



Survival of Major Food Pathogens in Natural Zeolite (Clinoptilolite) at Different Ratios and in Chicken Wings After Dipping

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Abstract: The aim of this study was to determine the viability of *Salmonella* Typhimurium and *Listeria monocytogenes* in solutions prepared with readily available natural zeolite and in chicken wings decontaminated with these solutions. To determine the effect of zeolite on pathogen viability, solutions of different concentrations (5%, 10%, 25%) were prepared and contaminated. Their numbers were then determined at different times (2, 6, and 24 hours) during storage at 4 °C. To determine the effect of zeolite on the viability of pathogens in chicken wings, contaminated chicken wings were immersed in zeolite solutions prepared at three different concentrations (5%, 10%, 25%) for two different times (1.5 min, 3 min) and their numbers were determined. According to the results of this study, the number of *S. Typhimurium* decreased by approximately 2.5 log₁₀, and the number of *L. monocytogenes* decreased by approximately 1.4 log₁₀ in zeolite solutions. The number of pathogens was significantly reduced in decontaminated chicken wings (P≤0.05). In addition, increasing the concentration of zeolite and changing the time had a significant effect on the number of *S. Typhimurium* (P≤0.05). In conclusion, zeolite was found to be antimicrobial against *S. Typhimurium* and *L. monocytogenes* and has the potential to be used in the decontamination of poultry meat. It is envisaged that zeolite may be a natural alternative to ensure food safety in the near future. To this end, zeolite should be extensively investigated in other potential food applications.

Keywords: Chicken wings, Clinoptilolite, *Listeria monocytogenes*, *Salmonella Typhimurium*, Zeolite.

Farklı Oranlardaki Doğal Zeolitde (Klinoptilolit) ve Daldırma Sonrası Tavuk Kanatlarda Önemli Gıda Patojenlerin Yaşam Kabiliyetleri

Özet: Bu çalışmanın amacı kolaylıkla temin edilebilen doğal zeolit ile hazırlanmış solüsyonlarda ve bu solüsyonlar ile dekontamine edilmiş tavuk kanatlarında *Salmonella Typhimurium* ve *Listeria monocytogenes*'in yaşam kabiliyetlerini belirlemektir. Zeolitin, patojenlerin yaşam kabiliyeti üzerine etkisini belirlemek için farklı konsantrasyonlarda (%5, %10, %25) solüsyonlar hazırlanıp kontamine edildi. Daha sonra 4 °C'de muhafaza boyunca farklı sürelerde (2., 6., 24. saat) sayıları belirlendi. Zeolitin, tavuk kanatlarında patojenlerin yaşam kabiliyetine etkisinin belirlenmesinde ise kontamine edilmiş tavuk kanatları üç farklı konsantrasyonda (%5, %10, %25) hazırlanan zeolit solüsyonlarına iki farklı sürede (1,5 ve 3 dk) daldırma işlemi yapıp sayısı belirlendi. Bu çalışmanın sonuçlarına göre, zeolit solüsyonlarında *S. Typhimurium* sayısı yaklaşık 2,5 log₁₀ azaldığı saptandı. Dekontamine edilmiş tavuk kanatlarında patojenlerin sayısı önemli ölçüde azaldığı saptandı (P≤0,05). Ayrıca zeolit konsantrasyonunun artırılması ve sürenin değişimi *S. Typhimurium* sayısı üzerinde önemli etkisinin olduğu tespit edildi (P≤0,05). Sonuç olarak zeolitin *S. Typhimurium* ve *L. monocytogenes*'e karşı antimikrobiyal etkisinin olduğu ve kanatlı etlerinin dekontaminasyonunda kullanım potansiyeli olduğu ortaya konuldu. Yakın gelecekte gıda güvenliğinin sağlanması için zeolit doğal bir alternatif olabileceği öngörülmektedir. Bunun için zeolitin diğer potansiyel gıda uygulamaları içinde kapsamlı bir şekilde araştırılması gerekmektedir.

Anahtar Kelimeler: Klinoptilolit, *Listeria monocytogenes*, *Salmonella Typhimurium*, Tavuk kanat, Zeolit.

Introduction

Poultry meat has a very important place in human nutrition due to its protein content, which is rich in essential amino acids, B-complex vitamins and unsaturated fatty acids, as well as low fat and cholesterol content (Güngören et al., 2023; Keykhosravi et al., 2020; Mehdizadeh and Langroodi, 2019). However, contaminated poultry meat can deteriorate rapidly due to the creation of a favourable environment for microbial growth, such as water activity and high pH (Silva et al., 2018). Therefore, the presence of possible pathogens and spoilage microorganisms in these products causes health problems and economic losses in the poultry industry (İncili et al., 2020). Poultry meat and meat products appear to be responsible for a significant proportion of foodborne illness caused by these pathogens, and the use of antimicrobials is therefore important to reduce the risk of these pathogens and protect human health. Many methods have been tried to improve the microbial and chemical quality of poultry meat and meat products. A wide range of decontamination methods are available for chemical decontamination in the meat and meat products industry (Özbay and Sarıçoban, 2014). However, as these products still pose a risk in terms of shelf life and public health, interest in natural preservatives and additives has recently increased (Aydemir and Arslan, 2023).

Zeolites, commonly found in nature, are microporous crystalline aluminosilicates consisting of AlO_4 and SiO_4 tetrahedral units and are used in various industries (Huwei et al., 2021). Zeolites are edible, biocompatible and most likely non-toxic substances, but they have several special properties, such as molecular sieve structure, ionic exchangeability and water absorbency. These properties allow them to be used in various applications in different fields. (Hecht et al., 2011; Papaioannou et al., 2002).

Zeolites (clinoptilolite) have been used as additives in food and feed for several years due to their ability to adsorb toxins produced by moulds and parasites, fungal mycotoxins, ammonium ions and heavy metals (Deshmukh et al., 2023; Singh and Kumar, 2023; Tzia and Zorpas, 2012; Villa et al., 2022). In addition, the use of zeolites in food packaging materials can prevent spoilage reactions by selectively absorbing oxygen, thereby increasing the shelf life of the product (Kombaya-Touckia-Linin et al., 2019; Lu et al., 2017). They can also be used for odour absorption in the packaging of food products that are sensitive to odours and generate bad odours, or absorb odours from the environment (Sharma et al., 2023). Another important feature of zeolites, their antimicrobial effect that prevents the growth of harmful microorganisms, has been studied by various researchers (Janićijević et al., 2020; Prabhu and Devaraju, 2018; Sánchez et al., 2017; Soysal et al., 2015; Tunç and Duman, 2011). This demonstrates the potential of zeolites as antimicrobial agents.

The potential food applications of zeolites are that they are classified as generally recognised as safe (GRAS) substances by the United States Food and Drug Administration (USFDA, 2015) and the European Food Safety Authority (EFSA, 2011). These substances, which have been

approved by organisations, have been widely researched for medical applications or environmental remediation, but have been less studied and researched for food applications. (Eroğlu et al., 2017 ; Lopes et al., 2021). Therefore, it was concluded that more research on zeolites is needed in various fields related to food science and technology.

The aim of this study was to determine the viability of *Salmonella* Typhimurium and *Listeria monocytogenes* in solutions prepared with readily available natural zeolite and in chicken wings decontaminated with these solutions.

Materials and Methods

Ethics Committee: This study is not subject to HADYEK permission in accordance with Article 8 (k) of the "Regulation on Working Procedures and Principles of Animal Experiments Ethics Committees.

Preparation of inoculum: For the preparation of the inoculum, reference strains of *Salmonella* Typhimurium (NCTC 74, 12416, and ATCC 14028) and *Listeria monocytogenes* (N 7144, RSKK 474, and 476) were employed. The method used by İncili et al. (2020) was applied. An inoculum of approximately $6.0 \log_{10}/mL$ was used for the survival assay of pathogens in zeolite and for chicken wing samples.

Zeolite supply and preparation: Zeolite (Nanokar, Türkiye) was supplied by purchase. Zeolite was prepared at 5%, 10% and 25% concentrations. Sterile distilled water was used to prepare different zeolite concentrations and mixed until the zeolite dissolved.

Preparation of chicken wings: On the day of the experiment, fresh chicken wings were purchased from a local market in Şanlıurfa and brought to the laboratory in the cold chain, and the experiments were performed as soon as possible. To all samples, 0.5 mL of diluted bacterial cocktail was added by spreading it on all surfaces of the samples and allowed to adhere for 15 minutes at room temperature. The samples were then randomly selected and divided into ten groups: control (no treatment), three different zeolite concentrations (5%, 10% and 25%) and two different immersion times (1, 5 and 3 min). The groups were marinated by the immersion method. To obtain the concentrations of zeolite used in the study, the zeolite was diluted with sterile distilled water and shaken well to mix it. The ratio of immersion liquid to meat sample was 2:1 and immersion procedures were performed in sterile glass jars.

Pathogens survival experiment in zeolite: To evaluate the antibacterial effect of zeolite, approximately $6.0 \log_{10}/mL$ *Salmonella* Typhimurium and *Listeria monocytogenes* were added to three different zeolite concentrations (5%, 10% and 25%). The number of pathogens was determined immediately after inoculation and after 2, 6 and 24 hours of incubation at 4 °C. The experiment was performed in triplicate.

Microbiological analyses: Each marinated meat sample (25 ± 1 g) was collected under aseptic conditions and transferred to sterile sampling bags. Next, 225 mL of 0.1%

peptone water (PW) was added to the sampling bags, and the mixture was homogenized using a stomacher (BagMixer Interscience, France) for 3 minutes. For the detection of *L. monocytogenes*, Oxford agar (Biokar, France) was used, while xylose-lysine-deoxycholate agar (XLD agar) (Biokar, France) was employed for *S. Typhimurium*. The XLD and Oxford plates were incubated at 37 ± 1 °C for 24 hours, and the number of colonies with specific morphology was recorded.

pH analyses: The pH of the chicken wing samples was measured using a pH meter (HI 11310, Hanna Instruments, USA). The fluid (rinse fluid) remaining in the sample bags after microbiological analysis of the chicken wing samples was used for pH analyses.

Statistical analyses: Microbial counts and pH values of the samples were subjected to statistical analysis. Microbiological data were logarithmically transformed for statistical analysis. The general linear model (GLM) was used for statistical analysis. In the GLM procedure, zeolite concentrations (5%, 10% and 25%) and immersion times (1, 5 and 3 min) were considered as fixed effects and replications as random effects. Multiple comparisons were made using the Tukey test ($P\leq 0.05$). In this study, all data were obtained from three independent replicates and results are presented as mean \pm standard error of the mean.

Results

pH value: The average pH values of chicken wings samples at 4 °C are depicted in Table 1. There was no difference between the groups in terms of pH ($P\geq 0.05$).

Table 1. pH values of chicken wings (Mean \pm SE).

Concentration	Time	pH
Control		6.67 \pm 0.28
5%	1.5 min.	6.63 \pm 0.01
	3 min.	6.44 \pm 0.06
10%	1.5 min.	6.61 \pm 0.07
	3 min.	6.53 \pm 0.07
25%	1.5 min.	6.53 \pm 0.12
	3 min.	6.58 \pm 0.02
Statistics	C	$P\geq 0.05$
	T	$P\geq 0.05$
	CxT	$P\geq 0.05$

C: Concentration, T:Time

Pathogens survival experiment at zeolite concentrations: The number of *S. Typhimurium* decreased by approximately 2.5 \log_{10} (Figure 1), while the number of *L. monocytogenes* decreased by approximately 1.4 \log_{10} (Figure 2). Although increasing the zeolite concentration had an insignificant effect on reducing the number of bacteria ($P\geq 0.05$), time had a significant effect on the number of *S. Typhimurium* ($P\leq 0.05$).

Survival of pathogens in chicken wings after zeolite decontamination: Compared to the control group, the number of *S. Typhimurium* was significantly reduced in the

samples of chicken wings immersed in zeolite (Figure 3). The highest decrease was observed at 10% and 25% concentrations after 3 min. *S. Typhimurium* counts decreased by 0.86, 1.20 and 1.28 \log_{10} after 3 min. decontamination at 5%, 10% and 25% concentrations, respectively. Concentration time interaction was not significant for *S. Typhimurium* counts. Compared to the control group, the number of *L. monocytogenes* was significantly reduced in the samples of chicken wings immersed in zeolite (Figure 4). *L. monocytogenes* counts decreased by 1.31, 1.46 and 1.59 \log_{10} after 3 min. decontamination at 5%, 10% and 25% concentrations, respectively. Concentration time interaction was not significant for *L. monocytogenes* counts.

Discussion

The unique structural properties of zeolite provide them with adsorptive, ion exchange and molecular sieving properties (Dikić, 2021). Due to their existing properties, they can have an antimicrobial effect. In the present study, zeolite was found to significantly reduce the number of *S. Typhimurium* and *L. monocytogenes* in both the survival experiment and chicken wing meat ($P\leq 0.05$). There is previous evidence that zeolite can be used as an antimicrobial agent (Uchida et al., 1992; Mallek, 2012; Pajnik et al., 2020). Although zeolite has been used as an antimicrobial agent, to the best of our knowledge, no research on the decontamination of pathogens in chicken meat has been found (Villa et al., 2022). Mallek et al. (2012) reported that the addition of zeolite (0.5 or 1% a/a) to chicken diets resulted in a significant ($P\leq 0.05$) reduction in total culturable microbial levels and also resulted in improved organoleptic quality of meat.

The results of the present study showed that zeolite exhibited antimicrobial activity against Gram-positive (*L. monocytogenes*) and Gram-negative (*S. Typhimurium*) bacteria. The high ion exchange capacity of zeolite enhanced this antimicrobial property. It has been recommended that zeolite should be combined with ions such as zinc oxide (ZnO) ions, and silver (Ag +) ions for a higher antimicrobial effect (Dutta and Wang, 2019; Wang et al., 2019). In particular, Ag + doped zeolite systems have been reported to exhibit broad-spectrum antimicrobial activity against both Gram-negative (*Escherichia coli* and *S. Typhimurium*) and positive (*L. monocytogenes*, *Staphylococcus aureus*) bacteria (Janićijević et al., 2020; Sánchez et al., 2017).

It is known that *S. Typhimurium* can grow optimally at a pH range of 6.5-7.5 and can survive between pH 4.5 and 9.0, while *L. monocytogenes* is highly resistant to low temperature and pH (İncili et al., 2021). The pH values of the zeolite concentrations used in the study are at values where bacteria can survive (Table 1). Therefore, we believe that pH has no effect on the decrease in bacterial numbers. Its believe that the main reduction in bacterial numbers is due to the high ion exchange and absorption properties of the zeolite This is because it has been reported that clinoptilolite can adsorb bacteria and thus cause a decrease in bacterial numbers (Prasai et al., 2017). It is emphasised that the rough

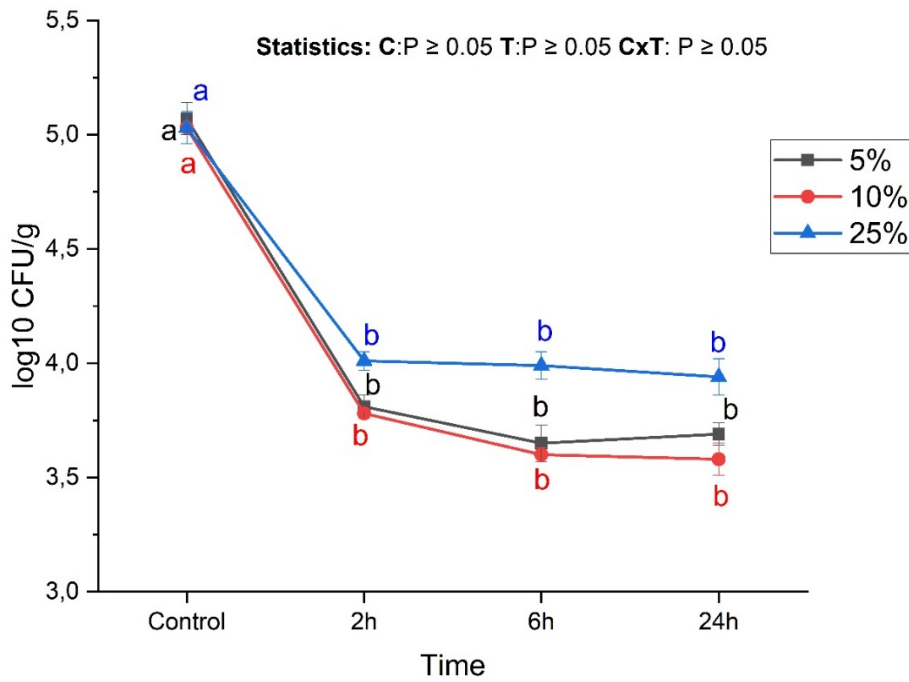


Figure 1. Survival of *Listeria monocytogenes* in zeolite at 4 °C for 24 hours (log₁₀ CFU/g±SE). ^{a-b}: The mean values with different letters among the sampling hour are significantly different (P≤0.05). C: Concentration, T: Time.

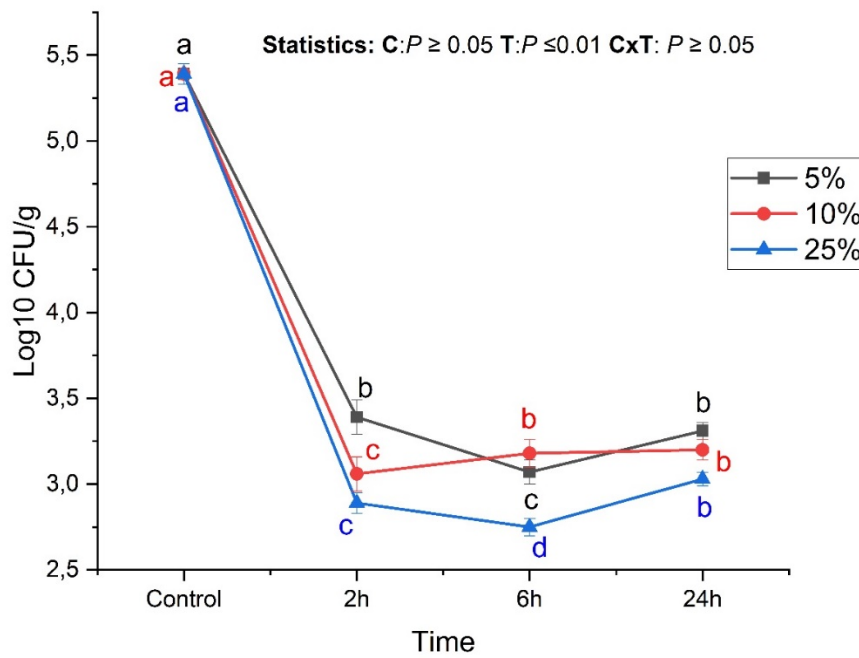


Figure 2. Survival of *Salmonella* Typhimurium in zeolite at 4 °C for 24 hours (log₁₀ CFU/g±SE). ^{a-d}: The mean values with different letters among the sampling hour are significantly different (P≤0.05). C: Concentration, T: Time.

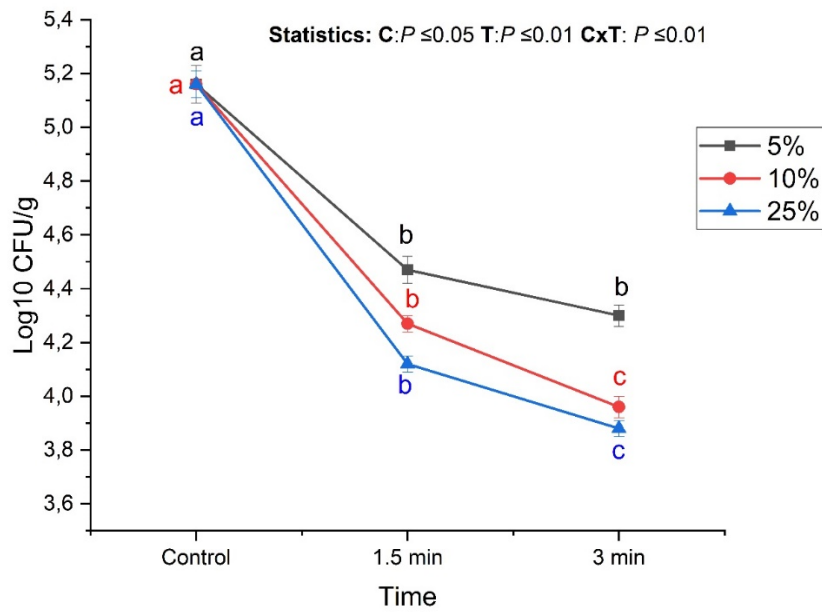


Figure 3. Mean *Salmonella Typhimurium* counts (log10 CFU/g±SE) in chicken wings at different zeolite concentrations at different times. a-c: The mean values with different letters among the sampling hour are significantly different (P≤0.05). C: Concentration, T:Time.

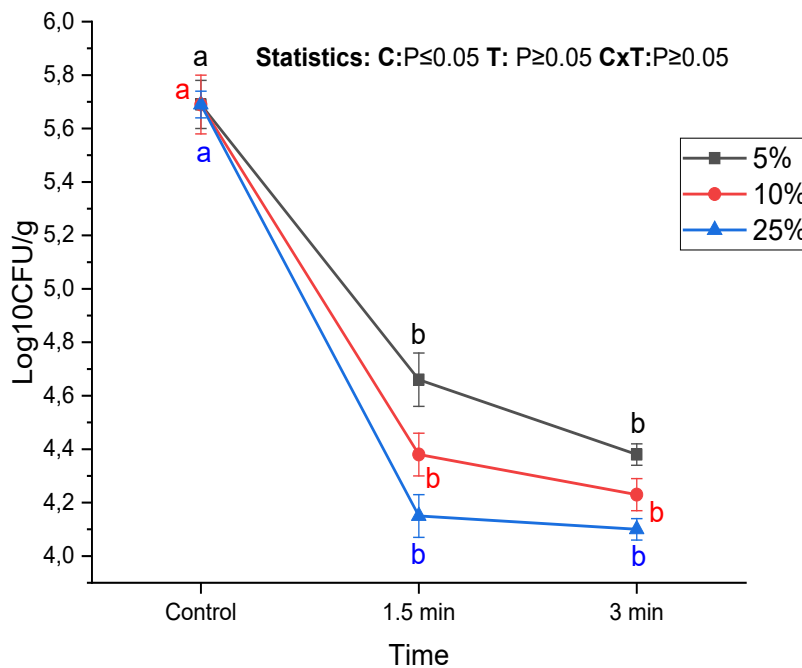


Figure 4. Mean *Listeria monocytogenes* counts (log10 CFU/g±SE) in chicken wings at different zeolite concentrations at different times. a-c: The mean values with different letters among the sampling hour are significantly different (P≤0.05). C: Concentration, T:Time.

surfaces of clinoptilolite particles provide a better microenvironment for the adsorption of bacteria (Hrenovic et al., 2005). An in vitro study by Wu et al. (2013) reported that *Escherichia coli* and *S. Typhimurium* were adsorbed by

clinoptilolite (Wu et al., 2013). In addition, we believe that the different levels of *S. Typhimurium* and *L. monocytogenes* bacteria in zeolite solutions are due to the different effects of zeolite on gram-negative and gram-positive bacteria and,

most importantly, the different adsorption properties of zeolite for each bacterium. In fact, clinoptilolite has been reported to adsorb selectively on bacterial species (Prasai et al., 2017).

In zeolite solutions, the number of *S. Typhimurium* decreased by 2.5 log₁₀ (Figure 1) and the number of *L. monocytogenes* decreased by approximately 1.4 log₁₀ (Figure 2). For chicken wing decontamination, the numbers of *S. Typhimurium* and *L. monocytogenes* decreased by 1.28 (Figure 3) and 1.59 log₁₀ (Figure 4), respectively. The greater reduction in *S. Typhimurium* in the zeolite solution can be explained by the fact that bacteria firmly attached to the wing meat can be protected from the effects of antibacterial agents (İncili et al., 2020). The opposite situation for *L. monocytogenes* can be explained by the fact that the bacteria cannot fully adhere to the wing meat after contamination and also that the bacteria enter the stationary phase in the zeolite solution.

In the zeolite solution, the number of *S. Typhimurium* decreased significantly after 2 and 6 hours, but not after 24 hours (Figure 2), while the number of *L. monocytogenes* decreased significantly after 2 hours, but not after 24 hours. This may be explained by the fact that bacteria develop resistance to the antimicrobial mechanisms of zeolite after a certain period of time. Indeed, Wang et al. (2019) showed that environmental conditions such as exposure to acids can harm bacteria. However, bacteria that are not fatally injured can enter the stationary phase and/or regain the ability to regrow. Bacteria have also been found to be highly adaptable to environmental conditions over time (Chung et al., 2018). In chicken wings decontaminated with zeolite solution, *S. Typhimurium* continued to decrease at 10% and 25% concentrations with time (Figure 3). However, the interaction of concentration and time was not effective for *L. monocytogenes* (Figure 4). This may be explained by the slowing of growth of *L. monocytogenes* against antimicrobial mechanisms and entry into stationary phase (İncili et al., 2020).

As a result, zeolite was shown to be antimicrobial against *S. Typhimurium* and *L. monocytogenes* and has a potential for use in the decontamination of poultry meat. Due to the high ion exchange properties of zeolite, modified zeolites can have very different, perhaps more potent, effects on pathogens. Therefore, zeolite can be combined with modification for stronger bactericidal effects. It is envisaged that zeolite may be a natural alternative for food safety in the near future. To this end, zeolite should be extensively investigated in other potential food applications

Conflict of Interest

The authors stated that they did not have any real, potential or perceived conflict of interest.

Ethical Approval

This study is not subject to HADYEK permission in accordance with Article 8 (k) of the "Regulation on Working

Procedures and Principles of Animal Experiments Ethics Committees".

Similarity Rate

We declare that the similarity rate of the article is 12% as stated in the report uploaded to the system.

Explanation

Some data from this study was presented as an abstract at the 10th Veterinary Food Hygiene Congress on 25-27 April 2024.

Author Contributions

Motivation / Concept: MEA, MNG, ES
 Design: MEA
 Control/Supervision: MEA
 Data Collection and / or Processing: MEA, MNG
 Analysis and / or Interpretation: MEA, MNG
 Literature Review: MEA, ES
 Writing the Article: MEA, ES
 Critical Review: MEA

References

- Aydemir ME, Arslan A, 2023: Investigation the Effects of Jerusalem Thorn (*Paliurus spina-christi* Mill.), Oriental Hackberry (*Celtis tournefortii* L.) Fruits and Black Cumin (*Nigella sativa* L.) Seed on Microbial Quality and Physicochemical Properties of Meatballs. *Harran Üniv Vet Fak Derg*, 12(1), 27-34.
- Chung D, Cho TJ, Rhee MS, 2018: Citrus fruit extracts with carvacrol and thymol eliminated 7-log acid-adapted *Escherichia coli* O157: H7, *Salmonella typhimurium*, and *Listeria monocytogenes*: A potential of effective natural antibacterial agents. *Int Food Res*, 107, 578-588.
- Deshmukh RK, Hakim L, Akhila K, Ramakanth D, Gaikwad KK, 2023: Nano clays and its composites for food packaging applications. *Int Nano Lett*, 13(2), 131-153.
- Dikić J, Lukić I, Pajnik J, Pavlović J, Hrenović J, Rajić N, 2021: Antibacterial activity of thymol/carvacrol and clinoptilolite composites prepared by supercritical solvent impregnation. *J Porous Mater*, 28(5), 1577-1584.
- Dutta P, Wang B, 2019: Zeolite-supported silver as antimicrobial agents. *Coord Chem Rev*, 383, 1-29.
- Eroglu N, Emekci M, Athanassiou CG, 2017: Applications of natural zeolites on agriculture and food production. *J Sci Food Agri*, 97(11), 3487-3499.
- Güngören A, Güngören G, Şimşek ÜG, Yılmaz Ö, Bahşi M, Aslan, S. 2023: Quality properties and fatty acids composition of breast meat from Japanese quails with different varieties grown under warm climate. *Veterinaria*, 72(2), 163-173.
- Hrenović J, Tibljaš D, Orhan Y, Büyükgüngör H, 2005: Immobilisation of *Acinetobacter calcoaceticus* using natural carriers. *Water SA*, 31(2), 261-266.
- Huwei S, Asghari M, Zahedipour-Sheshglani P, Alizadeh M, 2021: Modeling and optimizing the changes in physical and biochemical properties of table grapes in response to natural zeolite treatment. *LWT*, 141, 110854.
- İncili GK, Akgöl M, Aydemir ME, Alan S, Mutlu M, İlhak Oİ, Öksüztepe G, 2020: Fate of *Listeria monocytogenes* and

- Salmonella Typhimurium in homemade marinade and on marinated chicken drumsticks, wings and breast meat. *LWT*, 134, 110231.
- İncili GK, Aydemir ME, Akgöl M, Kaya B, Kanmaz H, Öksüztepe G, Hayaloğlu AA, 2021: Effect of Rheum ribes L. juice on the survival of *Listeria monocytogenes*, *Escherichia coli* O157: H7 and *Salmonella Typhimurium* and chemical quality on vacuum packaged raw beef. *LWT*, 150, 112016.
- Janićijević D, Uskoković-Marković S, Ranković D, Milenković M, Jevremović A, Vasiljević BN, Bajuk-Bogdanović D, 2020: Double active BEA zeolite/silver tungstophosphates–Antimicrobial effects and pesticide removal. *Sci Total Environ*, 735, 139530.
- Keykhosravi K, Khanzadi S, Hashemi M, Azizzadeh M, 2020: Chitosan-loaded nanoemulsion containing *Zataria Multiflora* Boiss and *Bunium persicum* Boiss essential oils as edible coatings: Its impact on microbial quality of turkey meat and fate of inoculated pathogens. *Int J Biol Macromol*, 150, 904-913.
- Kombaya-Touckia-Linin EM, Gaucel S, Sougrati MT, Stievano L, Gontard N, Guillard V, 2019: Elaboration and Characterization of Active Films Containing Iron–Montmorillonite Nanocomposites for O₂ Scavenging. *Nanomater*, 9(9), 1193.
- Lopes MM, Coutinho TC, Malafatti JOD, Paris EC, de Sousa CP, Farinas CS, 2021: Immobilization of phytase on zeolite modified with iron (II) for use in the animal feed and food industry sectors. *Process Biochem*, 100, 260-271.
- Lu L, Chen C, Samarasekera C, Yeow JT, 2017: Influence of zeolite shape and particle size on their capacity to adsorb uremic toxin as powders and as fillers in membranes. *J Biomed Mater Res B Appl Biomater*, 105(6), 1594-1601.
- Mallek Z, Fendri I, Khannous L, Ben Hassena A, Traore AI, Ayadi MA, Gdoura R, 2012: Effect of zeolite (clinoptilolite) as feed additive in Tunisian broilers on the total flora, meat texture and the production of omega 3 polyunsaturated fatty acid. *Lipids Health Dis*, 11, 1-7.
- Mehdizadeh T, Langroodi AM, 2019: Chitosan coatings incorporated with propolis extract and *Zataria multiflora* Boiss oil for active packaging of chicken breast meat. *Int J Biol Macromol*, 141, 401-409.
- Özbay SD, Sarıçoban C, 2014: Et ve Et Ürünlerine Uygulanan Bazı Dekontaminasyon Yöntemleri. *Eur. J. Sci. Technol*, 1 (3): 92-99
- Pajnik J, Lukić I, Dikić J, Asanin J, Gordic M, Misić D, Korzeniowska M, 2020: Application of supercritical solvent impregnation for production of zeolite modified starch-chitosan polymers with antibacterial properties. *Mol*, 25(20), 4717.
- Papaioannou DS, Kyriakis SC, Papasteriadis A, Roubies N, Yannakopoulos A, Alexopoulos C, 2002: Effect of in-feed inclusion of a natural zeolite (clinoptilolite) on certain vitamin, macro and trace element concentrations in the blood, liver and kidney tissues of sows. *Res J Vet Sci*, 72(1), 61-68.
- Prabhu R, Devaraju A, 2018: Developing an antimicrobial packaging to improve the shelf life of meat using silver zeolite coating on BOPP film. *Mater Today: Proceedings*, 5(6), 14553-14559.
- Prasai TP, Walsh KB, Bhattarai SP, Midmore DJ, Van TT, Moore RJ, Stanley D, 2017: Zeolite food supplementation reduces abundance of enterobacteria. *Microbiol Res*, 195, 24-30.
- Sánchez MJ, Mauricio JE, Paredes AR, Gamero P, Cortés D, 2017: Antimicrobial properties of ZSM-5 type zeolite functionalized with silver. *Mater Lett*, 191, 65-68.
- Sharma P, Sutar PP, Xiao H, Zhang Q, 2023: The untapped potential of zeolites in techno-augmentation of the biomaterials and food industrial processing operations: A review. *J Future Foods*, 3(2), 127-141.
- Silva F, Domingues FC, Nerín C, 2018: Trends in microbial control techniques for poultry products. *Crit Rev Food Sci Nutr*, 58(4), 591-609.
- Singh R, Kumar S, 2023: Nanomaterials: Plethora of Opportunities as Smart Packaging, Preserving, and Processing Agent in Food Industry. In *Nanotechnology Advancement in Agro-Food Industry* (pp. 43-79). Singapore: *Springer Nature Singapore*.
- Soysal Ç, Bozkurt H, Dirican E, Güçlü M, Bozhüyük ED, Uslu AE, Kaya S, 2015: Effect of antimicrobial packaging on physicochemical and microbial quality of chicken drumsticks. *Food Control*, 54, 294-299.
- Tunç S, Duman O, 2011: Preparation of active antimicrobial methyl cellulose/carvacrol/montmorillonite nanocomposite films and investigation of carvacrol release. *LWT-Food Sci Technol*, 44(2), 465-472.
- Tzia C, Zorpas AA, 2012: Zeolites in food processing industries. *Handbook of natural zeolites*, 601-651.
- Uchida T, Maru N, Furuhashi M, Fujino A, Muramoto S, Ishibashi A, Koshiba K, Shiba T, Kikuchi T, 1992: Anti-bacterial zeolite balloon catheter and its potential for urinary tract infection control. *Hinyokika Kyo*, 38, 8, 973-978.
- Villa CC, Valencia GA, Córdoba AL, Ortega-Toro R, Ahmed S, Gutiérrez TJ, 2022: Zeolites for food applications: A review. *Food Biosci*, 46, 101577.
- Wang L, Dionysiou DD, Wu W, Chen H, Xie X, Lin J, 2019: Zinc oxide-coated zeolite adsorbs and inactivates waterborne *Staphylococcus aureus*. *Chemosphere*, 229, 1-7.
- Wu QJ, Wang LC, Zhou YM, Zhang JF, Wang T, 2013: Effects of clinoptilolite and modified clinoptilolite on the growth performance, intestinal microflora, and gut parameters of broilers. *Poult sci*, 92(3), 684-692.