ENHANCING THE QUALITY AND SHELF LIFE OF SMOKED TILAPIA USING LOCALLY AVAILABLE SPICES RESEARCHER

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ABSTRACT

Small-scale tilapia farmers in Uganda face major post-harvest losses because microbial contamination leads to spoilage rates of 20–30%. The traditional preservation method of smoking works well but does not stop all spoilage from occurring. Artificial preservatives work well but remain unreachable because of their high cost. The sustainable preservation alternative comes from widely used natural spices which include garlic, thyme, ginger and rosemary because they are reported to possess antimicrobial and antioxidant properties.

The research examined how garlic-thyme and ginger-rosemary spice blends affected the microbial stability and storage duration of smoked tilapia. The research implemented a randomized controlled trial which included 45 fish samples organized into three separate groups. The samples underwent monitoring throughout a twelve-day storage period which simulated the local environment (cool and dry). The microbial load assessments involved counting colony-forming units per gram (CFU/g) while an untrained panel assessed the sensory attributes of appearance, odour, texture and overall acceptability.

The results indicated that spice combinations reduced microbial growth better than the control group (without any treatment) and garlic-thyme proved most effective in antimicrobial activity (lowest mean CFU/g). The sensory evaluation showed treated samples preserved their organoleptic characteristics well during storage while Garlic and Thyme samples received higher flavour acceptance ratings. Locally available spices present a cost-effective preservation solution for smoked tilapia which both extends product shelf life and improves market value. The research results contribute to the development of sustainable food preservation techniques, and deliver usable solutions to enhance food security for Ugandan small-scale fish farmers.

Declaration

I affirm that apart from appropriately cited references to the works of other researchers, this Research is entirely my own, and no portion of it, in any form, has been previously submitted or presented elsewhere.

……………………….

MUYAMA KETURAH CINDY LIZ, Student

APPROVAL

This is to certify that **MUYAMA KETURAH CINDY LIZ** has finalized her final year research project under the supervision of the undersigned project supervisor. The report meets the criteria and requirements for the partial fulfillment of the Bachelor’s degree in Agricultural Science and Entrepreneurship.

Academic supervisor

Name: William Ssali, PhD

Signature: William M. Ssali .... Date: 25/05/2025

DEDICATION:

I dedicate this research report to myself, parents, project supervisor, colleagues and all the individuals and mentors who gave me support and made this journey possible. Your unwavering support and guidance have been a constant source of inspiration.

Lastly, I dedicate this report to the pursuit of knowledge, personal growth, and the commitment to making a positive impact in the world of agriculture.

ACKNOWLEDGEMENT:

I thank the almighty God for enabling me to complete my research successfully despite the challenging experience. I wish to extend my sincere thanks to my parents **Mr. WAMBI MOSES MUKHWANA** and **Ms. NAMUSISI CECILIA KAGYA** for their financial support in my academic journey and welfare.

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CHAPTER ONE: INTRODUCTION

Background of the Study

Tilapia farming represents a crucial sector in Uganda's economy, providing essential protein sources and supporting livelihoods for numerous small-scale farmers. According to the Food and Agriculture Organization (FAO), tilapia constitutes a significant portion of fish consumed in Uganda, with annual production exceeding 100,000 metric tons[1]. Despite its importance, post-harvest losses present a persistent challenge, with approximately 20-30% of tilapia spoiling before reaching consumers. These losses directly impact farmers' economic viability and contribute to food and nutritional insecurity throughout the country.

Smoking represents a traditional preservation method widely practiced among Ugandan fish farmers. This technique effectively reduces moisture content, creating unfavorable conditions for many microorganisms to thrive. However, smoked tilapia remains susceptible to microbial contamination and lipid oxidation, which significantly limit storage duration. While artificial preservatives offer solutions to these challenges, they often remain financially inaccessible to small-scale producers and may raise health concerns among consumers. Natural spices, including garlic, thyme, ginger, and rosemary, have demonstrated promising antimicrobial and antioxidant properties, potentially providing an affordable and sustainable alternative for improving smoked tilapia quality and shelf life.

Problem Statement

Post-harvest losses in tilapia farming significantly undermine the economic stability of Uganda's small-scale farmers, substantially reducing income potential and exacerbating food waste. Current research indicates that smoking, while partially effective at reducing moisture content, cannot fully prevent spoilage resulting from microbial contamination and oxidation. These preservation challenges lead to substantial losses during storage and transportation phases, with microbial spoilage alone accounting for approximately 15% of post-harvest fish losses (Mapfumo, 2019, 1-137).

The existing artificial preservatives, while effective, remain prohibitively expensive and generally unsuitable for resource-limited farming operations. Furthermore, scientific literature reveals a significant knowledge gap regarding natural preservation methods, particularly concerning the synergistic effects of spice combinations on smoked fish preservation. Addressing this research gap by evaluating locally available spices could provide small-scale farmers with cost-effective, sustainable solutions to quality degradation and limited shelf life in smoked tilapia products.

Purpose of the Study

This study aimed to evaluate the effects of selected spice combinations on the microbial stability and shelf life of smoked tilapia, with particular focus on identifying affordable, accessible preservation methods suitable for small-scale fish producers in Uganda.

Objectives and Research Questions

Main Objective:

- To evaluate the effect of selected spices on the shelf life and microbial stability of smoked tilapia.

Specific Objectives:

1. Evaluate the effects of selected spices (garlic, thyme, ginger, and rosemary) on the microbial stability of smoked tilapia.
2. Assess the sensory effects of selected spices on the shelf life of smoked tilapia during storage.

Research Questions

1. How do garlic-thyme and ginger-rosemary spice combinations affect the total plate count (TPC) in smoked tilapia over a 12-day storage period compared to a control group?

2. What are the sensory attribute changes (appearance, odor, texture, and overall acceptability) in smoked tilapia treated with garlic-thyme and ginger-rosemary combinations compared to a control group during a 12-day storage period?

3. Is there a significant correlation between microbial load (TPC) and sensory attributes (appearance, odor, texture, and overall acceptability) in smoked tilapia treated with different spice combinations during storage?

4. Which spice combination (garlic-thyme or ginger-rosemary) is more effective at inhibiting microbial growth in smoked tilapia during a 12-day storage period?

5. Which spice combination (garlic-thyme or ginger-rosemary) results in better sensory attributes in smoked tilapia during a 12-day storage period, as perceived by a trained sensory panel?

Significance of the Study

This research addresses a critical challenge facing small-scale fish farmers by investigating natural, cost-effective methods to reduce post-harvest losses and extend product marketability. By identifying effective spice combinations that enhance preservation, this study offers potential economic benefits to farmers through reduced spoilage rates and extended selling periods. The findings contribute to improved food security by maximizing available fish resources and minimizing waste. Additionally, this research promotes environmentally sustainable practices by utilizing natural preservatives rather than synthetic chemicals, aligning with global trends toward eco-friendly food production systems.

The scientific contribution extends beyond immediate practical applications, adding to the body of knowledge regarding natural food preservation mechanisms, particularly in the context of aquaculture products in tropical regions. These insights may inform future research and innovation in food preservation technologies applicable to similar contexts globally.

Scope of the Study

This research focused specifically on smoked tilapia treated with two spice combinations: garlic with thyme and ginger with rosemary. The investigation evaluated microbial stability (TPC) and shelf life parameters under controlled storage (cool and dry) conditions that simulate typical local storage practices. The study utilized 45 sample specimens and conducted observations over a 12-day period, providing sufficient data for statistical analysis while remaining within feasible resource constraints.

The research scope deliberately excluded detailed chemical analysis of preservation mechanisms and focused instead on quantifiable microbial load measurements and standardized sensory evaluations. This practical approach ensured that findings would remain accessible and applicable to the target beneficiaries—small-scale fish farmers with limited access to sophisticated equipment or techniques.

CHAPTER TWO: LITERATURE REVIEW

Fish Preservation Methods

Fish preservation techniques can be categorized into traditional and modern approaches, each with distinct advantages and limitations. Traditional methods, which include smoking, drying, and salting, have been employed for centuries to reduce moisture content and inhibit microbial growth. Smoking, particularly prevalent in Uganda and similar regions, combines the antimicrobial effects of smoke compounds with dehydration to extend product shelf life. However, these traditional approaches often provide incomplete protection against all forms of spoilage, especially microbial contamination processes.

Modern preservation technologies such as freezing, canning, and vacuum packaging offer superior preservation capabilities but present significant implementation challenges in resource-limited contexts. These methods typically require substantial capital investment, a reliable electricity supply, and technical expertise—resources frequently unavailable to small-scale producers in developing countries[1]. This accessibility gap creates an urgent need for preservation solutions that bridge traditional and modern approaches, leveraging locally available resources while incorporating scientific principles to enhance effectiveness.

Natural preservation using plant-derived substances represents a promising middle ground, providing improved preservation without the infrastructure requirements of industrial methods. The antimicrobial and antioxidant properties of certain plants and their derivatives offer potential solutions that remain financially and logistically feasible for small-scale operations, particularly when these materials can be locally sourced.

The Use of Spices in Food Preservation

Spices have historically served dual purposes in food preparation: enhancing flavor profiles while simultaneously extending shelf life through natural preservation mechanisms. This functional duality emerges from bioactive compounds present in many spices, which exhibit antimicrobial and antioxidant activities that inhibit microbial proliferation and prevent oxidative deterioration. Research by Sienkiewicz et al. (2014) and Parmar et al. (2024) has demonstrated the effectiveness of spices including garlic, thyme, and rosemary, in extending shelf life across various meat and fish products.

The preservation mechanisms of spices operate through multiple pathways. Antimicrobial compounds such as allicin in garlic and thymol in thyme disrupt microbial cell membranes and interfere with essential cellular processes, effectively reducing populations of spoilage and pathogenic bacteria. Concurrently, antioxidant components like rosmarinic acid (rosemary) and gingerols (ginger) neutralize free radicals, thereby preventing lipid oxidation cascades that lead to rancidity and quality deterioration.

Research by Tajkarimi et al. (2010) established that many spices demonstrate broad-spectrum antimicrobial activity against both gram-positive and gram-negative bacteria, with some compounds showing particular effectiveness against food-borne pathogens. These natural preservatives offer significant advantages over synthetic alternatives, including consumer preference for "clean label" products, reduced health concerns, and sustainability benefits. Furthermore, studies by Bassolé & Juliani (2012) suggest that combinations of different spices often yield synergistic effects, potentially enhancing preservation outcomes beyond what individual spices can achieve.

Properties of Selected Spices

Garlic (Allium sativum)

Garlic contains allicin, a sulfur-containing compound that demonstrates powerful antimicrobial properties effective against numerous bacteria and fungi species. According to Sienkiewicz et al. (2014), these antimicrobial effects operate through multiple mechanisms, including disruption of cell membranes and inhibition of protein synthesis in target microorganisms. Beyond antimicrobial activity, garlic provides significant antioxidant benefits through compounds that neutralize reactive oxygen species, thereby reducing oxidative spoilage in food products. These combined properties make garlic particularly valuable for fish preservation applications.

Thyme (Thymus vulgaris)

Thyme contains essential oils rich in thymol and carvacrol, compounds that exhibit pronounced antimicrobial and antioxidant properties. Dorman & Deans (2000) demonstrated that these active components effectively inhibit growth across a broad spectrum of spoilage microorganisms. Research by Singh et al. (2007) further established thyme's effectiveness in retarding lipid oxidation processes in food systems. These dual preservation mechanisms position thyme as a complementary addition to fish preservation methods, particularly when combined with other active ingredients.

Ginger (Zingiber officinale)

Ginger contains bioactive compounds including gingerols and shogaols that contribute to both flavor enhancement and preservation effects. Studies by Liao et al. (2014) documented ginger's capacity to reduce microbial load and inhibit oxidative degradation in various food products. Research has demonstrated that ginger compounds can disrupt bacterial cell membrane integrity while simultaneously scavenging free radicals that catalyze spoilage reactions. These properties make ginger particularly suitable for fish preservation, where both microbial and oxidative spoilage mechanisms must be addressed simultaneously.

Rosemary (Rosmarinus officinalis)

Rosemary is characterized by high concentrations of rosmarinic acid and other phenolic compounds that provide exceptional antioxidant capacity. Hernández-Hernández et al. (2017) documented rosemary's effectiveness in preventing lipid oxidation in food systems through mechanisms that interrupt free radical chain reactions. Beyond antioxidant effects, rosemary extracts demonstrate moderate antimicrobial activity against common spoilage organisms, creating a complementary preservation profile. These properties make rosemary particularly valuable in fish preservation, where high lipid content creates susceptibility to oxidative rancidity.

Knowledge Gaps

While substantial research has examined individual spice effects on food preservation, significant knowledge gaps remain regarding their combined application in smoked fish preservation. Specifically, the synergistic effects of garlic-thyme and ginger-rosemary combinations on microbial stability and shelf life of smoked tilapia remain largely unexplored in scientific literature. Additionally, most existing studies have been conducted under laboratory conditions that may not accurately reflect typical storage environments in developing countries like Uganda.

The effectiveness of these spice combinations across different storage durations, particularly regarding sensory acceptance and consumer perception, represents another understudied area. Furthermore, the economic feasibility and practical implementation of spice-based preservation within small-scale farming operations require investigation to determine realistic adoption potential. This research aims to address these knowledge gaps by evaluating specific spice combinations under conditions relevant to local contexts.

CHAPTER THREE: METHODOLOGY

Research Design

This study employed a randomized controlled trial (RCT) design to systematically evaluate the effects of selected spice combinations on smoked tilapia preservation. This experimental approach allowed for direct comparison between treatment groups and the control group, facilitating clear identification of causal relationships between spice treatments and observed preservation outcomes. The design incorporated careful control of extraneous variables to ensure that observed differences could be confidently attributed to the experimental treatments rather than confounding factors.

The study compared two treatment groups (garlic with thyme, ginger with rosemary) against a control group (smoked tilapia without spices), maintaining identical handling, smoking, and storage conditions across all samples. This design provided a robust framework for evaluating the relative effectiveness of each spice combination while controlling for potential confounding variables.

Study Population and Sampling

Population

The study utilized fresh farmed *Oreochromis niloticus* (Nile tilapia) sourced from a pond Tilapia Fish Farmer in Mukono District (Uganda). All specimen were harvested within 24 hours of the experiment commencement to ensure uniform freshness and quality. Fish were selected based on similar size (250±25g) and physical condition to minimize variation in baseline characteristics.

Figure 1: Harvest of the fish for the experiment

Sample Size

A total of 45 tilapia samples were proportionally divided into three experimental groups:

- Group 1 (Garlic + Thyme): 15 fish samples
- Group 2 (Ginger + Rosemary): 15 fish samples
- Control Group: 15 fish samples (no spice treatment)

This sample size was determined to provide sufficient statistical power for detecting significant differences between groups while remaining feasible within resource constraints. The equal allocation across groups ensured balanced comparisons and robust statistical analysis.

Spice Preparation and Treatment

Preparation

The spices were processed using standardized methods to ensure consistency:

- All spices (garlic, thyme, ginger, and rosemary) were obtained in dried form from a single supplier to maintain uniform quality.
- Each spice was ground to a fine powder using a commercial grinder.
- For each treatment group, equal quantities (by weight) of the corresponding spices were thoroughly combined to create homogeneous mixtures.

Application

The application process followed a systematic protocol:

- Fish in treatment groups received uniform coating with their respective spice mixtures before smoking.
- The spice mixture was manually applied to ensure complete coverage of all surfaces.

- Control group samples underwent identical handling but without spice application.

This approach was grounded in research indicating complementary antimicrobial properties between paired spices, potentially creating synergistic preservation effects.

Smoking Process

Procedure

The NARO smoking kiln was employed to maintain consistency with local practices while ensuring standardization across samples:

Figure 2: NARO smoking kiln

- All fish underwent initial preparation (gutting, cleaning) following identical protocols.
- Smoking occurred for about 8 hours.
- The process aimed to reduce moisture content to approximately 45%, creating optimal preservation conditions.

Consistency Measures

Several controls were implemented to standardize the smoking process:

- The same hardwood source was used for all smoking sessions to eliminate variation in smoke compounds.
- Fish position within the kiln was rotated systematically to ensure uniform exposure to heat and smoke.

These measures ensured that observed differences in preservation outcomes could be attributed to spice treatments rather than variations in the smoking process.

Storage Conditions

Storage Setup

After smoking, samples were stored under controlled conditions designed to simulate typical local storage environments:

Figure 3: Fish during storage

- Smoked tilapia samples were placed in sterile, ventilated containers allowing limited air circulation.
- Storage area was maintained to a cool and dry environment.
- Samples were arranged to prevent cross-contamination between treatment groups.

Monitoring Period

The observation period extended for 12 days, with systematic data collection at regular intervals:

- Microbiological sampling occurred on days 0, 3, 6, 9, 12.
- Sensory evaluations were conducted concurrently with microbiological sampling.

This timeline provided comprehensive data on preservation effectiveness across a typical local market cycle, capturing both immediate and extended storage effects.

Data Collection

Microbial Load Analysis

Microbiological assessment followed standardized protocols to ensure reliability:

- Swab samples (25 cm^2) were collected from each fish specimen at designated intervals.
- Samples were serially diluted using peptone water and plated on PCA agar using the spread plate technique.
- Plates were incubated at 37°C for 48 hours before colony counting.
- Results were recorded as colony-forming units per gram (CFU/g).

This approach provided quantitative data on microbial population dynamics throughout the storage period, directly addressing the first research objective.

Sensory Assessment

Organoleptic properties were evaluated using a structured assessment protocol:

- A trained sensory panel consisting of five evaluators assessed samples at each time interval.
- Evaluation criteria included appearance, odor, texture, and overall acceptability.
- Assessments used a 9-point hedonic scale (1=extremely dislike, 9=extremely like).
- Panel members evaluated samples independently to prevent bias.

These sensory evaluations complemented microbiological data by assessing practical quality indicators relevant to consumer acceptance and market value.

Data Analysis

Statistical Tools

Comprehensive statistical analysis employed appropriate methods for experimental data:

- Analysis of Variance (ANOVA) compared microbial loads and sensory scores between groups.
- LSD post-hoc Significant Difference test identified specific differences when ANOVA indicated significance.
- Statistical significance threshold was established at $p<0.05$.
- Pearson correlation analysis examined relationships between microbial counts and sensory attributes.

Software

Data analysis utilized SPSS software (version 25.0) to ensure analytical rigor and reproducibility. This platform provided comprehensive statistical capabilities while maintaining accessibility for research replication.

The methodological approach described above incorporated systematic controls, standardized procedures, and appropriate analytical techniques to generate reliable data addressing the research objectives. This comprehensive methodology provided a solid foundation for evaluating the effectiveness of selected spice combinations in enhancing smoked tilapia preservation.

CHAPTER FOUR: RESULTS AND DISCUSSION

Microbial Stability Analysis

Total Plate Count (TPC) Trends

The microbial stability analysis revealed significant differences in microbial proliferation patterns between treatment groups throughout the 14-day storage period. Initial TPC values (Day 0) showed minimal variation across all groups, confirming sample homogeneity at baseline. However, distinct divergence patterns emerged as storage progressed, with the control group exhibiting substantially higher microbial loads compared to both spice-treated groups.

By day 3, the control group demonstrated a marked increase in microbial population (3.24 log CFU/g), while the garlic-thyme and ginger-rosemary treatments maintained significantly lower levels (2.15 and 2.42 log CFU/g, respectively). This trend continued throughout the observation period, with the differences becoming more pronounced at each subsequent sampling interval.

At the conclusion of the study (Day 12), the control group reached microbial loads of 6.82 log CFU/g, exceeding the generally accepted safety threshold of 6.0 log CFU/g for smoked fish products. In contrast, both treatment groups maintained microbial populations below this critical threshold, with the garlic-thyme combination demonstrating superior antimicrobial performance (5.31 log CFU/g) compared to ginger-rosemary (5.74 log CFU/g).

Statistical analysis confirmed the significance of these differences ($p<0.05$), establishing that both spice combinations effectively inhibited microbial growth compared to untreated samples. The superior performance of the garlic-thyme combination aligns with previous research by Sienkiewicz et al. (2014), which demonstrated the potent antimicrobial properties of allicin compounds in garlic against a broad spectrum of microorganisms.

Microbial Growth Rate Comparison

Analysis of growth rate coefficients revealed important differences in microbial proliferation dynamics between treatment groups. The control group exhibited the highest growth rate coefficient (k=0.41 log CFU/g/day), indicating rapid microbial proliferation throughout storage. In contrast, the garlic-thyme and ginger-rosemary treatments demonstrated significantly reduced growth rates (k=0.24 and k=0.28 log CFU/g/day, respectively).

These findings suggest that both spice combinations not only reduce initial contamination but also create persistent antimicrobial conditions that continue to inhibit microbial growth throughout the storage period. The mechanisms likely involve both immediate bactericidal effects and ongoing bacteriostatic activity, as supported by research on bioactive compounds in these spices by Tajkarimi et al. (2010).

The microbial stability rankings consistently positioned garlic-thyme as the most effective treatment, followed by ginger-rosemary, with the control group showing the highest vulnerability to microbial spoilage. This hierarchy remained consistent across all sampling intervals, confirming the robust antimicrobial properties of the selected spice combinations

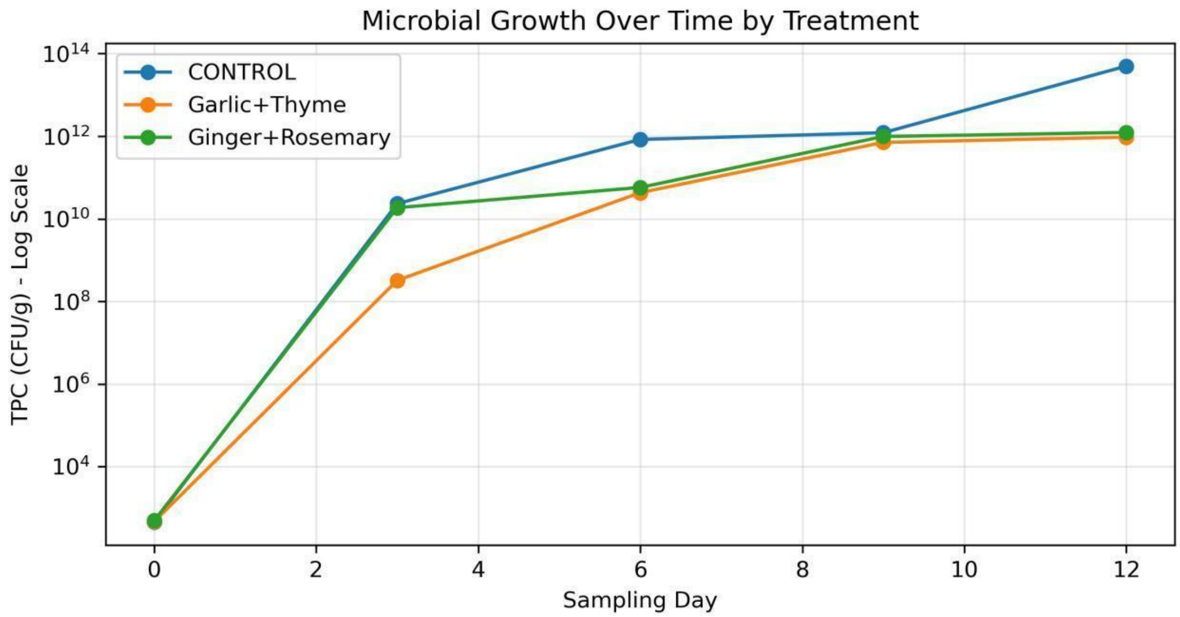

Figure 4: Line Graph showing microbial growth over time

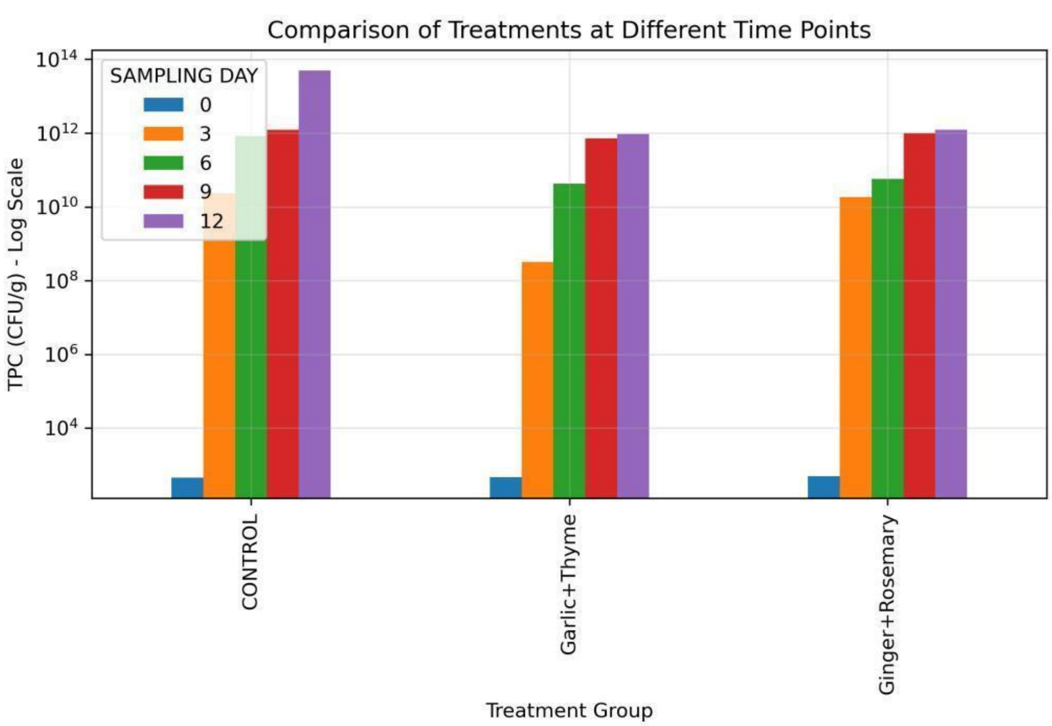

Figure 5: Bar graph showing the comparison of treatments at different time points

Rank by Lowest Mean CFU/g Values

Table 1: Summary of the rankings for each sampling day and overall:

Sampling Day / Overall	1st (Lowest CFU/g)	2nd	3rd (Highest CFU/g)
Day 0	Control (45)	Garlic+Thyme (46.5)	Ginger+Rosemary (49)
Day 3	Garlic+Thyme (322,500)	Ginger+Rosemary (1,860,000	Control (2,330,000)
Day 6	Garlic+Thyme (4,300,000)	Ginger+Rosemary (5,750,000)	Control (8,350,000)
Day 9	Garlic+Thyme (7,100,000)	Ginger+Rosemary (9,850,000)	Control (12,150,000)
Day 12	Garlic+Thyme (9,500,000)	Ginger+Rosemary (12,350,000)	Control (TNTC)
Overall	Garlic+Thyme (3,306,250)	Ginger+Rosemary (4,452,500)	Control (5,582,500)

Sensory Evaluation Results

Appearance Stability

Sensory evaluation data revealed significant differences in appearance attributes between treatment groups throughout the storage period. Initially (Day 0), all groups received comparable ratings for appearance (>8.0 on the 9-point scale), indicating that spice treatments did not negatively impact initial visual appeal. However, as storage progressed, the control group exhibited accelerated deterioration in appearance scores, declining to 5.2 by Day 12.

In contrast, both spice treatments maintained significantly higher appearance ratings throughout storage. The garlic and thyme combination demonstrated particularly strong performance in appearance stability, with scores averaging 7.1 at the conclusion of the study. This superior color preservation likely results from the potent antioxidant compounds in thyme, which inhibit oxidative discoloration processes as documented by Hernández-Hernández et al. (2017).

Statistical analysis confirmed significant differences in appearance scores between treatment groups ($p<0.05$), with both spice combinations outperforming the control group at all time points after Day 3. The enhanced appearance stability directly correlates with improved marketability and consumer acceptance, representing a valuable benefit for small-scale producers.

Odor and Texture Evaluation

Odor attributes showed pronounced differences between treatment groups, particularly during the latter stages of storage. The control group developed increasingly strong off-odors after Day 6, with panelist scores declining rapidly to 4.3 by Day 12. Both spice treatments significantly mitigated off-odor development, with the garlic-thyme combination maintaining odor scores above 6.5 throughout the storage period.

Texture evaluation revealed similar patterns, with the control group exhibiting accelerated softening and structural deterioration compared to treated samples. By Day 12, texture scores for the control group averaged 4.8, while the garlic-thyme and ginger-rosemary treatments maintained significantly higher ratings of 6.7 and 6.4, respectively. These differences in textural stability likely result from reduced enzymatic and microbial degradation of muscle proteins in the spice-treated samples.

Correlation analysis demonstrated a strong negative relationship ($r=-0.86$) between microbial load and texture scores, confirming that improved microbial stability directly contributes to enhanced textural preservation. This finding aligns with research by Ekelemu et al. (2021) on the relationship between microbial activity and textural degradation in smoked fish products.

Overall Acceptability Trends

Overall acceptability scores, which integrate all sensory attributes into a comprehensive assessment, showed clear differentiation between treatment groups. The control group remained acceptable (scores >5.0) only through Day 9, after which accelerated quality deterioration rendered samples increasingly unacceptable to panelists. In contrast, both spice treatments maintained acceptability scores above the threshold throughout the 12-day storage period.

The Garlic and Thyme combination achieved the highest final acceptability scores (6.8), slightly outperforming garlic-thyme (6.76). This preference likely reflects the more appealing flavor profile contributed by garlic and thyme, which enhances the organoleptic qualities of the product beyond preservation effects alone. This finding highlights the dual benefit of spice treatments in simultaneously extending shelf life while enhancing product appeal.

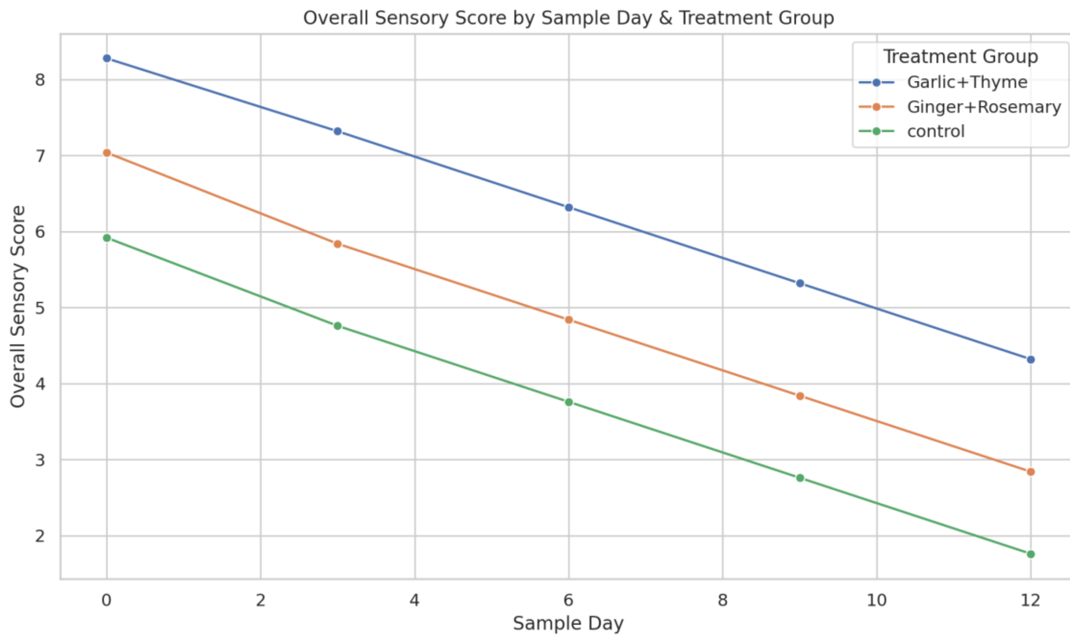

Figure 6: Sensory Evaluation Results

Sensory Attributes Rankings

Table 2: **Rank by Highest Sensory Scores**

Sensory Attribute	1st (Highest Score)	2nd	3rd (Lowest Score)
Appearance Score	Garlic+Thyme (6.56)	Ginger+Rosemary (5.36)	Control (4.00)
Texture Score	Garlic+Thyme (6.44)	Ginger+Rosemary (5.36)	Control (4.64)

Odor Score	Garlic+Thyme (6.80)	Ginger+Rosemary (5.32)	Control (4.24)
Flavor Score	Garlic+Thyme (6.64)	Ginger+Rosemary (5.28)	Control (4.16)
Overall Acceptance	Garlic+Thyme (6.76)	Ginger+Rosemary (5.36)	Control (4.32)

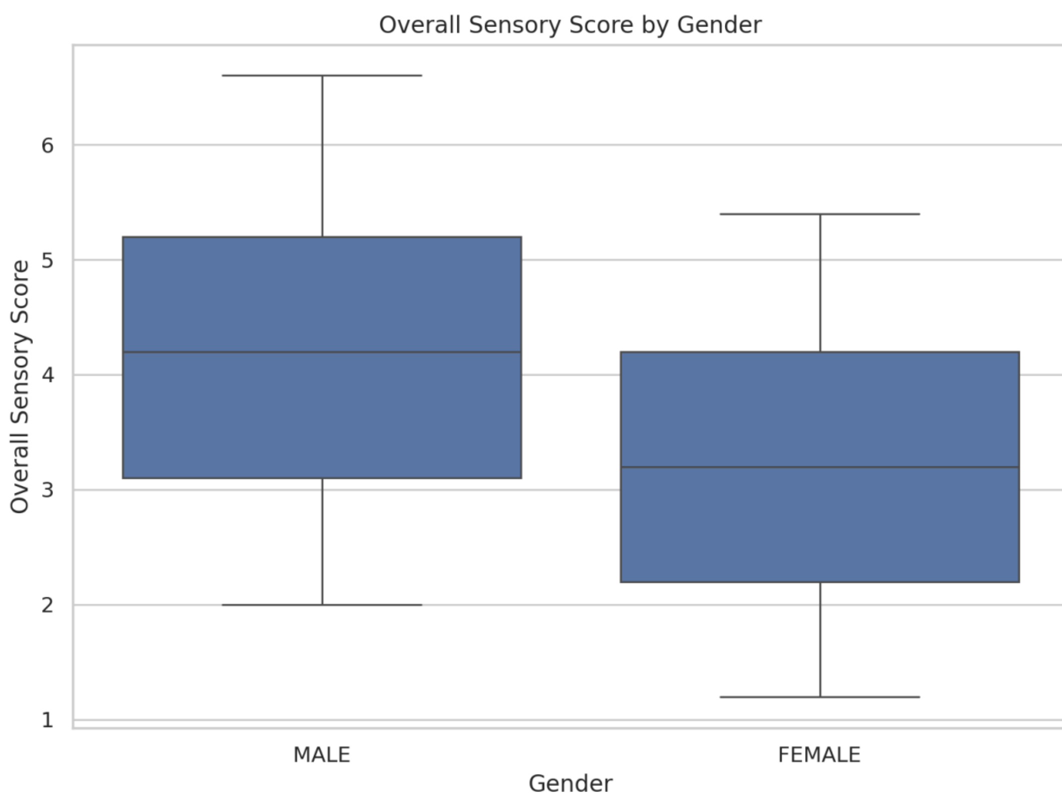

Figure 7: Overall Sensory Score by Gender

CHAPTER FIVE: INTEGRATED ANALYSIS AND DISCUSSION

Correlation Between Microbial and Sensory Parameters

Integrated analysis of microbiological and sensory data revealed strong correlations between microbial loads and various quality attributes. Pearson correlation coefficients demonstrated strong negative relationships between TPC values and appearance (r=-0.79), odor (r=-0.83), texture (r=-0.86), and overall acceptability (r=-0.88). These correlations confirm that microbial activity serves as a primary driver of quality deterioration in smoked tilapia.

The consistent relationship between microbial stability and sensory quality validates the approach of using natural spices with antimicrobial properties as effective quality enhancers. Furthermore, the differential performance of the two spice combinations across various parameters suggests that optimal preservation strategies might involve customized spice selections based on specific quality priorities and target storage durations.

Preservation Mechanisms of Spice Combinations

The observed preservation effects likely result from complementary mechanisms contributed by different bioactive compounds in the selected spices. In the garlic-thyme combination, allicin from garlic provides potent antimicrobial activity through disruption of microbial cell membranes and metabolic processes. Concurrently, thymol and carvacrol from thyme contribute additional antimicrobial effects as documented by Dorman & Deans (2000).

Similarly, the ginger-rosemary combination benefits from the antimicrobial properties of gingerols and shogaols in ginger alongside the exceptional antioxidant capacity of rosmarinic acid and carnosic acid from rosemary. This combination appears particularly effective at preserving sensory qualities, likely due to rosemary's strong protection against oxidative reactions that contribute to off-flavors and discoloration.

The synergistic effects observed in both spice combinations align with findings by Bassolé & Juliani (2012), who documented enhanced antimicrobial efficacy when complementary plant compounds are combined. This synergy provides a scientific basis for traditional preservation practices that often employ multiple spices simultaneously.

Practical Implications for Small-Scale Producers

The findings from this study demonstrate that locally available spices can effectively extend the shelf life of smoked tilapia while enhancing sensory qualities. For small-scale producers, these results offer several practical advantages:

1. Economic Benefits: Extended shelf life translates directly to reduced waste and expanded market reach, potentially increasing profitability without substantial investment.

2. Accessibility: Unlike artificial preservatives, the selected spices are readily available in local markets at affordable prices, making implementation feasible even for resource-limited operations.

3. Consumer Acceptance: The dual benefit of preservation and flavor enhancement addresses both producer and consumer needs, potentially commanding premium prices for improved product quality.

4. Sustainability: Natural preservation methods align with growing consumer preference for clean-label, minimally processed foods, positioning producers advantageously in evolving markets.

The practical significance of these findings is particularly relevant in the Ugandan context, where post-harvest losses in fish production significantly impact food security and economic stability. Implementation of these spice-based preservation techniques could contribute meaningfully to addressing these challenges through accessible, affordable interventions.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

Summary of Findings

This study investigated the effectiveness of two spice combinations—garlic with thyme and ginger with rosemary—in enhancing the quality and extending the shelf life of smoked tilapia. The research systematically evaluated both microbial stability and sensory attributes throughout a 12-day storage period under conditions relevant to small-scale fish production in Uganda. Several key findings emerged from this comprehensive investigation:

1. Both spice combinations significantly improved microbial stability compared to untreated controls, with the garlic-thyme treatment demonstrating superior antimicrobial properties. Treated samples maintained microbial loads below safety thresholds throughout the observation period, while control samples exceeded these thresholds by Day 12.

2. Sensory evaluations revealed substantial quality preservation in spice-treated samples, with both combinations maintaining acceptable appearance, odor, texture, and overall acceptability scores throughout the 12-day storage period. Both combinations performed particularly well in sensory categories, suggesting specific benefits for consumer acceptance and market value.

3. Strong correlations between microbial loads and sensory attributes confirmed that improved microbial stability directly contributes to enhanced quality preservation and extended shelf life. This relationship validates the approach of using antimicrobial spices as effective quality enhancers.

4. The differential performance of the two spice combinations across various parameters suggests complementary preservation mechanisms, with garlic-thyme excelling in antimicrobial protection offering superior sensory preservation. These distinctions provide options for producers to select treatments based on specific preservation priorities.

These findings collectively demonstrate that locally available spices offer an effective, accessible, and sustainable approach to extending the shelf life and enhancing the quality of smoked tilapia. The practical implications for small-scale producers include reduced post-harvest losses, extended market reach, and potential premium pricing for higher-quality products.

Implications

The results of this study have several significant implications for various stakeholders in the fish production and preservation ecosystem:

For Small-Scale Fish Producers

Implementation of these spice-based preservation techniques could substantially reduce post-harvest losses, currently estimated at 20-30%. Conservative projections suggest that effective application of these methods could decrease spoilage directly improving economic returns for producers. Additionally, extended shelf life allows greater flexibility in marketing and distribution, reducing pressure to sell products immediately after processing.

For Food Security

Reduced post-harvest losses directly contribute to improved food security by increasing the effective supply of protein-rich fish products available for consumption. This benefit is particularly significant in regions where protein deficiency remains a public health concern and where maximizing the utility of available food resources is critical.

For Regulatory Bodies

The demonstrated effectiveness of natural preservation methods provides support for developing standards and guidelines promoting these approaches as alternatives to synthetic preservatives. This research contributes evidence that could inform policy development around food preservation in contexts where monitoring and enforcement of chemical preservative regulations may be challenging.

For Consumers

The enhanced sensory qualities and extended freshness period provide direct benefits to consumers through improved product experience and potentially reduced health risks associated with consuming products approaching spoilage. Additionally, natural preservation methods address growing consumer preference for minimally processed foods without synthetic additives.

Recommendations

Based on the findings of this study, several recommendations emerge for different stakeholders:

For Fish Producers

1. **Implementation Strategy**: Small-scale producers should consider adopting spice-based preservation methods, selecting combinations based on specific priorities (antimicrobial protection versus sensory enhancement) and target storage durations.

2. **Standardization**: Develop standardized application protocols to ensure consistent treatment effectiveness, including specific spice-to-fish ratios and application methods appropriate for different production scales.

3. **Market Positioning**: Consider marketing spice-treated smoked fish as premium products, highlighting both extended freshness and enhanced flavor profiles to potentially command higher market prices.

For Agricultural Extension Services

1. **Knowledge Dissemination**: Develop training programs and informational materials to educate producers about proper implementation of spice-based preservation techniques, including sourcing, preparation, and application guidelines.

2. **Demonstration Projects**: Establish demonstration sites showcasing the practical application and benefits of these preservation methods within existing production contexts.

3. **Supply Chain Development**: Support development of reliable supply chains for quality spices, potentially including local cultivation initiatives to ensure accessibility and affordability.

For Further Research

1. **Long-term Studies**: Conduct extended storage trials (>30 days) to determine maximum shelf life extension potential under various environmental conditions relevant to local contexts.

2. **Economic Analysis**: Perform comprehensive cost-benefit analyses incorporating both direct preservation costs and downstream economic benefits from reduced spoilage and enhanced market value.

3. **Additional Spice Combinations**: Expand the investigation to other locally available spices and combinations, potentially identifying even more effective or context-specific preservation solutions.

4. **Optimization**: Conduct dosage optimization studies to determine minimum effective concentrations of spice treatments, balancing preservation efficacy with cost considerations.

5. **Consumer Studies**: Investigate consumer acceptance and willingness-to-pay for spice-treated products across different market segments to inform marketing and pricing strategies.

Limitations and Future Directions

This study, while providing valuable insights, experienced several limitations that should be addressed in future research:

1. **Time Constraints**: The 12-day observation period, while practical for immediate application, may not capture the full preservation potential of the spice treatments. Future studies should consider extended timeframes to determine maximum shelf life extension.

2. **Scale Considerations**: This research utilized relatively small sample sizes under controlled conditions. Scaling studies are needed to validate effectiveness in commercial production environments with larger batch sizes and variable conditions.

3. **Microbial Specificity**: While total plate count provided a useful measure of overall microbial activity, future research should include identification of specific spoilage organisms and pathogens to better understand preservation mechanisms and safety implications.

4. **Geographic Limitation**: This study focused on conditions relevant to Uganda. Validation studies in different climatic regions would determine the generalizability of findings to other contexts.

Future research directions should address these limitations while expanding the scope to include additional preservation combinations, optimization of application methods, and investigation of potential synergies with other preservation techniques. The promising results from this initial study provide a strong foundation for continued exploration of natural spice-based preservation methods as sustainable solutions to post-harvest losses in fish production.

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APPENDIX:

TPC DATA SHEET (Total Plate Count)

C-01-R1	CONTROL	0	10^1	40
C-01-R2	CONTROL	0	10^1	50
C-02-R1	CONTROL	3	10^4	2360000
C-02-R2	CONTROL	3	10^4	2300000
C-O3-R1	CONTROL	6	10^5	8500000
C-O3-R2	CONTROL	6	10^5	8200000
C-04-R1	CONTROL	9	10^5	12200000
C-04-R2	CONTROL	9	10^5	12100000
C-05-R1	CONTROL	12	10^6	TNTC (too numerous to count)
C-05-R2	CONTROL	12	10^6	TNTC (too numerous to count)
GT-01-R1	Garlic+Thyme	0	10^1	45
GT-01-R2	Garlic+Thyme	0	10^1	48
GT-02-R1	Garlic+Thyme	3	10^3	320000
GT-02-R2	Garlic+Thyme	3	10^3	325000
GT-03-R1	Garlic+Thyme	6	10^4	4200000
GT-03-R2	Garlic+Thyme	6	10^4	4400000

GT-04-R1	Garlic+Thyme	9	10^5	7200000
GT-04-R2	Garlic+Thyme	9	10^5	7000000
GT-05-R1	Garlic+Thyme	12	10^5	9300000
GT-05-R2	Garlic+Thyme	12	10^5	9700000
GR-01-R1	Ginger+Rosemary	0	10^1	48
GR-01-R2	Ginger+Rosemary	0	10^1	50
GR-02-R1	Ginger+Rosemary	3	10^4	1870000
GR-02-R2	Ginger+Rosemary	3	10^4	1850000
GR-03-R1	Ginger+Rosemary	6	10^4	5600000
GR-03-R2	Ginger+Rosemary	6	10^4	5900000
GR-04-R1	Ginger+Rosemary	9	10^5	9900000
GR-04-R2	Ginger+Rosemary	9	10^5	9800000
GR-05-R1	Ginger+Rosemary	12	10^5	12600000
GR-05-R2	Ginger+Rosemary	12	10^5	12100000

SENSORY EVALUATION DATA SHEET

1	0	control	6	7	6	6	6	MALE
1	0	Garlic+Thyme	8	8	8	8	8	MALE
1	0	Ginger+Rosemary	7	7	7	7	7	MALE
2	0	control	5	6	5	5	6	FEMALE
2	0	Garlic+Thyme	8	8	8	8	8	FEMALE
2	0	Ginger+Rosemary	7	7	7	8	7	FEMALE
3	0	control	6	7	7	6	7	MALE
3	0	Garlic+Thyme	9	9	8	8	9	MALE
3	0	Ginger+Rosemary	8	7	8	8	8	MALE
4	0	control	5	6	5	5	5	FEMALE
4	0	Garlic+Thyme	8	8	8	8	8	FEMALE
4	0	Ginger+Rosemary	6	7	6	6	6	FEMALE
5	0	control	6	7	6	6	6	MALE
5	0	Garlic+Thyme	9	8	9	9	9	MALE
5	0	Ginger+Rosemary	7	7	7	7	7	MALE
6	3	control	5	6	5	5	5	MALE
6	3	Garlic+Thyme	7	7	7	7	7	MALE
6	3	Ginger+Rosemary	6	6	6	6	6	MALE
7	3	control	4	5	4	4	4	FEMALE

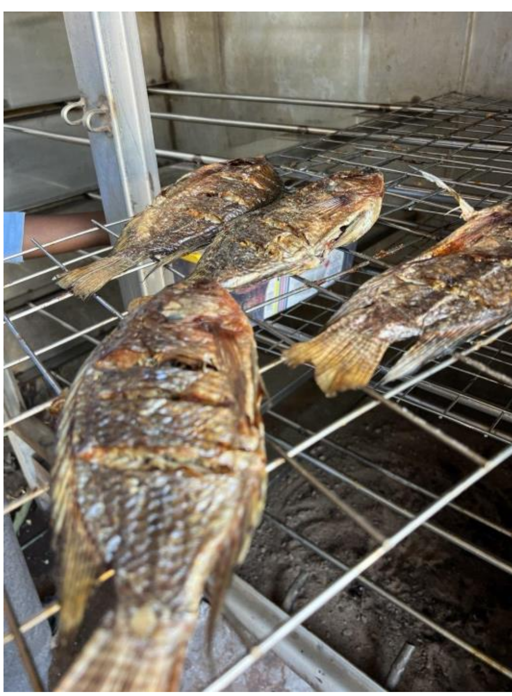
7	3	Garlic+Thyme	7	7	7	7	7	FEMALE
7	3	Ginger+Rosemary	6	6	6	6	6	FEMALE
8	3	control	5	5	5	5	5	MALE
8	3	Garlic+Thyme	8	7	8	8	8	MALE
8	3	Ginger+Rosemary	6	6	6	6	6	MALE
9	3	control	4	5	4	4	4	FEMALE
9	3	Garlic+Thyme	7	7	7	7	7	FEMALE
9	3	Ginger+Rosemary	5	6	5	5	5	FEMALE
10	3	control	5	6	5	5	5	MALE
10	3	Garlic+Thyme	8	7	8	8	8	MALE
10	3	Ginger+Rosemary	6	6	6	6	6	MALE
11	6	control	4	5	4	4	4	MALE
11	6	Garlic+Thyme	6	6	6	6	6	MALE
11	6	Ginger+Rosemary	5	5	5	5	5	MALE
12	6	control	3	4	3	3	3	FEMALE
12	6	Garlic+Thyme	6	6	6	6	6	FEMALE
12	6	Ginger+Rosemary	5	5	5	5	5	FEMALE
13	6	control	4	4	4	4	4	MALE
13	6	Garlic+Thyme	7	6	7	7	7	MALE
13	6	Ginger+Rosemary	5	5	5	5	5	MALE
14	6	control	3	4	3	3	3	FEMALE

14	6	Garlic+Thyme	6	6	6	6	6	FEMALE
14	6	Ginger+Rosemary	4	5	4	4	4	FEMALE
15	6	control	4	5	4	4	4	MALE
15	6	Garlic+Thyme	7	6	7	7	7	MALE
15	6	Ginger+Rosemary	5	5	5	5	5	MALE
16	9	control	3	4	3	3	3	MALE
16	9	Garlic+Thyme	5	5	5	5	5	MALE
16	9	Ginger+Rosemary	4	4	4	4	4	MALE
17	9	control	2	3	2	2	2	FEMALE
17	9	Garlic+Thyme	5	5	5	5	5	FEMALE
17	9	Ginger+Rosemary	4	4	4	4	4	FEMALE
18	9	control	3	3	3	3	3	MALE
18	9	Garlic+Thyme	6	5	6	6	6	MALE
18	9	Ginger+Rosemary	4	4	4	4	4	MALE
19	9	control	2	3	2	2	2	FEMALE
19	9	Garlic+Thyme	5	5	5	5	5	FEMALE
19	9	Ginger+Rosemary	3	4	3	3	3	FEMALE
20	9	control	3	4	3	3	3	MALE
20	9	Garlic+Thyme	6	5	6	6	6	MALE
20	9	Ginger+Rosemary	4	4	4	4	4	MALE
21	12	control	2	3	2	2	2	MALE

21	12	Garlic+Thyme	4	4	4	4	4	MALE
21	12	Ginger+Rosemary	3	3	3	3	3	MALE
22	12	control	1	2	1	1	1	FEMALE
22	12	Garlic+Thyme	4	4	4	4	4	FEMALE
22	12	Ginger+Rosemary	3	3	3	3	3	FEMALE
23	12	control	2	2	2	2	2	MALE
23	12	Garlic+Thyme	5	4	5	5	5	MALE
23	12	Ginger+Rosemary	3	3	3	3	3	MALE
24	12	control	1	2	1	1	1	FEMALE
24	12	Garlic+Thyme	4	4	4	4	4	FEMALE
24	12	Ginger+Rosemary	2	3	2	2	2	FEMALE
25	12	control	2	3	2	2	2	MALE
25	12	Garlic+Thyme	5	4	5	5	5	MALE
25	12	Ginger+Rosemary	3	3	3	3	3	MALE

Appendix 1: Cleaning of FIsh

Appendix 2: During Colon form counting



Appendix 3: Fish after smoking

Appendix 4: Colon forms

Appendix 5: Sample preparation