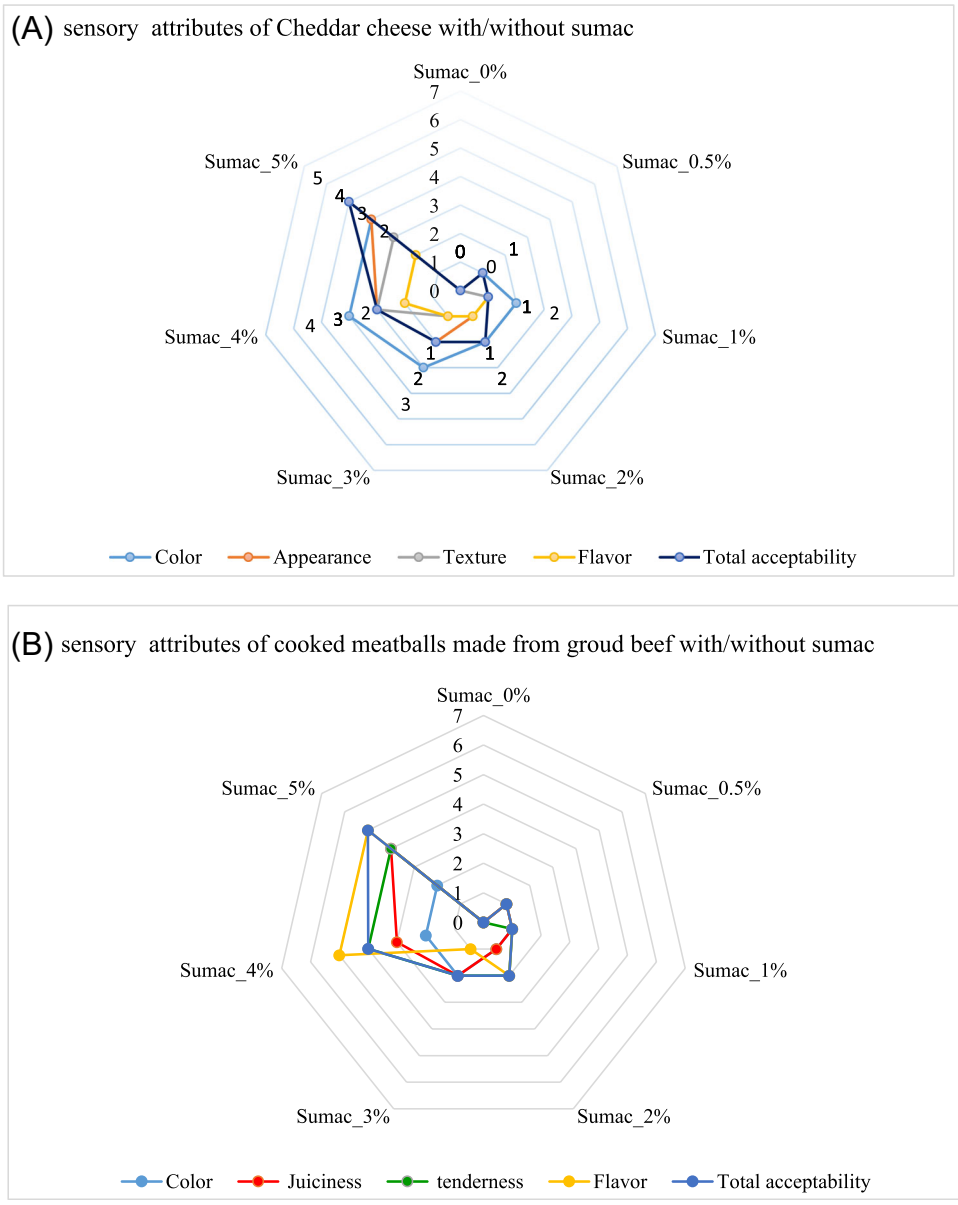


FIGURE 4 Sensory attributes (measured on day 0) of (A) Cheddar cheese with/without sumac and (B) cooked meatballs made from ground beef with/without sumac.

4 | CONCLUSIONS

The results of this study demonstrated the antioxidant and antimicrobial properties of the staghorn sumac fruit extract using Cheddar cheese and raw ground beef models. Sumac fruit is rich in phenolic compounds and its antioxidant and antimicrobial activities are possibly associated with anthocyanins, hydrolyzed tannins, gallic acid, caffeic acid, ellagic acid and quercetin. Treatment with sumac extracts (2%−5%) delayed the lipid oxidation and retarded the growth of microorganisms (*E. coli*) of cheese during room temperature storage. To minimize the negative effect of sumac extract on the flavor of Cheddar cheese, less than 3% of sumac extract addition was recommended. The optimal amount of sumac extract treatment for cheese was 2% when antioxidative and anti-spoilage potential of sumac extract were considered. Sumac extended the storage shelf life of ground beef during refrigeration. The level of 3% was the optimal sumac concentration to effectively control oxidative and microbiology degradation of ground beef without compromising consumer overall acceptability of cooked beef meatballs. This study expands the food applications of staghorn sumac as a natural preservative functional ingredient for retarding lipid oxidation and limiting microbiological spoilage of lipid-rich food products during handling and storage. The results of this research will benefit those health-conscious consumers favoring a natural multifunctional ingredient (e.g., sumac) to preserve food products with potential health

benefits. The safety and acceptability of using sumac extracts in meat and dairy products remain to be determined in further studies. It remains to know how untrained consumers perceive the incorporation of sumac into dairy and meat products.

AUTHOR CONTRIBUTIONS

Sunan Wang: Conceptualization; writing—original draft; writing—review and editing; resources; methodology; visualization; data curation. **Shaoping Nie:** Resources. **Ren-You Gan:** Resources. **Fan Zhu:** Conceptualization; supervision; project administration; resources; methodology; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

ETHICS STATEMENT

None declared.

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REFERENCES

Aliakbarlu, J. & Mohammadi, S. (2015). Effect of sumac (*Rhus coriaria* L.) and barberry (*Berberis vulgaris* L.) water extracts on microbial growth and chemical changes in ground sheep meat. *Journal of Food Processing and Preservation*, *39*, 1859–1866.

Amaral, A. B., Silva, M. V. D., & Lannes, S. C. D. S. (2018). Lipid oxidation in meat: Mechanisms and protective factors - a review. *Food Science and Technology*, *38*, 1–15.

Andersen, L. T., Ardö, Y., & Bredie, W. L. P. (2010). Study of taste-active compounds in the water-soluble extract of mature Cheddar cheese. *International Dairy Journal*, *20*, 528–536.

Astegiano, S., Bellio, A., Adriano, D., Bianchi, D. M., Gallina, S., Gorlier, A., Gramaglia, M., Lombardi, G., Macori, G., Zuccon, F., & Decastelli, L. (2014). Evaluation of hygiene and safety criteria in the production of a traditional piedmont cheese. *Italian Journal of Food Safety*, *3*, 1705.

Borchardt, J. R., Wyse, D. L., Sheaffer, C. C., Kauppi, K. L., Fulcher, R. G., Ehlke, N. L., Biesboe, D. D., & Bey, R. F. (2008). Antioxidant and antimicrobial activity of seed from plants of the Mississippi river basin. *Journal of Medicinal Plants Research*, *2*, 81–93.

Botsoglou, N. A., Fletouris, D. J., Papageorgiou, G. E., Vassilopoulos, V. N., Mantis, A. J., & Trakatellis, A. G. (1994). Rapid, sensitive, and specific thiobarbituric acid method for measuring lipid peroxidation in animal tissue, food, and feedstuff samples. *Journal of Agricultural and Food Chemistry*, *42*, 1931–1937.

Brown, E. J., Khodr, H., Hider, C. R., & Rice-Evans, C. A. (1998). Structural dependence of flavonoid interactions with Cu^{2+} ions: Implications for their antioxidant properties. *Biochemical Journal*, *330*, 1173–1178.

Cai, Y. Z., Mei Sun, S., Jie Xing, X., Luo, Q., & Corke, H. (2006). Structure-radical scavenging activity relationships of phenolic compounds from traditional Chinese medicinal plants. *Life Sciences*, *78*, 2872–2888.

Carocho, M., Morales, P., & Ferreira, I. C. F. R. (2018). Antioxidants: Reviewing the chemistry, food applications, legislation and role as preservatives. *Trends in Food Science & Technology*, *71*, 107–120.

Cevallos-Cevallos, J. M., Danyluk, M. D., & Reyes-De-Corcuera, J. I. (2011). GC-MS based metabolomics for rapid simultaneous detection of *Escherichia coli* O157:H7, *Salmonella typhimurium*, *Salmonella muenchen*, and *Salmonella Hartford* in ground beef and chicken. *Journal of Food Science*, *76*, 238–246.

Chibane, L. B., Degraeve, P., Ferhout, H., Bouajila, J., & Oulahal, N. (2019). Plant antimicrobial polyphenols as potential natural food preservatives. *Journal of the Science of Food and Agriculture*, *99*, 1457–1474.

Choi, K. H., Lee, H., Lee, S., Kim, S., & Yoon, Y. (2016). Cheese microbial risk assessments - A review. *Asian-Australasian Journal of Animal Sciences*, *29*, 307–314.

Domínguez, R., Pateiro, M., Gagaoua, M., Barba, F. J., Zhang, W., & Lorenzo, J. M. A. (2019). Comprehensive review on lipid oxidation in meat and meat products. *Antioxidants*, *8*, 1–31.

Drake, S. L., Carunchia-Whetstine, M. E., Drake, M. A., Courtney, P., Fligner, K., Jenkins, J., & Pruitt, C. (2007). Sources of umami taste in Cheddar and Swiss cheeses. *Journal of Food Science*, *72*, S360–S366.

Fang, J., Feng, L., Lu, H., & Zhu, J. (2022). Metabolomics reveals spoilage characteristics and interaction of *Pseudomonas lundensis* and *Brochothrix thermosphacta* in refrigerated beef. *Food Research International*, *156*, 111139.

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 meatballs. *Meat Science*, *69*, 371–380.

Freitas, R., Brito, M. A. V. P., Nero, L. A., & de Carvalho, A. F. (2013). Microbiological safety of minas frescal cheese (MFC) and tracking the contamination of *Escherichia coli* and *Staphylococcus aureus* in MFC processing. *Foodborne Pathogens and Disease*, *10*, 951–955.

Hough, G., Puglieso, M. L., Sanchez, R., & Da Silva, O. M. (1999). Sensory and microbiological shelf-life of a commercial Ricotta cheese. *Journal of Dairy Science*, *82*, 454–459.

Kim, H. J., Kim, D., Kim, H. J., Song, S. O., Song, Y. H., & Jang, A. (2018). Evaluation of the microbiological status of raw beef in Korea: Considering the suitability of aerobic plate count guidelines. *Korean Journal for Food Science of Animal Resources*, *38*, 43–51.

Kim, K., Lee, H., Gwak, E., & Yoon, Y. (2014). Kinetic behavior of *Escherichia coli* on various cheeses under constant and dynamic temperature. *Asian-Australasian Journal of Animal Sciences*, *27*, 1013–1018.

Kirby, C. W., Wu, T., Tsao, R., & McCallum, J. L. (2013). Isolation and structural characterization of unusual pyranoanthocyanins and related anthocyanins from staghorn sumac (*Rhus typhina* L.) via UPLC–ESI-MS, 1H, 13C, and 2D NMR spectroscopy. *Phytochemistry*, *94*, 284–293.

Kossah, R., Zhang, H., & Chen, W. (2011). Antimicrobial and antioxidant activities of Chinese sumac (*Rhus typhina* L.) fruit extract. *Food Control*, *22*, 128–132.

Mahajan, D., Bhat, Z. F., & Kumar, S. (2016). Pine needles (*Cedrus deodara* (Roxb.) Loud.) extract as a novel preservative in cheese. *Food Packaging and Shelf Life*, *7*, 20–25.

MFHPB-18. (2015). *Determination of the aerobic colony counts in Foods. In The compendium of analytical methods, volume 2*. Health Products and Food Branch of Health Canada.

Ombarak, R. A., Hinenoya, A., Awasthi, S. P., Iguchi, A., Shima, A., Elbagory, A. R. M., & Yamasaki, S. (2016). Prevalence and pathogenic potential of *Escherichia coli* isolates from raw milk

and raw milk cheese in Egypt. *International Journal of Food Microbiology*, *221*, 69–76.

Papastergiadis, A., Mubiru, E., Van Langenhove, H., & De Meulenaer, B. (2012). Malondialdehyde measurement in oxidized foods: Evaluation of the spectrophotometric thiobarbituric acid reactive substances (TBARS) test in various foods. *Journal of Agricultural and Food Chemistry*, *60*, 9589–9594.

Pattison, T. L., Lindsay, D., & Von Holy, A. (2003). *In vitro* growth response of bread-spoilage *Bacillus* strains to selected natural antimicrobials. *Journal of Basic Microbiology*, *43*, 341–347.

Peng, Y., Zhang, H., Liu, R., Mine, Y., McCallum, J., Kirby, C., & Tsao, R. (2016). Antioxidant and anti-inflammatory activities of pyranoanthocyanins and other polyphenols from staghorn sumac (*Rhus hirta* L.) in Caco-2 cell models. *Journal of Functional Foods*, *20*, 139–147.

Proestos, C., Chorianopoulos, N., Nychas, G. J. E., & Komaitis, M. (2005). RP-HPLC analysis of the phenolic compounds of plant extracts. Investigation of their antioxidant capacity and antimicrobial activity. *Journal of Agricultural and Food Chemistry*, *53*, 1190–1195.

Puligundla, P. & Lim, S. (2022). Biocontrol approaches against *Escherichia coli* O157:H7 in foods. *Foods*, *11*, 756.

Reitznerová, A., Šuleková, M., Nagy, J., Marcinčák, S., Semjon, B., Čertík, M., & Klempová, T. (2017). Lipid peroxidation process in meat and meat products: A comparison study of malondialdehyde determination between modified 2-thiobarbituric acid spectrophotometric method and reverse-phase high-performance liquid chromatography. *Molecules*, *22*, 1988.

Revilla, E., Ryan, J. M., & Martín-Ortega, G. (1998). Comparison of several procedures used for the extraction of anthocyanins from red grapes. *Journal of Agricultural and Food Chemistry*, *46*, 4592–4597.

Riddet, W., Whitehead, H. R., Robertson, P. S., & Harkness, W. L. (1961). Fat oxidation in cheddar cheese. *Journal of Dairy Research*, *28*, 139–149.

Del Rio, D., Rodriguez-Mateos, A., Spencer, J. P. E., Tognolini, M., Borges, G., & Crozier, A. (2013). Dietary (poly) phenolics in human health: Structures, bioavailability, and evidence of protective effects against chronic diseases. *Antioxidants & Redox Signaling*, *18*, 1818–1892.

Robbins, K., Jensen, J., Ryan, K. J., Homco-Ryan, C., McKeith, F. K., & Brewer, M. S. (2003). Consumer attitudes towards beef and acceptability of enhanced beef. *Meat Science*, *65*, 721–729.

Safarov, J. (2020). Comparative evaluation of phenolic and antioxidant properties of red and white quinoa (*Chenopodum qunoa* Willd.) seeds. *Journal Raw Materials to Processed Foods*, *1*, 28–33.

Sagdic, O., Ozturk, I., Yilmaz, M. T., & Yetim, H. (2011). Effect of grape pomace extracts obtained from different grape varieties on microbial quality of beef patty. *Journal of Food Science*, *76*, M515–M521.

Santiago-López, L., Aguilar-Toalá, J. E., Hernández-Mendoza, A., Vallejo-Cordoba, B., Liceaga, A. M., & González-Córdova, A. F. (2018). Bioactive compounds produced during cheese ripening and health effects associated with aged cheese consumption. *Journal of Dairy Science*, *101*, 3742–3757.

Santos, D., Monteiro, M. J., Voss, H.-P., Komora, N., Teixeira, P., & Pintado, M. (2021). The most important attributes of beef sensory quality and production variables that can affect it: A review. *Livestock Science*, *250*, 104573.

Schilling, M. W., Yoon, Y., Tokarskyy, O., Pham, A. J., Williams, R. C., & Marshall, D. L. (2009). Effects of ionizing irradiation and hydrostatic pressure on *Escherichia coli* O157:H7 inactivation, chemical composition and sensory acceptability of ground beef patties. *Meat Science*, *81*, 705–710.

Scott-Bullard, B. R., Geornaras, I., Delmore, R. J., Woerner, D. R., Reagan, J. O., Morgan, J. B., & Belk, K. E. (2017). Efficacy of a blend of sulfuric acid and sodium sulfate against shiga toxin-producing *Escherichia coli, Salmonella*, and nonpathogenic *Escherichia coli* biotype I on inoculated prerigor beef surface tissue. *Journal of Food Protection*, *80*, 1987–1992.

Shan, B., Cai, Y.-Z., Brooks, J. D., & Corke, H. (2009). Antibacterial and antioxidant effects of five spice and herb extracts as natural preservatives of raw pork. *Journal of the Science of Food and Agriculture*, *89*, 1879–1885.

Shan, B., Cai, Y. Z., Brooks, J. D., & Corke, H. (2011). Potential application of spice and herb extracts as natural preservatives in cheese. *Journal of Medicinal Food*, *14*, 284–290.

Singh, T. K., Drake, M. A., & Cadwallader, K. R. (2003). Flavor of cheddar cheese: A chemical and sensory perspective. *Comprehensive Reviews in Food Science and Food Safety*, *2*, 166–189.

Slinkard, K. & Singleton, V. L. (1977). Total phenol analysis: Automation and comparison with manual methods. *American Journal of Enology and Viticulture*, *28*, 49–55.

Tapp, W., Nathan, Y., Janeal, W. S., Apple, J. K., Dikeman, M. E., & Godbee, R. G. (2012). Noni puree (*Morinda citrifolia)* mixed in beef patties enhanced color stability. *Meat Science*, *91*, 131–136.

Turgut, S. S., Soyer, A., & Işıkçı, F. (2016). Effect of pomegranate peel extract on lipid and protein oxidation in beef meatballs during refrigerated storage. *Meat Science*, *116*, 126–132.

Uhart, M., Maks, N., & Ravishankar, S. (2006). Effect of spices on growth and survival of *Salmonella typhimurium* DT 104 in ground beef stored at 4 and 8°C. *Journal of Food Safety*, *26*, 115–125.

Valerio, F., Skandamis, P. N., Failla, S., Contò, M., Di Biase, M., Bavaro, A. R., Pirovano, M. P., & Lavermicocca, P. (2020). Microbiological and physicochemical parameters for predicting quality of fat and low-fat raw ground beef during refrigerated aerobic storage. *Journal of Food Science*, *85*, 465–476.

Vandal, J., Abou-Zaid, M. M., Ferroni, G., & Leduc, L. G. (2015). Antimicrobial activity of natural products from the flora of Northern Ontario, Canada. *Pharmaceutical Biology*, *53*, 800–806.

Vrdoljak, J., Dobranić, V., Filipović, I., & Zdolec, N. (2016). Microbiological quality of soft, semi-hard and hard cheeses during the shelf-life. *Macedonian Veterinary Review*, *39*, 59–64.

Wang, S., & Zhu, F. (2017). Chemical composition and biological activity of staghorn sumac (*Rhus typhina)*. *Food Chemistry*, *237*, 431–443.

Wang, S., & Zhu, F. (2018). Quality attributes of bread fortified with staghorn sumac extract. *Journal of Texture Studies*, *49*, 129–134.

Wu, T., McCallum, J. L., Wang, S., Liu, R., Zhu, H., & Tsao, R. (2013). Evaluation of antioxidant activities and chemical characterisation of staghorn sumac fruit (*Rhus hirta* L.). *Food Chemistry*, *138*, 1333–1340.

Yadolahi-Baghloei, M., Pajohi-Alamoti, M., & Bazargani-Gilani, B. (2017). Behavior of *Staphylococcus aureus* affected by sumac water extract *in vitro* and koobideh kebab. *Journal of Food Processing and Preservation*, *41*, e13078.

Zhang, X., Li, D., Meng, Q., He, C., & Ren, L. (2016). Effect of mulberry leaf extracts on color, lipid oxidation, antioxidant enzyme activities and oxidative breakdown products of raw ground beef during refrigerated storage. *Journal of Food Quality*, *39*, 159–170.

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