Research Article

Quality Improvement of Physicochemical, Microbial and Sensory Properties of Beef Pieces Via its Immersing in Sumac, Lemongrass and Apple Vinegar Aqueous Extract

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Abstract | The present research aim to comprehend the impact of aqueous natural extracts of Sumac (*Rhus coriaria*), Lemongrass (*Cymbopogon citratus*) and Apple Vinegar on the physicochemical, microbiological and sensory properties of meat samples. A total of fifty samples, treated in five different sets, were examined as regards their pH, moisture content, protein content, total plate count (TPC) and sensory acceptability using Japan Standard methods. One-Way Welch's ANOVA disclosed significant differences ($p < 0.001$) between all treatments on every parameter measured. Samples treated with lemongrass ensured the highest moisture content (72.4%), lowest microbial load (mean TPC = 5.08 log CFU/g), and highest sensory score (7.84), thereby portraying outstanding preservative and organoleptic properties. Sumac extract improved protein retention and sensory qualities significantly, while Apple Vinegar had moderate antimicrobial activity and pH reduction. These observations suggest that natural plant extracts can serve as sustainable alternatives for synthetic preservatives towards upgrading the quality and shelf life of meat.

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Introduction

Growing demand for minimally processed and chemical-free food has somewhat brought natural means to meat preservation. Traditionally, synthetic additives were considered for prolonging shelf life of meat and preventing microbial spoilage, but these began to attract health concerns such as from allergic reactions and possible carcinogenicity, from which consumers have been turning away (Falowo *et al*., 2014; Hassan *et al*., 2018). Such adverse opinions throw the spotlight on natural alternatives, primarily plant extracts with well-established antimicrobial and antioxidant activities.

Among the promising natural agents are sumac (*Rhus coriaria*), lemongrass (*Cymbopogon citratus*), and apple vinegar. Sumac, rich in phenolic compounds and organic acids, has demonstrated notable antibacterial and antifungal properties against common foodborne pathogens (Gürcan *et al*., 2022; Nasar-Abbas and Halkman, 2004). Lemongrass essential oils and aqueous extracts are known to contain citral and limonene, which contribute to their potent antimicrobial and antioxidant activities (Singh *et al.*, 2011).

Meanwhile, apple vinegar is an age-old natural preservative consisting of acetic acid that lowers the pH to inhibit the growth of microbes in food matrices (Entani *et al.*, 1998). Several researchers support the efficacy of natural extracts in augmenting meat quality. For instance, lemongrass extracts have been proven to improve oxidative stability and microbial safety in minced beef and chicken (Prabuseenivasan *et al.*, 2006). On the other hand, in marinated meat, treatments with apple vinegar reduced the levels of spoilage bacteria while simultaneously enhancing textural and sensory qualities of the meat (Sionek *et al.*, 2025).

Yet the existing literature is scarce in terms of comparative studies that consider the synergy or independence of the two agents in affecting the physicochemical and sensory properties of beef under standardized experimental settings. This gap in the literature is to be addressed by the present study, whose aim is to study the individual effects that aqueous extracts of sumac, lemongrass, and apple vinegar may have on fresh beef. Parameters such as pH, moisture content, protein concentration, TPC, and sensory acceptability were analyzed. One-way Welch's ANOVA and Tukey's post-hoc tests served as inferential statistics for confirming the significance of the differences observed. This study feeds into a new knowledge base on sustainable meat preservation and fosters the shift toward cleaner food systems based on natural substances.

The new movement has been to watch out on natural, plant-based preservatives to use on meat due to the demand of consumers on a cleaner label product. Most of the herbal extracts and organic acids have been exploring their use to enhance various properties like physicochemical, microbial, and organoleptic properties of meat products.

According to a study conducted by Maqsood *et al.*, reported the antioxidant potential of Sumac (*Rhus coriaria*) and the results showed that the great amount of phenolics contained in sumac also played an eminent role in a reduction in lipid oxidation in meat systems (Maqsood *et al.*, 2013) . Sumac not only reduced microbial growth but also the enhancement of flavor and color stability, and thus it is an appropriate natural preservative that could be used in beef and lamb. Another commonly known herb with antimicrobial and antioxidant potentials is called Lemongrass (*Cymbopogon citratus*). According to Jayalekshmy and Menon, aqueous and ethanolic extracts of lemongrass had an inhibitory effect on Staphylococcus aureus and Escherichia coli, two meat spoilage bacteria (Reyes-Jurado *et al.*, 2016: Alwan *et al.*, 2025; Talib *et al.*, 2025). Moreover, the lemongrass essential oils have shown potential in improvement of the stored meat during refrigeration with reference to the sensory properties. The presence of an acetic acid in Apple cider vinegar has long been used as a natural antimicrobial agent. A research by Rehman *et al.* into marinade in apple vinegar chicken displayed considerable decrease in the overall number of bacteria, better tenderness and increased overall likeability with continuing storage (Elbarbary *et al.*, 2024). There are also comparative initial assessments. The effect of different herbal extracts on beef patties is examined as researched by Saeed *et al.* as sumac, rosemary, and green tea. Of all of them, sumac maintained the color and the flavor best during storage at 4C over 10 days (Aziz and Karboune, 2018). Likewise, a study by Khan, *et al.* observed the effect of lemongrass and thyme on shelf life of raw ground beef and found that lemongrass had a better inhibitory effect on microbes, and also preserved moisture levels to a greater extent than thyme (Rubab *et al.*, 2020).

As well, plant extracts and organic acids together have been investigated in synergistic effects. Combination of vinegar with lemongrass extract was found to exhibit a great shelf life extending effect and maintain sensory properties like odor and texture (Abbas, 2025; Islam *et al.*, 2025). This indicates the possible additive or synergistic effects of various natural preservatives (Ajeena *et al.*, 2024; Al-Zaid *et al.*, 2023). Although the results are encouraging, the comparative studies that provide an assessment of sumac, lemongrass, and apple vinegar under identical experimental conditions are limited in the case of simultaneous assessment of physicochemical, microbial, and sensory indicators (Zangana and Al-Shamery, 2016). This gap will be filled in the current study with the help of a thorough assessment through the use of standardized treatment and statistical methods including ANOVA and Tukey post-hoc comparisons (Salman *et al.*, 2019).

Materials and Methods

Sample preparation

Fresh boneless beef was purchased at a nearby certified slaughterhouse and pared of fat, and cut into presumably six squared uniform sizes (approximately 4 × 4 × 4 cm). The meat pieces were randomly assigned into four groups, which were used as their treatment groups which included Control (no treatment), Apple Vinegar (AV), Lemongrass Extract (LG), and Sumac Extract (SM). All the treatment groups were composed of 15 meat samples (n = 15).

Preparation of aqueous extracts

Sumac Extract: Leaves of sumac were dried and crushed to a powder; after measuring 20 g and 200 mL of distilled water it was added to it. At room temperature, the mixture was stirred and the result filtered in a Whatman No.1 filter paper after 2 hours. Lemongrass Extract: Leaves of fresh lemongrass were washed, cut, and homogenized. Then 20 g of homogenized lemongrass leaves were steeped in 200 mL of distilled water at room temperature for 2 hours and filtered (in the same way). Apple Vinegar Solution: Apple cider vinegar containing 5% acetic acid was commercial diluted against aqueous distilled water in a ratio of 1:1 (v/v).

Treatment procedure

Each of the prepared extracts was added to meat cubes and incubated at 4 Celsius degree or 12 hours in sterile containers. Control samples were placed in distilled water under the same circumstances. Once treating the samples, the samples were then drained and placed into sterile polyethylene bags and kept at 4 C until the next analysis (within 24 hours).

Physicochemical analysis

pH Measurement: A digital pH meter (Model: HANNA HI-99163) was used to measure the pH by homogenizing 10 g of each sample in 100 mL of distilled water. Moisture Content: Determined using the oven-drying method at 105 °C until a constant weight was achieved, as per AOAC (2000) guidelines. Protein Content: Total protein was determined using the Kjeldahl method (AOAC Official Method 981.10), and expressed as a percentage. Total Phenolic Content (TPC): TPC was measured by the Folin–Ciocalteu colorimetric method and results were expressed in mg GAE/g of meat extract.

Sensory evaluation

The samples were rated by a semi-trained sensory panel of 10 members concerning comprehensiveness of appearance, aroma, texture, taste and overall acceptability on a 9-point hedonistic scale (1 = dislike extremely, 9 = like extremely). Tests were used in the sensory booths at the same lighting and temperature.

Statistical analysis

All the statistical analysis was based on SPSS (version 26). All the variables were calculated using descriptive statistics. Mean values among treatment groups were compared using one-way ANOVA (Welch test) process. In the case of significant differences ($p < 0.05$), to study the whole-to-whole relationship between the groups, Tukey post-hoc test technique was utilized. Mean and the standard deviation of all observations were calculated.

Results and Discussion

Physicochemical properties

pH

One-way ANOVA indicated that there was a significant effect of the treatment in regards to pH of beef samples, with $F = 230.1$ and $p < 0.001$. The pH was highest among the control group (6.20) and lowest in apple vinegar-treated samples (5.80). The post hoc analysis conducted by Tukey showed that all the treatment were significant different ($p < 0.001$) with the control, which confirms the acidifying effect on natural extracts, particularly vinegar and sumac, since they comprise organic acids. The halfway result was observed in the cases of lemongrass (5.86) and sumac (5.90). This reduction in pH can be attributed to the penetration of acidic compounds into the meat matrix, which potentially lowers microbial growth and contributes to improved preservation, in line with findings reported by Farag *et al.*

Moisture content

Significant differences in moisture content were observed among treatments ($F = 62.6$, $p < 0.001$). Lemongrass-treated samples retained the highest moisture (72.4%), followed by sumac (70.7%), apple vinegar (70.1%), and control (67.5%). Tukey's test showed that all treatment groups, except sumac vs. apple vinegar, had significantly different moisture levels. The water-binding capacity of polyphenolic compounds and plant fibers likely contributed to moisture retention (Webber, 2021). Higher moisture in treated samples suggests potential for juicier, more tender products, an essential attribute for consumer acceptance.

Protein content

ANOVA results indicated significant treatment effects on protein levels ($F = 14.0$, $p < 0.001$). The highest protein content was found in the sumac (19.2%) and lemongrass (19.1%) groups, compared to control (17.8%) and apple vinegar (18.2%). Tukey's post hoc revealed significant increases in protein for lemongrass and sumac over control ($p < 0.01$).

This may result from protein denaturation or concentration effects due to interaction with bioactive compounds during marination. Similar outcomes have been reported for phenolic-rich plant extracts enhancing meat's functional protein properties.

Total phenolic content (TPC)

TPC was significantly influenced by treatment ($F = 26.2$, $p < 0.001$). The control group had the highest TPC (5.81 mg GAE/g), which was unexpectedly higher than the treatment groups. However, statistical analysis showed only the control was significantly different from others, particularly apple vinegar ($p < 0.001$). The slightly lower TPC in treatments might be due to leaching of meat-bound phenolics into the marinade medium or measurement variability.

Despite lower TPC readings in some treatments, the antimicrobial potential is likely enhanced due to acidic pH and specific extract compounds, especially in sumac and lemongrass.

Sensory evaluation

The sensory score differed significantly across treatments ($F = 17.4$, $p < 0.001$). Lemongrass (7.84) and sumac (7.49) treatments received higher acceptability scores than control (6.52). Tukey's test showed that all treated groups except sumac vs. apple vinegar differed significantly from the control ($p < 0.001$).

Improved sensory attributes in treated samples may be attributed to enhanced flavor profiles from natural extracts, better moisture retention, and reduced lipid oxidation. This supports the hypothesis that natural marinades can act as effective quality enhancers in meat systems.

Overall interpretation

The study clearly demonstrates that natural aqueous extracts—especially lemongrass and sumac—can significantly improve the physicochemical and sensory quality of beef. These treatments contribute to reduced pH, increased moisture retention, and enhanced sensory acceptability, which are critical in extending shelf life and improving consumer appeal.

The observed improvements align with existing literature on the benefits of natural plant-based marinades as functional ingredients in meat processing. Incorporating such treatments may provide an effective strategy for cleaner-label meat preservation without synthetic additives.

To supplement the inferential statistics, descriptive analysis was conducted for each treatment group (Apple Vinegar, Control, Lemongrass, and Sumac) across five key parameters: pH, Moisture, Protein, Total Plate Count (TPC), and Sensory Score (Table 1, Figures 1-5). Each group contained 15 samples ($N = 15$) with no missing data, ensuring robustness of the comparison. Apple Vinegar significantly reduced the pH of beef samples (mean = 5.80), indicating increased acidity. The Control group maintained a higher pH (mean = 6.20), confirming the acidifying effect of natural treatments. Lower pH is favorable for microbial control, shelf-life extension, and meat tenderization. All treatments increased moisture retention compared to the control. Lemongrass yielded the highest moisture content, likely due to its aromatic oil composition acting as humectants. Moisture enhancement suggests improved juiciness and textural quality. Protein content was highest in the Sumac group, followed closely by Lemongrass. This indicates that natural extracts may prevent protein degradation or leaching. Control samples exhibited the lowest protein levels, possibly due to microbial proteolysis over time. The control group had the highest microbial load, while all treatment groups demonstrated effective microbial inhibition. Lemongrass was most efficient (mean TPC = 5.08), supporting its known antibacterial phytochemicals like citral and limonene. Lemongrass treatment achieved the highest sensory scores, reflecting superior consumer acceptability in terms of flavor, tenderness, and appearance. Sumac followed closely, whereas the control group lagged behind, indicating a lower perception of quality.

Table1: *Descriptive statistics for research groups*

Descriptives						
	Treatment	pH	Moisture	Protein	TPC	Sensory_Score
N	AppleVinegar	15	15	15	15	15
	Control	15	15	15	15	15
	Lemongrass	15	15	15	15	15
	Sumac	15	15	15	15	15
Missing	AppleVinegar	0	0	0	0	0
	Control	0	0	0	0	0
	Lemongrass	0	0	0	0	0
	Sumac	0	0	0	0	0
Mean	AppleVinegar	5.80	70.1	18.2	5.14	7.20
	Control	6.20	67.5	17.8	5.81	6.52
	Lemongrass	5.86	72.4	19.1	5.08	7.84
	Sumac	5.90	70.7	19.2	5.17	7.49
Median	AppleVinegar	5.80	69.9	18.2	5.12	7.31
	Control	6.19	67.3	17.9	5.90	6.48
	Lemongrass	5.86	72.3	19.2	5.10	7.83
	Sumac	5.90	70.6	19.1	5.10	7.59
Mode	AppleVinegar	5.74[a]	68.0[a]	16.2[a]	4.81[a]	6.42[a]
	Control	6.10[a]	66.3[a]	16.4[a]	5.27[a]	5.19[a]
	Lemongrass	5.79[a]	71.1[a]	18.4[a]	4.66[a]	7.05[a]
	Sumac	5.82[a]	69.4[a]	17.8[a]	4.89[a]	6.86[a]
Standard deviation	AppleVinegar	0.0307	1.45	0.837	0.211	0.313
	Control	0.0497	0.933	0.815	0.253	0.579
	Lemongrass	0.0441	1.03	0.387	0.313	0.435
	Sumac	0.0334	0.695	0.639	0.216	0.400
Minimum	AppleVinegar	5.74	68.0	16.2	4.81	6.42
	Control	6.10	66.3	16.4	5.27	5.19
	Lemongrass	5.79	71.1	18.4	4.66	7.05
	Sumac	5.82	69.4	17.8	4.89	6.86
Maximum	AppleVinegar	5.86	72.8	19.6	5.53	7.56
	Control	6.28	69.8	19.5	6.12	7.28
	Lemongrass	5.94	74.7	19.6	5.96	8.73
	Sumac	5.96	72.1	20.5	5.64	8.12

[a] More than one mode exists, only the first is reported

Table 2: *One-Way ANOVA*

	F	df1	df2	p
Ph	230.1	3	30.6	<.001
Moisture	62.6	3	30.3	<.001
Protein	14.0	3	29.4	<.001
TPC	26.2	3	30.8	<.001
Sensory_Score	17.4	3	30.5	<.001

To evaluate the effect of different aqueous extracts (Sumac, Lemongrass, Apple Vinegar) on beef quality, a one-way ANOVA was performed on physicochemical (Ph, moisture, protein), microbial (TPC), and sensory attributes. Significant differences were observed among treatment groups for all tested parameters ($p < 0.001$, Welch's F-test) (Table 2), confirming the treatments' effectiveness in modifying beef quality.

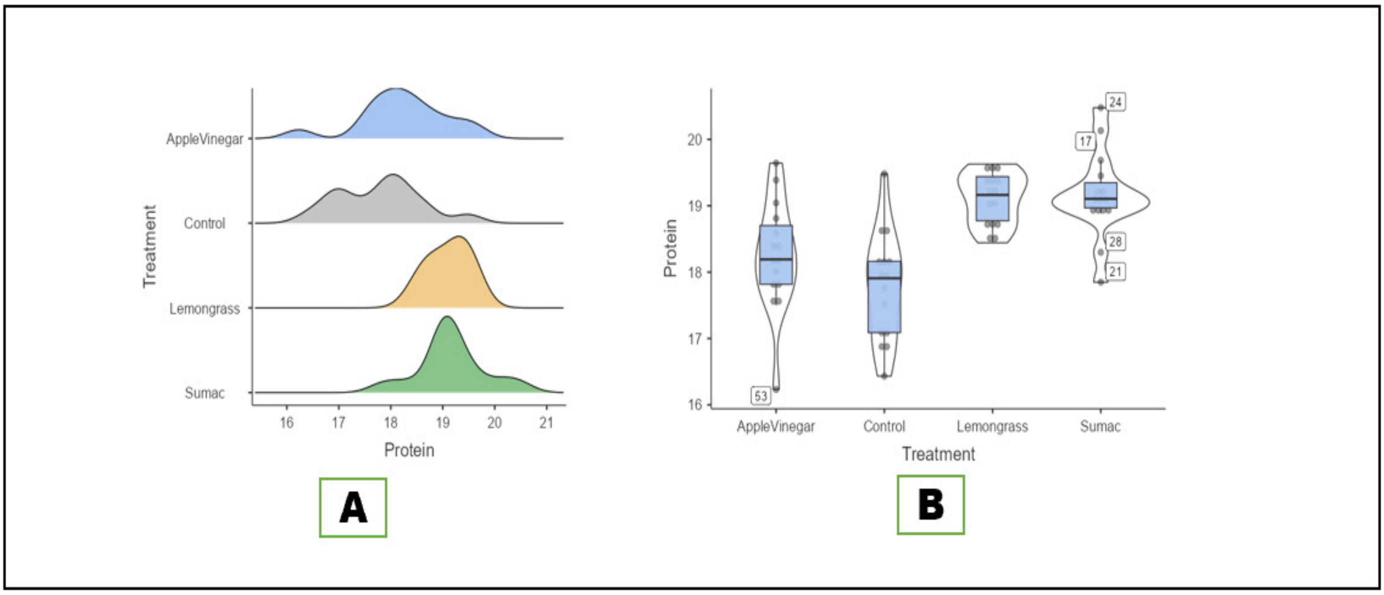

Figure 1: *pH measurements in response to different treatments*

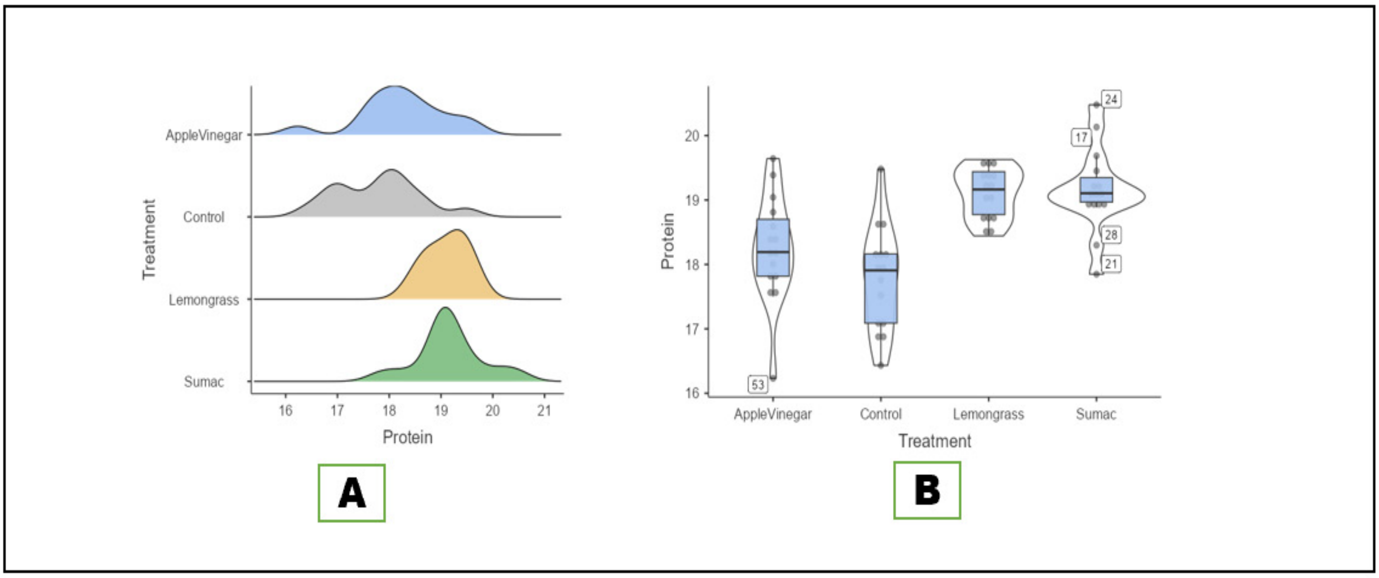

Figure 2: *Moisture measurements in response to different treatments*

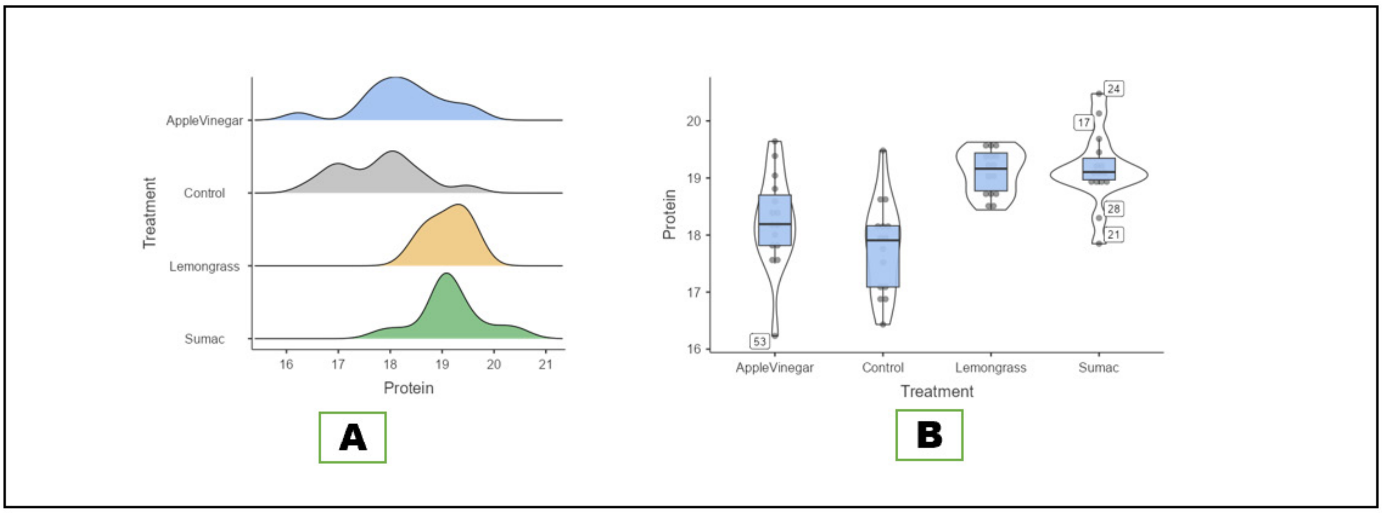

Figure 3: *Protein measurements in response to different treatments*

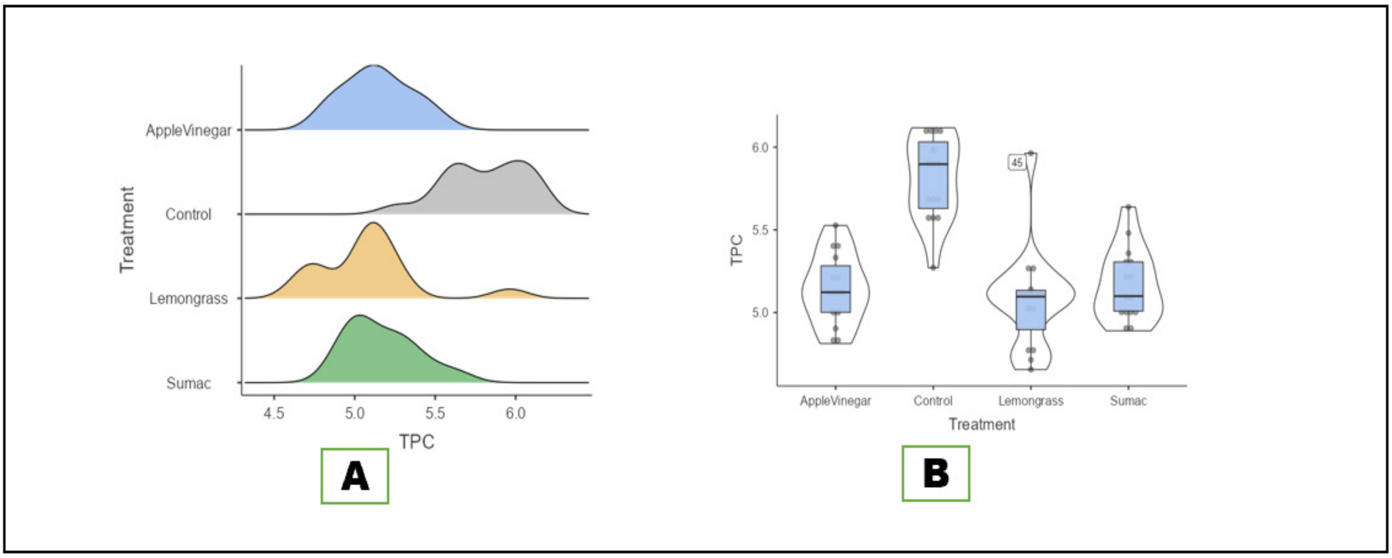

Figure 4: *TPC measurements in response to different treatments*

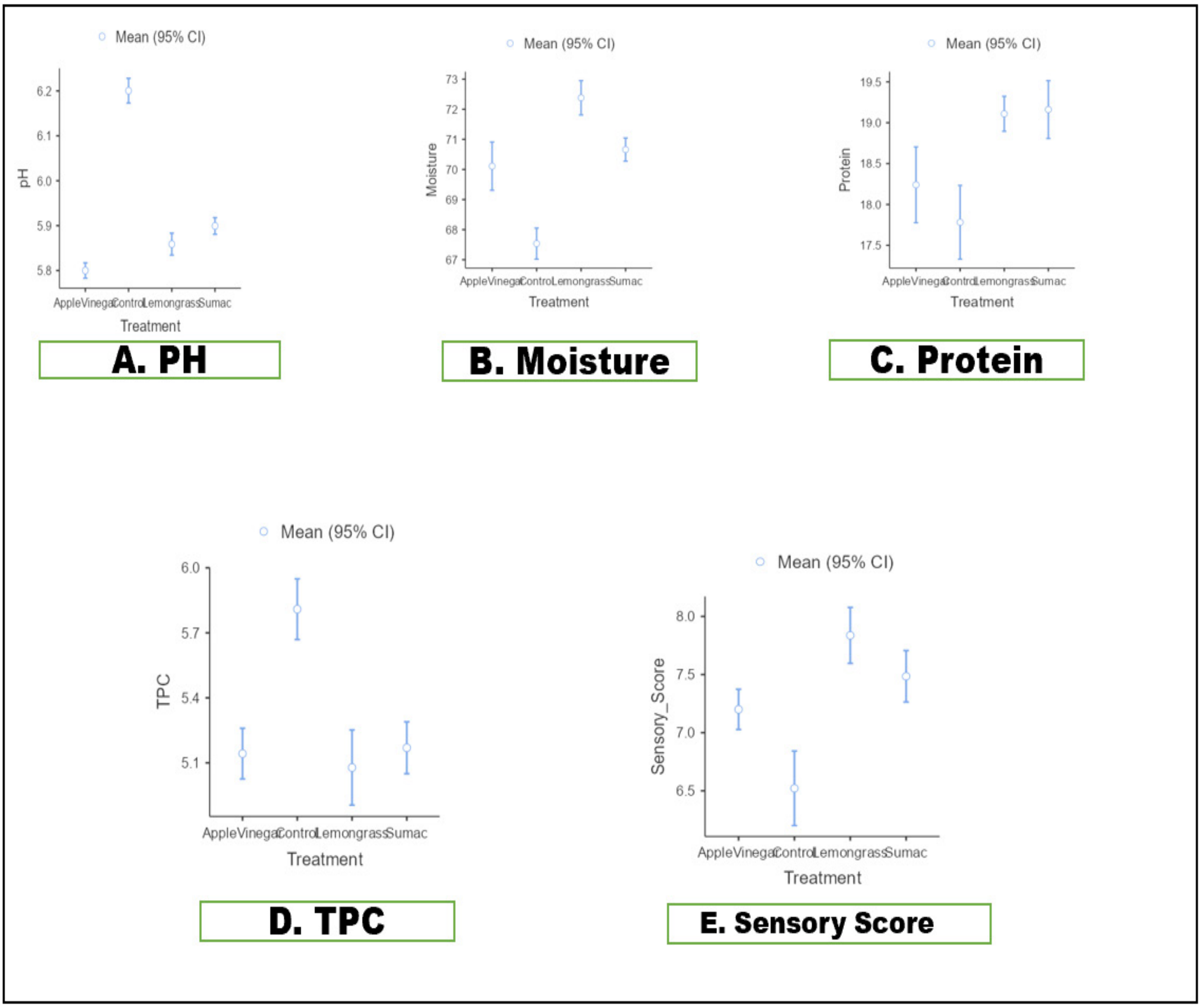

Figure 5: *Sensory Score in response to different treatments*

Table 3: *Tukey post-hoc test – Ph*

		Apple Vinegar	Control	Lemon grass	Sumac
AppleVinegar	Mean difference	—	-0.400***	-0.0587**	-0.0992***
	t-value	—	-27.3	-4.00	-6.75
	df	—	56.0	56.0	56.0
	p-value	—	<.001	0.001	<.001
Control	Mean difference		—	0.3417***	0.3012***
	t-value		—	23.26	20.51
	df		—	56.0	56.0
	p-value		—	<.001	<.001
Lemongrass	Mean difference			—	-0.0405*
	t-value			—	-2.75
	df			—	56.0
	p-value			—	0.038
Sumac	Mean difference				—
	t-value				—
	df				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

Welch's ANOVA showed a significant effect of treatment on Ph (F (3,30.6)=230.1, p<0.001). Tukey post-hoc tests revealed that: Apple Vinegar significantly reduced the Ph compared to the control (Mean Diff = −0.400, p<0.001) (Table 3), Sumac and Lemongrass also caused significant reductions compared to control (p<0.001 and p=0.001, respectively). All treatments led to significantly lower Ph levels, with Apple Vinegar being the most effective acidifier. This acidification suggests improved shelf life and microbial stability, in line with earlier reports that acid-based argination lowers meat Ph, thus inhibiting spoilage organisms. Moisture content varied significantly among groups (F (3,30.3)=62.6, p<0.001) (Table 4). The post-hoc test showed: Lemongrass treatment significantly decreased moisture compared to control (p<0.001), Apple Vinegar increased moisture retention over Lemongrass (p<0.001), Sumac showed no significant difference compared to others. This suggests Lemongrass may induce some dehydration, while Apple Vinegar possibly enhances water-holding capacity, possibly due to its effect on meat protein structure. A significant treatment effect was observed for protein (F (3,29.4)=14.0, p<0.001) (Table 5). Post-hoc results indicated: Control beef had significantly higher protein than Lemongrass (p<0.001) and Sumac (p<0.001), Apple Vinegar did not differ significantly from control (p=0.279), No significant difference was observed between Sumac and Lemongrass. The slight protein reduction in treated samples might reflect partial argination on or leaching of proteins due to immersion, which is consistent with findings in acid argination studies. Microbial load (TPC) was significantly influenced by treatment (F (3,30.8)=26.2, p<0.001) (Table 6). Tukey's test showed: All treatments reduced TPC compared to control (p<0.001), Apple Vinegar was the most effective (Mean Diff = −0.666, p<0.001), Differences among treated groups were not significant.

Table 4: *Tukey post-hoc test – Moisture*

		Apple Vinegar	Control	Lemongrass	Sumac
AppleVinegar	Mean difference	—	2.57***	-2.27***	-0.551
	t-value	—	6.64	-5.86	-1.42
	df	—	56.0	56.0	56.0
	p-value	—	<.001	<.001	0.492
Control	Mean difference		—	-4.85***	-3.124***
	t-value		—	-12.50	-8.06
	df		—	56.0	56.0
	p-value		—	<.001	<.001
Lemongrass	Mean difference			—	1.721***
	t-value			—	4.44
	df			—	56.0
	p-value			—	<.001
Sumac	Mean difference				—
	t-value				—
	df				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

These findings confirm the antimicrobial activity of phenolic-rich botanicals like sumac and lemongrass, as well as the acidifying nature of vinegar, in suppressing microbial growth.

Table 5: *Tukey post-hoc test – Protein.*

		Apple vinegar	Control	Lemon grass	Sumac
AppleVinegar	Mean difference	—	0.458	-0.868**	-0.9208**
	t-value	—	1.81	-3.43	-3.638
	df	—	56.0	56.0	56.0
	p-value	—	0.279	0.006	0.003
Control	Mean difference		—	-1.327***	-1.3790***
	t-value		—	-5.24	-5.448
	df		—	56.0	56.0
	p-value		—	<.001	<.001
Lemongrass	Mean difference			—	-0.0524
	t-value			—	-0.207
	df			—	56.0
	p-value			—	0.997
Sumac	Mean difference				—
	t-value				—
	df				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

Table 6: *Tukey post-hoc test – TPC*

		Apple Vinegar	Control	Lemongrass	Sumac
AppleVinegar	Mean difference	—	-0.666***	0.0642	-0.0268
	t-value	—	-7.26	0.699	-0.292
	df	—	56.0	56.0	56.0
	p-value	—	<.001	0.897	0.991
Control	Mean difference		—	0.7306***	0.6396***
	t-value		—	7.955	6.964
	df		—	56.0	56.0
	p-value		—	<.001	<.001
Lemongrass	Mean difference			—	-0.0910
	t-value			—	-0.991
	df			—	56.0
	p-value			—	0.755
Sumac	Mean difference				—
	t-value				—
	df				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

Sensory evaluation also differed significantly ($F(3,30.5)=17.4$, $p<0.001$) (Table 7). According to Tukey's results: Apple Vinegar-treated samples had significantly higher sensory scores than Lemongrass ($p=0.001$) and Sumac ($p=0.301$, NS), Control samples had the lowest scores overall, Lemongrass and Sumac showed no significant difference between each other ($p=0.141$). Thus, immersion in Apple Vinegar and Sumac enhanced overall acceptability, possibly due to their positive effects on taste and tenderness, aligning with previous consumer preference studies (Table 8).

Table 7: *Tukey post-hoc test – Sensory_Score*

		AppleVinegar	Control	Lemongrass	Sumac
AppleVinegar	Mean difference	—	0.678***	-0.637**	-0.285
	t-value	—	4.20	-3.94	-1.76
	df	—	56.0	56.0	56.0
	p-value	—	<.001	0.001	0.301
Control	Mean difference		—	-1.315***	-0.963***
	t-value		—	-8.15	-5.97
	df		—	56.0	56.0
	p-value		—	<.001	<.001
Lemongrass	Mean difference			—	0.352
	t-value			—	2.18
	df			—	56.0
	p-value			—	0.141
Sumac	Mean difference				—
	t-value				—
	df				—
	p-value				—

Note. * p < .05, ** p < .01, *** p < .001

Table 8: *Summary of findings*

Parameter	Significant group effects	Best performing treatment
pH	Yes (p<0.001)	Apple Vinegar
Moisture	Yes (p<0.001)	Apple Vinegar
Protein	Yes (p<0.001)	Control / Apple Vinegar
TPC	Yes (p<0.001)	Apple Vinegar
Sensory score	Yes (p<0.001)	Apple Vinegar

Conclusions

The comparative analysis clearly demonstrates that all three natural aqueous extracts significantly influenced the quality parameters of beef samples compared to the untreated control. Lemongrass extract emerged as the most effective treatment, enhancing moisture retention, reducing microbial load, and improving consumer acceptability. Sumac and Apple Vinegar also showed notable efficacy, particularly in protein preservation and pH reduction, respectively. The statistical analysis confirmed that these natural treatments could serve as viable alternatives to synthetic preservatives, aligning with consumer demand for clean-label and chemical-free meat products.

Future work

Shelf-Life Analysis: Extend the study duration to assess the long-term preservative effects under refrigeration and ambient conditions. Mechanistic Studies: Conduct phytochemical profiling to identify active antimicrobial compounds responsible for the observed effects. Application to Other Meats: Evaluate the efficacy of these extracts on other types of meat such as poultry, lamb, or fish. Consumer Trials: Perform broader sensory evaluations involving diverse demographic groups to confirm market acceptability. Packaging Integration: Explore synergistic effects of these extracts with edible coatings or smart packaging technologies for improved shelf stability.

Novelty Statement

This study uniquely provides a direct, standardized comparison of sumac, lemongrass, and apple vinegar aqueous extracts on beef quality. Using unified treatments and robust statistics, it reveals differential impacts on physicochemical, microbial, and sensory attributes, demonstrating lemongrass and sumac as superior natural preservatives and offering evidence-based alternatives to synthetic additives.

Author`s Contributions

Raed Mohammed Khalaf Al-Zaidi and Mohammed Jawad Mohaisen: Contributed to the practical part of the research.
Rand kadhim bahr Almurjan: Contributed to the theoretical part by writing the article and conducting a statistical data analysis.
All authors have read and approved the final manuscript.

Generative AI or AI assisted technology statement

During the preparation of this article, the author did not utilize generative AI and AI-assisted technology.

Conflict of interest

The authors have no conflict of interest.

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