





# Spoilage Dynamics, Microbial Ecology, and Comparative Antimicrobial Efficacy of Selected Spice Extracts against Foodborne Isolates from Meat and Tomato

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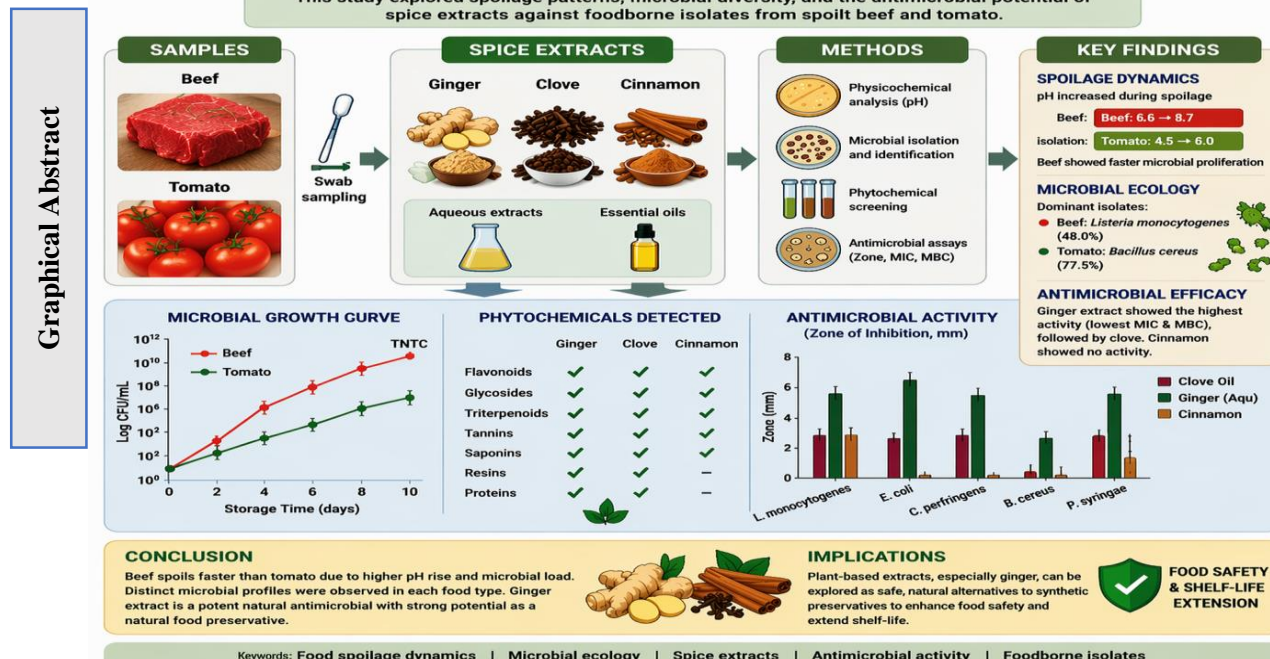
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Abstract	Article History
<p>Food spoilage remains a major challenge affecting food safety, quality, and shelf-life, particularly in perishable products such as meat and fresh produce. This study comparatively evaluated spoilage dynamics, microbial ecology, and the antimicrobial efficacy of selected spice extracts (ginger, clove, and cinnamon) against foodborne pathogens isolated from spoiled beef and tomato samples. Physicochemical analysis revealed a significant increase (<math>p &lt; 0.05</math>) in pH during spoilage, with beef showing a greater shift (<math>6.6 \pm 0.10</math> to <math>8.7 \pm 0.15</math>) than tomato (<math>4.5 \pm 0.08</math> to <math>6.0 \pm 0.12</math>). Microbial growth patterns indicated rapid proliferation in beef, reaching too numerous to count (TNTC) levels earlier than in tomato. Microbial identification showed the dominance of <i>Listeria monocytogenes</i> (48.0%) in beef, while <i>Bacillus cereus</i> (77.5%) predominated in tomato samples. Phytochemical screening confirmed the presence of bioactive compounds, including flavonoids, glycosides, and triterpenoids, in all plant extracts. Antimicrobial assays demonstrated that ginger extract exhibited the highest inhibitory activity, with the lowest minimum inhibitory concentration (MIC) (<math>0.50 \pm 0.02</math> mg/mL) against multiple isolates, while clove showed moderate activity and cinnamon showed no observable effect. These findings highlight the strong potential of ginger as a natural antimicrobial agent for food preservation. The study provides valuable insights into spoilage mechanisms and supports the application of plant-based preservatives as sustainable alternatives to synthetic additives to enhance food safety and shelf life.</p>	<p>Received: 08 Mar 2026 Accepted: 20 Apr 2026 Published: 02 May 2026</p>  <p>Scan QR code to view*</p> <p>License: CC BY 4.0*</p>  <p>Open Access article.</p>
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## Spoilage Dynamics, Microbial Ecology, and Comparative Antimicrobial Efficacy of Selected Spice Extracts Against Foodborne Isolates from Meat and Tomato

This study explored spoilage patterns, microbial diversity, and the antimicrobial potential of spice extracts against foodborne isolates from spoiled beef and tomato.



## Introduction

Food spoilage remains a critical global challenge affecting food safety, quality, and economic sustainability. According to the United Nations (UN), approximately one-third of food produced globally is lost or wasted, with a significant portion attributed to microbial spoilage (UN 2025; Karanth *et al.*, 2023). Microorganisms are the primary agents responsible for food deterioration, as they metabolize nutrients and produce undesirable compounds that negatively affect sensory attributes such as color, texture, odor, and taste (Mafe *et al.*, 2024; Cao *et al.*, 2023). These changes not only reduce consumer acceptability but also pose potential health risks.

Among perishable foods, meat products are particularly susceptible to rapid spoilage due to their high moisture content, near-neutral pH, and rich nutrient composition, which favour microbial proliferation. Spoilage in meat involves complex biochemical processes, including proteolysis and lipolysis, leading to the production of volatile compounds such as ammonia, amines, aldehydes, and sulfur-containing metabolites (Kang *et al.*, 2026). These compounds are responsible for the characteristic off-odors and textural degradation observed in spoiled meat. Furthermore, meat spoilage is closely associated with the growth of pathogenic microorganisms, making it a significant public health concern (Martín-Miguélez *et al.*, 2025).

In contrast, plant-based foods such as tomatoes generally exhibit slower spoilage rates due to their lower protein content and higher levels of organic acids and naturally occurring antimicrobial compounds. However, they remain vulnerable to contamination by environmental microorganisms, particularly soil-associated and spore-forming bacteria such as *Bacillus* spp. and *Pseudomonas* spp. (Rabasco-Vílchez *et al.*, 2025). The composition and dominance of microbial communities in foods are influenced by intrinsic factors such as pH, water activity, and nutrient availability, as well as extrinsic factors including storage conditions and handling practices (Hosseini *et al.*, 2024).

Changes in pH serve as an important indicator of spoilage progression. In meat systems, pH typically increases during storage due to the accumulation of alkaline metabolites resulting from microbial degradation of proteins (Wang *et al.*, 2022). This rise in pH further enhances microbial growth, accelerating spoilage. Similarly, in plant-based foods, pH changes occur due to the breakdown of organic acids, although these changes are generally less pronounced compared to animal-based foods (Storz *et al.*, 2022).

In recent years, there has been growing interest in the use of natural plant-derived compounds as alternatives to synthetic preservatives due to increasing consumer demand for clean-label and safer food products. Spices such as clove (*Syzygium aromaticum*), ginger (*Zingiber officinale*), and cinnamon (*Cinnamomum verum*) are rich in bioactive phytochemicals, including phenolics, flavonoids, tannins, and terpenoids, which have demonstrated significant antimicrobial properties (Khatri

*et al.*, 2023; Otunola, 2022). These compounds exert antimicrobial effects through mechanisms such as disruption of microbial cell membranes, inhibition of enzyme activity, and interference with genetic material (Tariq *et al.*, 2025).

Despite numerous studies on food spoilage and natural antimicrobials, there is limited comparative research that integrates spoilage dynamics, microbial ecology, and the antimicrobial efficacy of plant extracts across both animal and plant food systems. Understanding these interactions is essential for developing effective and sustainable food preservation strategies.

Therefore, this study aims to investigate the spoilage characteristics of beef and tomato by evaluating changes in physicochemical properties, microbial growth dynamics, and microbial diversity. Additionally, the study examines the phytochemical composition and antimicrobial efficacy of selected spice extracts (clove, ginger, and cinnamon) against isolated foodborne pathogens. This integrated approach provides valuable insights into the potential application of natural preservatives in enhancing food safety and extending shelf life.

## Materials and Methods

### Sample Collection

Fresh spices (clove (*Syzygium aromaticum*), ginger (*Zingiber officinale*) and cinnamon (*Cinnamomum verum*)) were purchased from a local market in Enugu, Nigeria. The samples were transported to the laboratory in sterile polyethylene bags and processed immediately. The selection of these plant materials was based on documented evidence of their antimicrobial properties and their availability within the study area.

Similarly, fresh beef and tomatoes were obtained from a local market in Enugu East, Nigeria. Samples were transported under hygienic conditions and stored at refrigeration temperature (4 °C) prior to analysis.

### pH and Sensory Evaluation

pH analysis of the fresh samples was measured using standard methods. Sensory evaluation of the fresh beef and tomato samples was conducted using a 9-point hedonic scale (1 = strongly dislike; 9 = greatly like) as described by (Okafor *et al.* 2024). 20 semi-trained panelists evaluated the samples. Scores of 5 or above were considered acceptable for all sensory attributes evaluated. The same procedures were evaluated after spoilage. The spoilage stage and time were established from preliminary studies.

### Preparation and Extraction of Plant Materials

#### Aqueous Extraction

The spices were washed, air-dried, and ground into fine powders. Twenty grams (20 g) of each powdered sample was soaked in 180 mL of distilled water in a conical flask and allowed to stand for 48 h with intermittent stirring. The mixtures were filtered using cheesecloth, and the filtrates were

concentrated using a water bath at 80 °C to obtain crude extracts. The extracts were stored in sterile amber bottles at 4 °C until use (Gonelimali *et al.*, 2018).

### Steam Distillation of Essential Oils

Essential oils were extracted using the steam distillation method. Forty grams (40 g) of each powdered spice was placed in a round-bottom flask containing distilled water. The mixture was heated to boiling (100 °C), allowing steam to pass through the plant material and extract volatile compounds. The vapour was condensed, and the oil layer was separated from the aqueous phase based on density differences using a separating funnel (Machado *et al.*, 2022). The extracted oils were stored in airtight containers at 4 °C.

### Phytochemical Analysis

Phytochemical screening of the plant extracts was conducted to detect the presence of bioactive compounds such as flavonoids, glycosides, tannins, saponins, and triterpenoids using standard qualitative methods. These phytochemicals are known to contribute to the antimicrobial properties of plant extracts (Dubale *et al.*, 2023).

### Microbiological Analysis

#### Sample Preparation and pH Determination

For pH determination, 10 g of each sample (beef and tomato) was homogenized in 100 mL of sterile distilled water. The mixture was shaken thoroughly, and the pH was measured using a calibrated pH meter.

#### Isolation and Enumeration of Microorganisms

Microbial samples were collected from beef and tomato surfaces using sterile swab sticks. The swabs were inoculated onto nutrient agar plates using the streak plate method. Plates were incubated at 37 °C for 24 h to allow microbial growth. Microbial load was determined using standard plate count techniques and expressed as colony-forming units (CFU/g). Serial dilutions were prepared, and appropriate dilutions were plated to obtain countable colonies (Itaman and Nwachukwu, 2021).

#### Subculturing and Stock Culture Preparation

Distinct colonies were subcultured onto fresh nutrient and MacConkey agar plates to obtain pure isolates. Stock cultures were prepared by inoculating isolates onto MacConkey agar slants and incubating at 37 °C. The cultures were stored at 4 °C for further analysis (Fowoyo and Baba-Ali, 2015).

#### Frequency Distribution of Isolates

The frequency distribution of microorganisms was determined by counting the total number of isolates and calculating the proportion of each organism using the formula:

$$\text{Frequency (\%)} = \frac{\text{Frequency of organisms}}{\text{Total number of organisms}} \times 100$$

### Identification of Microorganisms

#### Gram Staining

Gram staining was performed using standard procedures. Smears were prepared, heat-fixed, and stained sequentially with crystal violet, Gram's iodine, acetone, and safranin. The stained slides were observed under a microscope to determine Gram reaction (Taiwo *et al.*, 2018).

#### Spore Staining

Spore staining was carried out using malachite green. Heat was applied to facilitate stain penetration, followed by counterstaining to differentiate spores from vegetative cells.

#### Biochemical Tests

The isolates were further characterized using standard biochemical tests:

**Catalase test:** Detection of bubble formation upon addition of hydrogen peroxide (Amanullah *et al.*, 2020).

**Oxidase test:** Identification based on color change using oxidase reagent (Ohaegbu *et al.*, 2022).

**Coagulase test:** Determination of clot formation using plasma (Taiwo *et al.*, 2018).

**Indole test:** Detection of indole production using Kovac's reagent (Ohaegbu *et al.*, 2022).

#### Antimicrobial Susceptibility Testing

##### Agar Well Diffusion Method

Antimicrobial activity of plant extracts was evaluated using the agar well diffusion method. Sterile nutrient agar plates were inoculated with test organisms. Wells were created in the agar, and different extracts were added to them. Plates were incubated at 37 °C for 24–48 h, after which zones of inhibition were measured (Atef *et al.*, 2019).

##### Determination of Minimum Inhibitory Concentration (MIC)

The MIC was determined using serial dilution techniques. Different concentrations of plant extracts were prepared and inoculated with standardized microbial suspensions in nutrient broth. After incubation at 37 °C for 18–24 h, the MIC was recorded as the lowest concentration that inhibited visible growth (Nagalakshmi *et al.*, 2019).

##### Determination of Minimum Bactericidal Concentration (MBC)

The MBC was determined by subculturing from MIC tubes onto fresh agar plates. The lowest concentration of extract that showed no bacterial growth after incubation was recorded as the MBC (Nagalakshmi *et al.*, 2019).

#### Statistical Analysis

All experiments were conducted in triplicate, and results are expressed as mean ± standard deviation. Statistical analysis was performed using one-way ANOVA followed by Tukey's post hoc test at  $p < 0.05$

## Results

### Physicochemical and Sensory Properties of Food Samples

The physicochemical and sensory properties of fresh and spoiled beef with tomato samples are presented in Table 1. A significant increase ( $p < 0.05$ ) in pH was observed in both food

samples following spoilage. Beef showed a marked rise in pH from  $6.6 \pm 0.10$  to  $8.7 \pm 0.15$ , while tomato increased from  $4.5 \pm 0.08$  to  $6.0 \pm 0.12$ . The higher pH observed in spoiled beef was significantly different from that of tomato, indicating more pronounced biochemical deterioration in the animal-based sample.

**Table 1:** Physicochemical and Sensory Properties of Fresh and Spoilt Food Samples

Sample	Fresh		Spoilt				Overall Acceptability
	pH	Color	Appearance	Texture	Scent		
Beef	$6.6 \pm 0.10^b$	$8.7 \pm 0.15^a$	$3.25 \pm 0.12^b$	$2.45 \pm 0.10^b$	$2.90 \pm 0.14^a$	$2.21 \pm 0.09^b$	$2.70 \pm 0.11^b$
Tomato	$4.5 \pm 0.08^c$	$6.0 \pm 0.12^b$	$4.90 \pm 0.15^a$	$3.74 \pm 0.13^a$	$2.45 \pm 0.11^b$	$2.02 \pm 0.08^b$	$3.27 \pm 0.14^a$

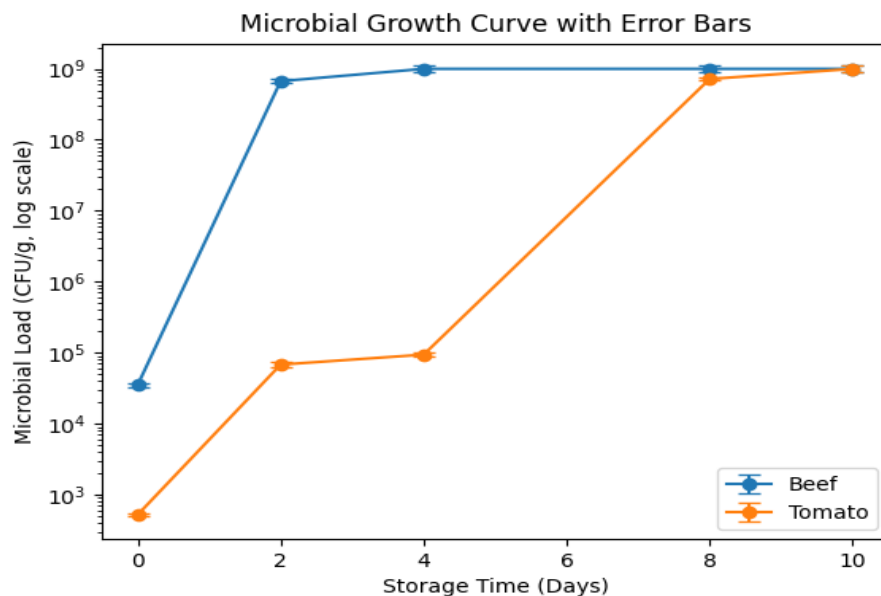
Values are mean  $\pm$  SD. Different superscripts within a column indicate significant differences ( $p < 0.05$ ).

Sensory evaluation revealed significant differences ( $p < 0.05$ ) between samples across most attributes. The sensory values for the fresh samples all recorded mean values of 8.5, as the samples were at their peak freshness. However, significant variations were observed for the spoiled samples. Tomato samples recorded higher scores in color ( $4.90 \pm 0.15$ ), appearance ( $3.74 \pm 0.13$ ), and overall acceptability ( $3.27 \pm 0.14$ ) compared to beef, suggesting better visual and general quality retention. In contrast, beef exhibited relatively higher texture scores ( $2.90 \pm 0.14$ ), although its overall acceptability

remained low. Both samples showed similarly low scent scores, indicating advanced spoilage. These results demonstrate that spoilage significantly reduces sensory quality, with more severe deterioration observed in beef.

### Microbial Growth Dynamics

The microbial growth patterns of beef and tomato samples during storage are illustrated in Figure 1. Both samples exhibited a progressive increase in microbial load over time; however, the rate of proliferation differed significantly.



**Figure 1:** Log-scale microbial growth curve of beef and tomato samples during storage with error bars representing standard deviation ( $\pm$  SD). Beef exhibited significantly faster microbial proliferation compared to tomato, reaching TNTC levels earlier.

Beef samples showed rapid microbial growth, reaching too numerous to count (TNTC) levels earlier than tomato. In contrast, tomato samples exhibited a slower growth pattern, with a delayed transition to high microbial loads. The log-scale representation further highlights the exponential nature of microbial proliferation, with beef entering the exponential growth phase earlier than tomato. This trend indicates that beef is more susceptible to rapid microbial colonization and

spoilage compared to tomato, likely due to its higher nutrient availability.

### Identification and Distribution of Microorganisms

The biochemical characteristics and frequency distribution of isolated microorganisms are presented in Table 2. The isolates comprised both Gram-positive and Gram-negative bacteria, with varying biochemical profiles.

**Table 2:** Identification and Frequency Distribution of Isolated Microorganisms

Organism	Gram	Spore	Catalase	Oxidase	Indole	Meat (%)	Tomato (%)
<i>Listeria monocytogenes</i>	+	-	+	-	-	48.0 <sup>a</sup>	-
<i>Escherichia coli</i>	-	-	+	-	+	24.0 <sup>b</sup>	-
<i>Clostridium perfringens</i>	+	+	-	-	-	28.0 <sup>b</sup>	-
<i>Bacillus cereus</i>	+	+	+	+	-	-	77.5 <sup>a</sup>
<i>Pseudomonas syringae</i>	-	-	+	-	-	-	22.5 <sup>b</sup>

Percentages represent frequency distribution. Different superscripts indicate significant differences ( $p < 0.05$ ). Qualitative analysis (+ = present, - = absent)

In beef samples, *Listeria monocytogenes* was the most predominant organism, with a significantly higher occurrence (48.0%,  $p < 0.05$ ) compared to *Escherichia coli* (24.0%) and *Clostridium perfringens* (28.0%). In contrast, tomato samples were dominated by *Bacillus cereus* (77.5%,  $p < 0.05$ ), followed by *Pseudomonas syringae* (22.5%).

The distribution pattern indicates a clear variation in microbial ecology between the two food types, with meat favouring pathogenic enteric and anaerobic bacteria, while plant-based

samples were dominated by environmental and spore-forming organisms.

### Phytochemical Composition of Plant Extracts

The phytochemical composition of clove, ginger, and cinnamon extracts is shown in Table 3. All spice extracts contained glycosides, flavonoids, proteins, resins, and triterpenoids, suggesting the presence of bioactive compounds with potential antimicrobial properties.

**Table 3:** Phytochemical Composition of Plant Extracts

Phytochemical	Clove	Ginger	Cinnamon
Alkaloids	-	-	-
Glycosides	+	+	+
Carbohydrates	-	-	-
Flavonoids	+	+	+
Proteins	+	+	+
Tannins	+	-	+
Resins	+	+	+
Saponins	+	-	-
Triterpenoids	+	+	+
Steroids	-	-	-
Starch	-	-	-

Qualitative analysis (+ = present, - = absent).

Clove and cinnamon uniquely contained tannins, whereas ginger lacked tannins and saponins but still retained other phytochemicals such as flavonoids and triterpenoids. The absence of alkaloids, steroids, carbohydrates, and starch was consistent across all samples.

These results indicate that while the extracts share several common phytochemicals, specific differences in composition may influence their antimicrobial efficacy.

### Antimicrobial Activity of Plant Extracts

The antimicrobial activity of the plant extracts, including zones of inhibition, minimum inhibitory concentration (MIC), and minimum bactericidal concentration (MBC), is presented in Table 4.

**Table 4:** Antimicrobial Activity of Plant Extracts showing the Zone of Inhibition (mm), MIC and MBC (mg/mL)

Organisms	Cloves				Ginger				Cinnamon			
	Oil	Aqu-eous	MIC	MBC	Oil	Aqu-eous	MIC	MBC	Oil	Aqu-eous	MIC	MBC
<i>Listeria monocytogenes</i>	3.4 ± 0.2	-	2.0 ± 0.1	4.0 ± 0.2	2.1 ± 0.1	-	0.50 ± 0.02	2.8 ± 0.1	-	-	-	-
<i>Escherichia coli</i>	2.0 ± 0.1	-	2.0 ± 0.1	6.8 ± 0.3	6.3 ± 0.3	5.6 ± 0.2	0.50 ± 0.02	4.3 ± 0.2	-	-	-	-
<i>Clostridium perfringens</i>	3.4 ± 0.2	-	2.0 ± 0.1	4.0 ± 0.2	1.0 ± 0.1	-	0.50 ± 0.02	2.0 ± 0.1	-	-	-	-
<i>Bacillus cereus</i>	1.5 ± 0.1	-	1.0 ± 0.05	3.2 ± 0.2	-	2.0 ± 0.2	-	-	-	-	-	-
<i>Pseudomonas syringae</i>	3.0 ± 0.2	-	1.0 ± 0.05	3.0 ± 0.1	-	2.5 ± 0.2	-	-	-	-	-	-

- indicates absence of antimicrobial activity or no observable inhibition under the tested conditions.

Ginger extracts exhibited the strongest antimicrobial activity across most test organisms. Ginger essential oil showed the highest inhibition against *Escherichia coli* ( $6.3 \pm 0.3$  mm) and the lowest MIC values ( $0.50 \pm 0.02$  mg/mL) against *Listeria monocytogenes*, *Escherichia coli*, and *Clostridium perfringens*, indicating high potency.

Clove extracts showed moderate antimicrobial activity, with inhibition zones ranging from  $1.5 \pm 0.1$  mm to  $3.4 \pm 0.2$  mm and higher MIC and MBC values compared to ginger, suggesting lower effectiveness.

Cinnamon extracts showed no observable antimicrobial activity against all tested organisms.

Among the isolates, *Escherichia coli* was the most susceptible organism, particularly to ginger extracts, while *Clostridium perfringens* and *Listeria monocytogenes* showed moderate sensitivity. *Bacillus cereus* and *Pseudomonas syringae* exhibited selective susceptibility depending on the extract type. Overall, the antimicrobial results indicate that ginger possesses superior inhibitory and bactericidal properties compared to clove and cinnamon.

## Discussion

### pH Changes and Spoilage Mechanisms

The significant increase in pH observed in both beef and tomato samples during spoilage reflects active microbial metabolism and biochemical degradation processes. The more pronounced alkaline shift in beef (pH 8.7) compared to tomato (pH 6.0) is consistent with protein-rich food systems, where microbial proteolysis leads to the production of ammonia, amines, and other basic compounds. This phenomenon has been widely reported in spoilage studies, where protein degradation results in alkaline metabolites that elevate pH levels (Kuang *et al.*, 2025; Hwang *et al.*, 2022).

Additionally, the rise in pH in meat products has been linked to the accumulation of nitrogenous compounds during microbial activity, which serves as a key indicator of spoilage progression and reduced food quality (Kang *et al.*, 2026). In contrast, tomatoes, which are naturally acidic, exhibited a less pronounced pH increase due to the breakdown of organic acids and slower microbial metabolism. These findings confirm that food composition plays a critical role in determining spoilage pathways and pH dynamics.

### Microbial Growth Dynamics and Shelf-Life Implications

The microbial growth curve demonstrated a rapid proliferation of microorganisms in beef compared to tomato, with beef reaching TNTC levels earlier. This aligns with previous reports that nutrient-rich foods, particularly those high in proteins and moisture, provide a favourable environment for rapid microbial colonization and growth (Dhiman *et al.*, 2025).

The exponential growth pattern observed in both samples follows classical microbial kinetics, where microorganisms transition from lag to exponential phases under favorable

conditions. The delayed growth in tomato can be attributed to its lower pH and presence of natural antimicrobial compounds, which can inhibit or slow microbial activity (Venkatachalam *et al.*, 2024).

These findings highlight the shorter shelf-life of animal-based foods compared to plant-based foods and emphasize the importance of preservation strategies to control microbial proliferation.

### Microbial Ecology and Food Safety Implications

The microbial profile revealed distinct differences between beef and tomato samples, reflecting the influence of food matrix on microbial ecology. The dominance of *Listeria monocytogenes* in beef is of particular concern due to its pathogenic nature and ability to survive under a wide range of environmental conditions, including refrigeration (Manyi-Loh and Lues, 2025). Similarly, the presence of *Escherichia coli* indicates possible contamination from handling or environmental sources and is widely recognized as an indicator organism for food safety (Nowicki *et al.*, 2021).

In contrast, *Bacillus cereus* was the predominant organism in tomatoes, which is consistent with its ubiquitous presence in soil and its ability to form heat-resistant spores (McDowell and Friedman, 2023). The occurrence of *Pseudomonas syringae* further supports the role of environmental contamination in plant-based foods.

These findings agree with previous studies showing that nutrient composition, pH, and environmental exposure influence the type and prevalence of spoilage microorganisms in foods (Hosseini *et al.*, 2024). The high prevalence of these organisms highlights the potential risk of foodborne illnesses associated with improperly stored or handled foods.

### Phytochemical Composition and Functional Implications

The phytochemical analysis revealed the presence of bioactive compounds such as flavonoids, glycosides, and triterpenoids in all plant extracts. These compounds are known to exhibit antimicrobial activity through mechanisms such as disruption of microbial cell membranes, inhibition of enzymatic activity, and interference with genetic material (Khatri *et al.*, 2023).

Ginger lacked tannins yet demonstrated strong antimicrobial activity, suggesting that compounds such as flavonoids and phenolic constituents may play a more dominant role in microbial inhibition. This observation supports previous studies indicating that multiple phytochemicals act synergistically to enhance antimicrobial efficacy rather than relying on a single compound class (Tariq *et al.*, 2025).

### Antimicrobial Activity of the Spice Extracts

The antimicrobial results clearly demonstrated that ginger extract exhibited superior inhibitory activity compared to clove and cinnamon. The larger zones of inhibition and lower MIC and MBC values associated with ginger indicate higher potency and effectiveness against the tested microorganisms.

The strong antimicrobial activity of ginger has been attributed to bioactive compounds such as gingerol, shogaol, and other phenolic constituents, which have been shown to disrupt microbial cell membranes and inhibit cellular processes (Tariq *et al.*, 2025). The higher susceptibility of *Escherichia coli* observed in this study is consistent with previous findings that Gram-negative bacteria can be sensitive to certain plant-derived compounds depending on their mode of action (Nowicki *et al.*, 2021).

Clove exhibited moderate antimicrobial activity, likely due to the presence of antimicrobial agent with strong bactericidal properties (Tariq *et al.*, 2025). However, its higher MIC and MBC values indicate lower efficacy compared to ginger.

The absence of antimicrobial activity in cinnamon may be attributed to factors such as low concentration of active compounds or inefficiencies in the extraction method. Previous studies have shown that extraction technique and solvent type significantly influence the bioactivity of plant extracts (Zivković *et al.*, 2025).

These findings support the growing interest in natural plant-based preservatives as alternatives to synthetic additives, particularly in enhancing food safety and extending shelf-life.

## Conclusion

This study demonstrated that spoilage in beef and tomato samples is characterized by significant physicochemical changes, rapid microbial proliferation, and distinct microbial distribution patterns influenced by food composition. Beef exhibited faster spoilage and higher microbial growth compared to tomato, confirming its greater susceptibility due to its nutrient-rich nature. The dominance of pathogenic and spoilage organisms further emphasizes the public health risks associated with improper food handling and storage.

The study also established that selected spice extracts possess varying antimicrobial potentials, with ginger showing the highest efficacy against the tested microorganisms. The strong inhibitory activity of ginger, supported by its low MIC and MBC values, highlights its potential as an effective natural preservative.

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## Disclosure of conflict of interest

The authors declare no conflict of interest.

## Author contributions

Chidinma A. Okafor: conceptualization, methodology, analysis and interpretation of data, review & editing, Ruth E. Ugwu and Joshua M. Akwah: investigation and original draft.

## Data availability statement

Data will be made available on request.

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