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Evaluation of the Inhibitory Effectiveness of Some Citrus Peel Tannins on the Microbial and Chemical Content of Minced Beef During Cold Storage at 4°C

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Abstract: The present study aimed to evaluate the inhibitory efficiency of aqueous extract tannins from four types of citrus peels (orange, lemon, grapefruit, and bitter orange) at two concentrations (0.25% and 0.5%) in reducing bacterial counts and chemical changes in minced beef stored at 4°C for 10 days, compared to a control treatment. The results revealed a significant effect ($p < 0.05$) for all extracts, leading to a reduction in bacterial growth compared to the control group, which exhibited the highest bacterial load on day 10 (9.8 log CFU/g). The oxidative rancidity test revealed a significant increase that led to the spoilage of the control treatment due to severe oxidation, with the rancidity value reaching 2.90 \{mg MDA/kg\} on the tenth day, while the pH value rose to 8.25 by the same day as a result of protein degradation and the release of volatile nitrogenous compounds. The results demonstrated the significant superiority of orange peel extract at a 0.5% concentration as an antioxidant and antibacterial agent throughout the storage period; it recorded the lowest total bacterial count on the tenth day at 6.85 log/g and the lowest oxidative rancidity value, averaging 0.40 mg MDA/kg. Meanwhile, bitter orange peel extract at 0.5% exhibited high synergistic efficacy, particularly in stabilizing the medium's acidity and preventing meat alkalinity, achieving the lowest pH value of 5.55 on day ten. This effectiveness of the extracts especially orange and bitter orange is attributed to their high content of tannins and phenolic compounds, which function as natural free radical scavengers and metal ion chelators, in addition to their capacity to form stable complexes with proteins that inhibit bacterial degrading enzymes. The study concludes that citrus peel tannins (particularly orange and bitter orange) can be applied as safe, effective natural alternatives to synthetic preservatives, extending the shelf life of refrigerated meat and supporting environmental sustainability through the recycling of agricultural waste.

Keywords: Citrus Peel Tannins, Minced Beef, Microbial Content, pH, Oxidative Rancidity

Introduction

Beef meat possesses high nutritional value due to its rich composition of essential nutrients for the human body, as it contains a high moisture percentage in addition to proteins, vitamins, and amino acids. These components are considered an important nourishing source for many microorganisms, which in turn cause spoilage and chemical changes in meat components, especially

during refrigerated storage [1], [2]. Although refrigeration slows down biological processes, lipid oxidation and microbial activity represent the main challenges facing the meat industry, as they lead to significant changes in pH values, the emergence of undesirable odors due to oxidative rancidity, and alterations in natural color [3], [4]. For a long time, chemical preservatives were relied upon to limit these problems; however, modern trends and consumer health awareness have driven the search for safe, natural alternatives extracted from plant sources [5].

Agricultural crop residues, specifically citrus peels (orange, lemon, bitter orange, and grapefruit peels), hold great importance due to their active compounds, such as phenolic compounds, flavonoids, and tannins [6],[7], [8]. These are complex substances possessing antioxidant capacity that prevents microbial and chemical spoilage through complex mechanisms of action, including the inhibition of bacterial enzymes and the precipitation of bacterial membrane proteins, in addition to their role in lowering pH and preventing oxidative rancidity [6], [9], [10].

Utilizing these peels not only contributes to extending meat shelf life and preserving its quality, but also represents an important step toward environmental sustainability by reducing agricultural waste and transforming it into materials of economic and scientific value [11], [12].

Based on what has been presented, and despite the high efficiency of citrus peels—where previous studies focused on only one or two types—there still remains a significant research gap regarding their application in the meat industry, specifically concerning differences in the active substances for each citrus type and their reflection on the chemical composition and preservation of meats from microbial spoilage. This study aims to extract tannins from orange, lemon, grapefruit, and bitter orange peels, and to evaluate their preservative efficiency in cooled beef meat by monitoring changes in the total bacterial content and measuring the stability of pH values during the storage period.

Materials and Methods

Meat Sampling

Fresh beef samples slaughtered in systematic slaughterhouses were collected from local markets in Tikrit city, specifically from the thigh muscle. The samples were preserved in sterile polyethylene bags inside a refrigerated container at less than 4 °C and transferred to the laboratories of the Life Sciences department to perform laboratory examinations. After cooling the meat for two hours, surface fat and connective tissues were removed, and the meat was ground into equal pieces in a regular manner and preserved in polyethylene bags [13].

Preparation of Extracts

Mature citrus fruits were collected from local markets in Tikrit city. After that, citrus peels (orange, lemon, grapefruit, bitter orange) were prepared after isolating them from the fruits, washed well with distilled water, and dried in a drying oven with permanent ventilation at a heat of 40 °C for two days. After that, they were ground finely with an electrical grinding device and preserved in opaque containers at a heat of less than 0 °C.

Preparation and Extraction of Aqueous Tannins

Tannins were extracted from dried citrus peel powders using the modified aqueous extraction method described by Ahmed et al. [14]. A balanced quantity of peel powder was extracted in distilled water at a ratio of (1:10 weight/volume) and raised in a water bath at a temperature of 60 °C for 30 minutes. The mixture was filtered using filter paper (Whatman No. 1), then the filtrate was treated with a centrifuge device at a speed of 2000 rpm for 20 minutes to separate impurities and collect the clear liquid. The clear liquid was exposed to drying at a low temperature to obtain dried crude tannin extract, which was preserved in opaque containers at a temperature of -18 °C until its use in preparing meat treatments.

Preparation of Treatments and Their Storage

Minced beef was divided into distinct treatment groups based on the batch weight. The dry tannin extracts were incorporated directly into the minced meat at concentrations of 0.25% and 0.5% (w/w, dry extract weight relative to meat weight). To ensure uniform distribution, the required amount of extract for each concentration was dissolved in a minimal volume of sterile distilled water (2 mL per 100 g of meat) and thoroughly mixed/kneaded with the minced beef manually using sterile

gloves for 3 min. The control group received an equivalent volume of sterile distilled water without extract to maintain identical moisture conditions across all treatments. After homogeneous mixing, the meat was shaped into 25 g discs, wrapped individually in impermeable polyethylene film, and stored in a refrigerator at 4 °C for quality evaluations on days 0, 3, 7, and 10.

Microbial Examinations

To estimate total bacterial count, 1 g of meat was taken and mixed with 9 mL of sterile peptone water, and 10 serial dilutions were prepared to perform precise microbial examination. A 0.1 mL aliquot was taken, spread onto a poured Plate Count Agar (PCA) plate using a glass spreader, and kept in an incubator for 48 hours at a heat of 30 °C. The results were expressed in logarithm/g meat [15].

Measurement of pH Value

pH value was measured by weighing 10 g of refrigerated minced meat and mixing it with 9 mL of neutral distilled water. They were mixed homogeneously using a laboratory homogenizing device for one minute, and after that, the pH value was measured by a device calibrated with a buffer solution [16].

Thiobarbituric Acid (TBA)

A. Sample Preparation

5 grams of minced meat were weighed, transferred to a vessel special for the mixing device, and 20 mL of TCA acid solution with a concentration of 7.5% was added. The mixture was mixed at high speed for 1–2 minutes to ensure homogeneity and the extraction of the malondialdehyde compound (MDA).

B. Filtrate Separation Process

The mixture was taken to a centrifuge device at 3000 to 4000 revolutions per minute (rpm) for 10–15 minutes, and the mixture was filtered using filter paper (Whatman No. 1). The clear liquid (supernatant) was obtained, and the protein precipitate was discarded.

C. Chemical Reaction

A 5 mL aliquot of the supernatant was mixed with 5 mL of thiobarbituric acid reagent (TBA 0.02 M) in a glass test tube with a tight cap. The tubes were closed well and mixed, then placed in a boiling water bath (100 °C) for 35 to 40 minutes. During this period, TBA reacts with MDA to produce a pink/red colored compound. The tubes were removed and cooled immediately in an icy water bath or under cold tap water to stop the reaction.

D. Spectrophotometric Measurement

Absorbance of the pink solution was measured using a Spectrophotometer device at a wavelength of 532 nm. A blank solution containing TCA and TBA only (without meat sample) was used to zero the device. Results express the TBA value in the amount of (milligram malondialdehyde per kilogram of meat) [17]:

$$\text{TBA value} = \text{Absorbance at 532 nm} \times K$$

(Where $K = 7.8$, a calculation constant approved for measuring malondialdehyde).

Statistical Analysis

A completely randomized design (CRD) was used for a factorial experiment of two factors: the factor of extract type (control, orange peel tannins, lemon, bitter orange, grapefruit) and the storage period across 4 periods (0, 3, 7, 10 days). Data were analyzed using SAS software [18], and analysis of variance (ANOVA) and Duncan's multiple range test were performed [19] at a significance level of $p < 0.05$.

Results and Discussion

Microbial Content

Table 1 illustrates the interactive effects on the total bacterial count (log CFU/g) for beef meat treated with tannin extracts of orange peels, lemon peels, grapefruit peels, and bitter orange peels at two concentrations (0.25% and 0.5%) across different refrigerated storage periods. An ascending significant effect was observed for storage periods; on Day 10, a significant rise ($p < 0.05$) was noticed in the control treatment and all extract treatments compared with Day 3 and Day 7 of storage. This ascending gradation of bacterial numbers indicates that bacterial growth is continuous during

different preservation periods, and that the additions did not produce a bactericidal effect; however, citrus peel tannin extracts reduced microbial growth compared to the control treatment, in which spoilage occurred due to high bacterial growth density by Day 7.

When examining the comparative impact of different citrus peel tannin extracts compared to the control during the storage period, the control group (which was not treated with any extract) recorded the highest logarithmic values for microbial growth throughout the experiment periods, exhibiting significantly higher values ($p < 0.05$) designated by the letter "a", and reaching its highest growth on the 10th day with a logarithmic average of 9.80, which serves as a statistical indicator for microbial spoilage in meat.

Table 1. Interactive effect averages for total bacterial count ($\log$ CFU/g) of beef meat treated with tannin extracts of orange, lemon, grapefruit, and bitter orange peels at two concentrations (0.25% and 0.5%) during different refrigerated storage periods.

Extract and concentration	Day 0	Day 3	Day 7	Day 10
Control	5.95 ± 0.05 a C	6.44 ± 0.04 a B	9.42 ± 0.02 a A	9.80 ± 0.02 a A
Orange 0.25	5.35 ± 0.05 e D	5.81 ± 0.03 e C	6.65 ± 0.05 d B	6.92 ± 0.01 c A
Orange 0.5	5.44 ± 0.04 de D	5.72 ± 0.02 e C	6.54 ± 0.06 e B	6.85 ± 0.03 d A
Lemon 0.25	5.46 ± 0.06 de D	6.08 ± 0.00 bc C	6.80 ± 0.02 bc B	6.97 ± 0.01 bc A
Lemon 0.5	5.47 ± 0.01 d D	6.16 ± 0.03 b C	6.72 ± 0.02 cd B	6.86 ± 0.01 d A
Grapefruit 0.25	5.57 ± 0.03 c D	6.17 ± 0.05 b C	6.81 ± 0.03 b B	7.02 ± 0.02 b A
Grapefruit 0.5	5.65 ± 0.01 ab D	6.19 ± 0.05 b C	6.77 ± 0.03 bc B	6.96 ± 0.03 bc A
Bitter orange 0.25	5.62 ± 0.02 bc D	5.93 ± 0.03 d C	6.78 ± 0.05 bc B	6.94 ± 0.01 c A
Bitter orange 0.5	5.67 ± 0.01 a D	5.81 ± 0.03 e C	6.78 ± 0.03 bc B	6.86 ± 0.01 d A

Small letters show the presence of a significant difference in vertical direction at ($p < 0.05$).

Capital letters show the presence of significant differences in horizontal direction at ($p < 0.05$).

Assessing extract concentration dynamics reveals a direct relationship between extract concentration and microbial suppression (concentration 0.25 versus 0.5), results reveal the presence of a direct relationship with the effect of concentration. It is noticed regularly when comparing the two concentrations of the same extract in advanced days (seventh and 10) that the higher concentration (0.5) is always accompanied by lower microbial numbers compared with the low concentration (0.25). This scientific reason goes back to the fact that raising concentration guarantees an increasing density of tannins and active biochemical substances in the medium, which enhances the ability to curb cell division of microbes and delays their reproduction for the longest possible period.

On the 10th day, we find that orange extract with its high concentration of 0.5 recorded the highest significant inhibition, as it recorded the lowest value of microbial growth with an average amounting to 6.85 with significant letter (d), which confirms that orange extract possesses the strongest, most sustainable, and stable inhibitory ability against microbial reproduction in the long run.

These outcomes mirror observations by Ahmed and Abd Elhameed [20], as a rise in microbial growth was recorded on Day 7 of storage for the control treatment compared with extracts from citrus peels which reduced microbial growth by 83.9%.

Results also agreed with Abdel-Aziz et al. [11], as it showed that using orange peel extracts at a percentage of 4% reduced microbial growth during storage periods. Also, Mkaem et al. [21] observed that citrus peel extracts work on reducing microbial growth by percentages reaching up to 77% during cold preservation at 4 °C.

Similarly, Eze et al. [8] demonstrated in their study published about meat preservation using citrus peel extracts containing tannins, where their GC-MS analyses proved that orange peels contain the highest percentage of tannins reaching up to 77.1%, which gives them antimicrobial activity directly superior to the rest of the varieties; this is the precise scientific explanation for the appearance of orange in our table as the best inhibitory treatment throughout 10 days.

Furthermore, results agree with Umaraw et al. [22] and Yu et al. [10], where they showed that tannins extracted from bitter orange peels (*Citrus aurantium*) possess very strong properties giving them the ability to inhibit aerobic bacteria and extend the shelf life of cooled meats in a manner close to traditional chemical substances, which supports the efficiency of bitter orange in our research as a strong candidate in second place after orange.

Comparison with meat bio-coatings research indicates the results of food microbiology researchers Guerrero et al. [23] when studying tannin extracts on beef meat, that tannin extract is capable of reducing bacterial load and inhibiting Enterobacteriaceae families, but its overall efficiency in the long run is governed by fast volatile rates of acids; this explains in a precise way the reason for the appearance of lemon and grapefruit in our table with relatively higher bacterial growth rates on Day 10 compared with the stability of orange.

Changes in pH Value

Table 2 shows a difference in the level of interaction in pH values in minced beef meat samples treated with citrus peel tannin extracts at two concentrations (0.25% and 0.5%) during cold storage periods for 10 days.

The results show the presence of a clear significant interaction ($p < 0.05$) between the extract and its concentration and storage periods. Data in the table's horizontal direction (capital letters) indicate the presence of a significant ascending rise in pH values in all addition groups during preservation periods, as it recorded the highest significant level on the 10th day of preservation compared to day zero of storage. The reason for this slow ascending rise in addition treatments with plant extracts is the limited consumption of organic acids naturally concentrated in citrus peels, such as ascorbic and citric acid, while the control treatment showed a rapid significant rise in pH value, reaching 5.40 on day zero and rising significantly to 8.25 on the 10th day. This rise in pH value is attributed to rapid microbial growth, which consumes sugars rapidly and starts analyzing proteins and nitrogenous substances, leading to the release of ammonia gas and volatile amine compounds that raise the alkalinity of the meat, giving an indicator of meat spoilage.

Table 2. Interaction in pH value for beef meat treated with tannin extracts of orange peels, lemon peels, grapefruit peels, and bitter orange peels at two dilutions (0.25 and 0.5) for different cooling periods at 4 °C.

Extract and concentration	Day 0	Day 3	Day 7	Day 10
Control	5.40 ± 0.20 a D	5.85 ± 0.05 a C	6.94 ± 0.06 a B	8.25 ± 0.25 a A
Orange 0.25	5.05 ± 0.15 bc D	5.55 ± 0.05 b C	5.75 ± 0.05 b B	5.85 ± 0.05 b A
Orange 0.5	4.95 ± 0.25 cd D	5.20 ± 0.20 d C	5.50 ± 0.10 d B	5.75 ± 0.05 bc A
Lemon 0.25	4.90 ± 0.10 cd D	5.40 ± 0.10 bc C	5.55 ± 0.04 cd B	5.70 ± 0.10 c A
Lemon 0.5	4.75 ± 0.15 d D	5.10 ± 0.20 d C	5.35 ± 0.08 e B	5.65 ± 0.05 c A
Grapefruit 0.25	5.37 ± 0.07 ab D	5.60 ± 0.00 b C	5.75 ± 0.05 b B	5.85 ± 0.04 b A
Grapefruit 0.5	5.05 ± 0.05 bc D	5.25 ± 0.15 cd C	5.65 ± 0.05 b B	5.80 ± 0.06 b A
Bitter orange 0.25	4.90 ± 0.20 cd D	5.35 ± 0.05 c C	5.65 ± 0.05 b B	5.85 ± 0.09 b A
Bitter orange 0.5	4.80 ± 0.20 d D	5.20 ± 0.10 d C	5.40 ± 0.00 de B	5.55 ± 0.05 c A

Small letters show the presence of a significant difference in vertical direction at ($p < 0.05$).

Capital letters show the presence of significant differences in horizontal direction at ($p < 0.05$).

As for the concentration effect, we find that the 0.5 concentration kept pH values low on Day 7 and Day 10 with a significant difference compared with the 0.25 concentration. This is attributed to the fact that increasing the concentration pumped a higher level of biologically active tannins and phenolic compounds, which led to curbing the growth of microorganisms.

On Day 10, we find that the treatment of bitter orange peel extract at a concentration of 0.5% and lemon peel extract at concentrations of 0.5% and 0.25% recorded high significant efficiency in reducing the alkaline rise in pH values, as these treatments recorded the lowest significant values, carrying the letter (c) with values of 5.55 and 5.65. The reason for this is their high ability to create a

high and stable acidic environment, preventing the growth of microorganisms through the effect of high acidity.

We notice that extract treatments kept a safe range for pH values between 5.55–5.85 compared to the control treatment, which recorded an alkaline rise (8.25). This is attributed to the inhibitory role of tannins against the enzymes of hydrolytic microorganisms. Elsheikh and Uçak [1] pointed out that tannins work as highly effective natural antioxidants against protease enzymes resulting from microorganisms, whereas we find that the control treatment lacks the presence of these compounds, which allows the activity of microorganisms in analyzing proteins and nitrogenous compounds. Conversely, the presence of tannins in extract treatments binds with proteins, forming a complex that hinders protein degradation. This mechanism matches what was reported by Molina-Mendoza and Santos-Buelga [7], who showed that tannins possess a high chemical affinity to bind with proteins rich in proline, forming a stable complex (tannin–protein) that resists destruction by microorganisms; this explains the stability in pH values and their decrease in treatments containing tannins, such as bitter orange and lemon.

Thiobarbituric Acid (TBA)

Table 3 shows the presence of high significant differences ($p < 0.05$) resulting from the interaction of treatment type with the time factor.

This big chemical deterioration becomes clear in the control treatment, as TBA values in it recorded a high significant superiority from 0.15 on day zero to 1.94 on Day 7 (a vertically) and the highest (A horizontally) on the 10th day as a result of severe rancidity and total oxidation that destroyed the chemical structure of the sample, recording 2.90. This big rise goes back to the control treatment not possessing any preservative substances preventing its occurrence, because of the exposure of free fatty acids to direct attack from oxygen and free radicals causing the occurrence of lipid auto-oxidation reactions (Lipid Peroxidation) rapidly.

Table 3. Interaction in Thiobarbituric Acid test for beef meat treated with extracts of tannins of orange peels, lemon peels, grapefruit peels, and bitter orange peels at two dilutions (0.25 and 0.5) for different cooling periods at 4 °C.

Extract and concentration	Day 0	Day 3	Day 7	Day 10
Control	0.15 ± 0.01 a D	0.60 ± 0.05 a C	1.94 ± 0.06 a B	2.90 ± 0.10 a A
Orange 0.25	0.16 ± 0.01 a D	0.25 ± 0.01 ef C	0.33 ± 0.03 de B	0.53 ± 0.04 cd A
Orange 0.5	0.14 ± 0.01 a D	0.20 ± 0.01 g C	0.24 ± 0.01 f B	0.40 ± 0.01 e A
Lemon 0.25	0.17 ± 0.01 a D	0.36 ± 0.03 c C	0.48 ± 0.02 b B	0.60 ± 0.01 b A
Lemon 0.5	0.14 ± 0.02 a D	0.31 ± 0.01 cd C	0.43 ± 0.03 bc B	0.53 ± 0.03 cd A
Grapefruit 0.25	0.15 ± 0.03 a D	0.39 ± 0.01 bc C	0.48 ± 0.02 b B	0.62 ± 0.01 b A
Grapefruit 0.5	0.14 ± 0.02 a D	0.40 ± 0.02 b C	0.49 ± 0.02 b B	0.60 ± 0.01 b A
Bitter orange 0.25	0.17 ± 0.01 a D	0.23 ± 0.03 fg C	0.29 ± 0.01 ef B	0.57 ± 0.02 bc A
Bitter orange 0.5	0.15 ± 0.01 a D	0.20 ± 0.01 g C	0.28 ± 0.01 ef B	0.48 ± 0.03 de A

Small letters show the presence of a significant difference in vertical direction at ($p < 0.05$).

Capital letters show the presence of significant differences in horizontal direction at ($p < 0.05$).

Also, addition treatments with tannin extracts of peels of orange, lemon, grapefruit, and bitter orange showed a significant superiority compared with the control treatment until Day 10 of storage, as the 0.5% orange treatment recorded the lowest value with a significant difference from the rest of the treatments (0.40), where addition treatments regularly preserved low TBA values. This reduction in TBARS values is attributed to the high content of citrus extracts in tannins, phenolic components, and vitamin C, which are compounds working as "natural free radical scavengers" that break the oxidation reactions chain before reaching final rancidity stages.

The concentration factor appears from the table as the higher concentration (0.5%) significantly surpassed the lower concentration (0.25%) in all advanced days (seventh and 10) for all types of extracts, preserving much lower carbonyl accumulation levels and with lower significant letters,

which proves that increasing the density of active substances prevents and delays the breakdown of fatty acids.

Comparative analysis at Day 10 highlights that the 0.5% orange extract recorded the lowest accumulation value of rancidity compounds with an average of 0.40 and carried alone a distinguished small letter (f), followed in efficiency by bitter orange extract at a concentration of 0.5%, which recorded 0.48.

The results show the occurrence of high oxidation and rancidity of fats in the control treatment, while extract treatments preserved low and stable values, which is evidence of the antioxidant properties possessed by tannins.

Orange extract at a concentration of 0.5% stood alone as the strongest antioxidant treatment in this experiment, as it recorded the lowest value for the accumulation of rancidity compounds (0.40mg MDA/kg). This high efficiency harmonizes with the results of Nupur et al. [24], which confirmed that orange peel extract works as a strong natural antioxidant inhibiting lipid oxidation reactions and lowering rancidity values (TBARS) and free fatty acids in minced beef meat during storage.

Tannins contain in their large structural framework a large number of hydroxyl groups ready to donate hydrogen atoms to active free radicals that react with fat bonds, which turns these radicals into stable compounds and prevents the occurrence of auto-oxidation reactions and the accumulation of malondialdehyde compounds.

This result agrees with what was reported by Abdel-Aziz et al. [11], as they found that treating beef meat with orange peel extract led to a significant big decrease in TBA values and delayed lipid oxidation reactions thanks to their high content of natural antioxidants.

This explanation is supported by what was reached by Yousof et al. [25], where they pointed out that the efficiency of tannins in preventing lipid oxidation surpasses in some instances simple monophenol compounds; due to the fact that their high molecular weight and multiplicity of their rings allow them to work as multi-stage antioxidants, as they do not scavenge free radicals only, but also perform "chelation" of free iron ions present in the medium, which are considered a basic catalyst (pro-oxidant) to start lipid rancidity and oxidation reactions [26], [27]. By that, orange and bitter orange extracts succeeded in closing oxidation pathways and preserving the quality of samples.

Conclusion

Results indicated that citrus peel extract significantly suppressed microbial growth by lowering bacterial counts and reducing oxidative rancidity compared to the control, with orange peel treatment yielding the highest efficiency.

Statistical analysis showed that increasing extract concentration to 0.5% achieved greater bacterial growth inhibition, maintained pH within acceptable limits, and decreased oxidative rancidity compared to the 0.25% concentration, confirming that higher tannin density inhibits bacterial enzymes.

Extracts containing tannins formed a tannin-protein inhibitory complex that stopped bacterial protease enzymes, which preserved proteins better than the control treatment; the control suffered rapid spoilage from protein breakdown that released ammonia gas, elevated pH, and caused total sample deterioration.

Recommendation

1. Use orange and bitter orange peel extracts as natural antioxidant preservatives in minced meat packaging plants to replace chemical options like sodium nitrate, which carry potential health risks.
2. Investigate combining citrus peel compounds into natural coatings for meat preservation applications.
3. Apply sensory tests to evaluate how peel extracts influence meat taste and overall palatability.
4. Recycle citrus processing waste by extracting active ingredients and testing their performance in meat preservation.

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