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Edible Coatings as a Sustainable Solution during Chilled Preserving Chicken Fillet

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Abstract

Chicken meat is highly demanded with especial considerations of safety and health concerns; so, innovative preservation techniques are essential in the consumer's acceptability of the meat products. So, the current study was conducted to evaluate the effect of plain carboxy-methyl-cellulose (CMC 10.0%) alone **(G1),** and fortified CMC with Arabic gum 2.0% (CMC-AG) **(G2)**, CMC with mastic gum 2.0% (CMC-MG) **(G3)**, and CMC with olibanum gum 2.0% (CMC-OG) **(G4)** as edible coating on the physical, bacteriological and chemical quality of chicken fillet during refrigeration; besides that, the anti-biofilm effect of the used treatments was investigated against some of isolated biofilm-positive strains, supported with molecular detection of biofilm regulating genes of some isolate *Staph. aureus* strains, that is reflecting its safety and keeping quality during refrigeration storage. Results revealed that control samples showed clear spoilage and loss of acceptability by the 5th day of storage, whereas CMC-coated fillets remained acceptable up to the 7th day, CMC-AG and CMC-MG up to the 8th day, and CMC-OG up to the 9th day, confirming a pronounced extension of shelf life. All treated groups exhibited significantly reduced drip loss, cooking loss, with higher cooking yield throughout storage, reflecting enhanced water-holding capacity; these improvements followed the order CMC-OG > CMC-MG > CMC-AG > CMC alone. Chemical spoilage indicators increased gradually with time; however, fortified coatings significantly delayed lipid oxidation and protein degradation. On the 8th day of refrigeration, TBA values were 0.84, 0.74, and 0.66 mg malonaldehyde/kg for CMC-AG, CMC-MG, and CMC-OG treated groups,

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respectively, while TVN values were 18.3, 17.8, and 14.3 mg/100 g, all markedly lower than the control and CMC-alone groups and closer to permissible limits. Microbiologically, coated samples showed significant reductions in aerobic plate count, coliforms, psychrotrophs, and *Staph. aureus*; with extended shelf life and limit acceptability up to nine days of refrigerated storage for the CMC-OG treated samples; so, CMC–OG consistently exhibited the strongest antibacterial effect. Molecular detection of *Staph. aureus* biofilm-associated genes revealed absence of *icaA* in all isolates, while *icaD* gene was detected in 80%; in addition, *spa* and *fnb*A genes were detected in in 40% of isolates, indicating a predominance of alternative, protein-mediated biofilm mechanisms. Moreover, control and plain CMC groups showed strong biofilm forming bacteria while the fortified CMC coating groups showed potent anti-biofilm effect especially against *E. coli* O_{44}:K_{74}, *E. coli* O_{25}:K_{11} and *Staph. aureus*; while moderate effect was recorded against *K. ozaenae and K. oxytoca*. On the other hand, *Staph. pseudintermedius* showed resistance to CMC-AG, whereas CMC-MG and CMC-OG had a potent effect. Overall, fortified CMC edible coatings—especially those containing olibanum gum—represent an effective natural approach for improving the technological quality, chemical stability, microbiological safety, and refrigerated shelf life of chicken fillet.

Introduction

Chicken meat holds a vital place in global nutrition due to its affordability, high protein content, and versatility in cooking applications. It serves as a primary source of animal protein for millions, contributing essential amino acids, vitamins, and minerals to human diets **(Grigore *et al.*, 2025)**.

However, the high demand and extensive production of chicken meat also bring significant challenges, particularly concerning microbial populations as it may be contaminated by different spoilage and/or poisoning foodborne as well as environmental pathogens **(Shanmugasundaram, 2025)**.

Contamination of chicken meat and meat products may occur at multiple points, including during processing, handling, and improper storage. Thus, besides stringent hygiene practices and proper cooking, innovative techniques and various food additives are of major concern to minimize health risks while ensuring chicken meat remains a safe and reliable nutrition source **(Mafe *et al.*, 2024).**

Besides that, biofilm formation by some of foodborne pathogens possess a significant risk on the consumer's health and food quality because of creating protective matrices that shield microbial communities, promoting persistent contamination in food production environments such as processing surfaces and equipment leading to cross-contamination during post-processing, compromising food safety and accelerating spoilage **(Liu *et al.*, 2023)**.

On the other hand, natural edible coatings operate as an innovative antioxidant and antibacterial barrier, extending the shelf life and quality of food items **(Elsabagh *et al.*, 2023)**. Fortification of such coatings with natural herbal extracts has become increasingly important to enhance physicochemical and microbiological quality of meat products while extending shelf life regarding its bioactive compounds such as phenolics, flavonoids, and essential oils that exhibit strong antioxidant and antimicrobial properties that help in inhibiting lipid oxidation, maintain color and texture, and reduce microbial growth **(Yu *et al.*, 2021)**. Also, it offers a clean-label, safe alternative to synthetic additives, aligning with consumer demand for natural and health-promoting foods **(Nieto *et al.*, 2023)**.

Gums have been used for their innovative techno-functional features as well as thickening, gelling, stabilizing, bulking, and emulsifying qualities in meat production. Arabic gum (*Acacia Senegal*), mastic gum (*Pistacia lentiscus*), and frankincense or olibanum gum (*Boswellia sacra*) have been traditionally used as natural food preservatives due to their antimicrobial and antioxidant properties **(Abdelkhalek *et al.*, 2024)**.

Arabic gum (AG) is widely applied as an edible coating to extend shelf life by reducing microbial growth and moisture loss. Moreover, mastic gum (MG), rich in antioxidants

and triterpenic acids, is known for its antibacterial and antifungal effects, aiding in food preservation and overall wholesome **(Bozorgi *et al.*, 2013)**. Furthermore, frankincense, also known as olibanum gum (OG), contains bioactive boswellic acids and terpenoids that provide antimicrobial activity against wide range of foodborne bacteria and fungi, contributing to food preservation and safety **(Ahmed *et al.*, 2025)**.

Therefore, the current study explored the effect of using functional carboxy-methyl-cellulose (CMC) edible coating fortified with Arabic, mastic and olibanum gum extracts on the physical, bacteriological and chemical quality of chicken fillet during refrigeration storage.

Materials and Methods

Materials

Raw fresh chicken fillet samples were purchased from the same poultry butcher in Benha city, Qalubiya governorate. Carboxy methyl cellulose (CMC) was obtained from Sigma-Aldrich, USA. In addition, Arabic gum (AG: E414), mastic gum (MG) and olibanum gum (OG) were obtained from Organic Nation®, an online store that sells pure gum powder.

Preparation of gum extracts

Ethanolic extracts from AG, MG and OG were prepared according to **Saleh *et al.* (2021), Letsiou *et al.* (2024),** and **Elhaddad *et al.* (2023)**, respectively; where the step of extraction was performed at National Research Centre, Dokki, Giza, Egypt.

Preparation of edible coating

The edible coat of CMC was prepared according to **Ali *et al.* (2023)** where 10.0% solution was prepared by mixing CMC with sterile distilled water and stirred for approximately 30 sec.**;** while it was fortified with previously prepared extracts of a concentration of 2% vol./vol. according to **Abdelkhalek *et al.* (2024)**.

Preparation of experimental groups

Chicken fillet samples were divided into five groups, twenty-one fillet cuts per group, represented by **C**: Control untreated fillet, **G1**: Treated fillet with plain CMC alone (10%), **G2**: Treated fillet with fortified CMC with 2% AG (CMC-AG), **G3**: Treated fillet with fortified CMC with 2% MG (CMC-MG), and **G4**: Treated fillet with fortified CMC with 2% OG (CMC-OG).

Treated groups **(G1 to G4)** were subjected to immersing in either CMC alone or fortified CMC with the prepared extracts for thirty seconds before leaving to dry in the room temperature representing outer edible coating. After dryness, all samples were taken from each group, examined and recorded as zero day, and kept in the refrigerator (4±1ºC) along the experimental period; where fillet samples were examined daily for the following criteria:

Physical evaluation

Color, odor, texture, taste after boiling in water bath, and overall appealing of the fillet samples were evaluated by five well-trained impartial investigators at the Food Hygiene unit, Animal Health Research Institute - Benha lab. Mean values of scores were recorded as overall sensory scores following **Mörlein (2019)** in scores (1 to 5), where ≤1- represented the worst while 5- represented the excellent mark.

Drip loss (%) was measured according **Kaić *et al.* (2021)** as an indicator of water holding capacity and meat quality; through excision of cylindrical cores (typically 25-30 mm diameter × 25 mm height, weighing 15-25g) from the meat sample parallel to the fiber orientation, blot the surface with filter paper to remove superficial moisture, record the initial weight, and suspend the core vertically and kept at refrigerator (4±1°C) allowing gravitational exudation of fluid without pressure.

Finally, re-weight the sample directly, calculating drip loss as a percentage of the initial sample weight using the formula: Drip Loss (%) = [(Initial weight - Final weight) / Initial weight] × 100.

Cooking yield was estimated, according to **USDA (2012),** by weighing each sample before cooking (raw weight) and immediately after cooking and cooling to room temperature (cooked weight). The cooking yield was calculated as a percentage using the following formula:

Cooking yield (%) = (Cooked weight / Raw

weight) × 100.

Cooking loss was determined from the difference between the raw and cooked weights of the samples. After recording the initial raw weight and the final cooked weight, cooking loss was calculated as a percentage according to the formula:
Cooking loss (%) = [(Raw weight − Cooked weight) / Raw weight] × 100.

Evaluation of the bacteriological quality
Tenth fold serial dilutions of each fillet group samples were prepared according to **ISO 6887-1 (2017),** followed by estimating the aerobic plate counting (APC), coliform, psychrotrophs, and *Staphylococcus aureus* counts according to **ISO 4833-1 (2022), ISO 17410 (2019), ISO 4832 (2006), and ISO 6888-1 (2021)** using plate count agar (OXOID) for APC and psychrotroph counting, violet red bile agar (OXOID) and Baird-Parker agar (Himedia) for coliform and *Staph. aureus* counting and incubation conditions according to the previously mentioned standard methods, respectively.
The isolated coliforms, from the untreated control group, were identified according to **Markey *et al.* (2013);** where the collected pink colonies were cultivated on differentiated media (Brilliant green media**,** Xylose-lysin-deoxycholate (XLD) agar, Tryptone Bile X-glucuronide (TBX) agar, Eosin methylene blue agar (EMB), biochemical tests; and serotyping of *E. coli* isolates.
The detected staphylococcus strains, from the untreated control group, were isolated and identified according to **Paul *et al.* (2009**) using mannitol and sucrose fermentation test, staph-tec® test (oxiod), DNase activity, V.P. test, coagulase test, and heamolytic activity.
Some of the identified *Staph. aureus* isolates, from the untreated control group, were molecularly examined, in RLQP of Animal Health Research Institute, to detect the presence of *spa, icaA, icaD* and *fnb*A biofilm regulatory genes using the following gene sequences and the mentioned references in **Table (A).**

Table (A). Primers sequences, target genes, amplicon sizes and cycling conditions.

Target gene	Primers sequences	Amplified segment (bp)	Primary denaturation	Amplification (35 cycles)			Final extension	Reference
				Secondary denaturation	Annealing	Extension		
spa	TCA ACA AAG AAC AAC AAA ATG C GCT TTC GGT GCT TGA GAT TC	226	94˚C 5 min.	94˚C 30 sec.	55˚C 30 sec.	72˚C 30 sec.	72˚C 7 min.	**Wada *et al.*, 2010**
icaA	CCT AAC TAA CGA AAG GTA G AAG ATA TAG CGATAA GTG C	1315	94˚C 5 min.	94˚C 30 sec.	49˚C 1 min.	72˚C 1.2 min.	72˚C 12 min.	**Ciftci *et al.* 2009**
icaD	AAA CGTAAG AGA GGT GG GGC AAT ATG ATC AAGATA	381	94˚C 5 min.	94˚C 30 sec.	49˚C 40 sec.	72˚C 45 sec.	72˚C 10 min.	
fnb A	CATAAATTGGGAGCAG-CATCA ATCAGCAGCTGAATTCCCATT	127	94˚C 5 min.	94˚C 30 sec.	58˚C 30 sec.	72˚C 30 sec.	72˚C 7 min.	**Vancraeynest *et al.*, 2004**

Additionally, the biofilm formation of the isolated strains of *E. coli,* Klebsiella and *S. aureus,* that were isolated from the examined control and treated groups, was evaluated on Congo Red Agar (CRA) medium according to **Subramanian *et al.* (2012**). Black colonies with a dry crystalline consistency indicate strong biofilm production. Weak biofilm remained pink while darkening of the colonies with absence of dry crystalline colonies indicated intermediate result. The experiment was performed in triplicate. *Edwardsiella tarda* MW362141 was used as control positive.

Chemical evaluations

The quality of chicken fillet was assessed by measuring its pH, Total Volatile Nitrogen (TVN), and Thiobarbituric Acid (TBA) values according to specific Egyptian Organization for Standardization (EOS) methods **(EOS 63-11, 63-9 and 63-10, 2006)**, respectively.

The experimental groups were examined at zero time (30 min. after dryness of the outer coat), and repeated daily until appearing of grossly spoilage signs (changes in color and/or odor and/or texture). Furthermore, the experiment was repeated in triplicate.

Statistical analysis

SPSS version 20 was used to analyze the data. The significance of the differences in the mean values of the groups under investigation was determined using ANOVA analysis and the Duncan posthoc value. A significance level of $P \leq 0.05$ was deemed significant.

Results

The findings in **Table (1)** indicated that treating chicken fillet with different fortified CMC-gum extracts coatings has a significant overall enhancement in the sensory quality. The treated samples showed significantly higher acceptability scores with longer shelf life depending on the type of treatment; where the plain CMC treated chicken fillet kept its sensory acceptability up to six days of storage; while for the 8th day for CMC-AG and CMC-MG, and for the 9th day for CMC-OG treated groups compared to the control samples, which exhibited spoilage signs after the 5th day of refrigeration. Although all fortified CMC treatments enhanced sensory acceptability regardless of the type of added extract, CMC alone also improved sensory characteristics, however to a lesser extent than fortified CMC, yet showed higher acceptability than the control group.

Table (1). Overall sensory appealing of chicken fillet group samples in cold storage (4±1^{O}C).

	C	CMC	CMC+AG	CMC+MG	CMC+OG
Zero day	4.9±0.01^{Aa} (VG)	4.9±0.01^{Aa} (VG)	4.9±0.01^{Aa} (VG)	4.9±0.01^{Aa} (VG)	4.9±0.01^{Aa} (VG)
2nd day	4.3±0.01^{Bb} (VG)	4.5±0.01^{Ba} (VG)	4.7±0.1^{Aa} (VG)	4.6±0.02^{Aa} (VG)	4.6±0.01^{ABa} (VG)
3rd day	3.6±0.01^{Cc} (G)	4.2±0.02^{Ca} (VG)	4.4±0.1^{Ba} (VG)	4.0±0.01^{Bb} (VG)	4.3±0.01^{Ba} (VG)
4th day	2.8±0.01^{Dc} (A)	3.5±0.01^{Db} (G)	4.0±0.02^{Ca} (G)	3.7±0.01^{BCa} (G)	3.8±0.01^{Ca} (VG)
5th day	2.1±0.01^{Ec} (A)	3.2±0.03^{Eb} (G)	3.6±0.01^{Da} (G)	3.4±0.02^{Ca} (G)	3.5±0.03^{Da} (G)
6th day	1.6±0.01^{Fd} (U)	2.3±0.02^{Fc} (A)	3.2±0.01^{Ea} (A)	3.0±0.01^{Db} (G)	3.2±0.03^{Ea} (G)
7th day	<1 (S)	1.8±0.02^{Gc} (U)	2.5±0.02^{Fb} (A)	2.7±0.01^{Eb} (A)	3.0±0.02^{EFa} (A)
8th day	<1 (S)	<1 (S)	2.1±0.02^{Gb} (A)	2.3±0.02^{Fb} (A)	2.6±0.01^{Fa} (A)
9th day	<1 (S)	<1 (S)	<2 (U)	<2 (U)	2.1±0.01^{G} (A)

The values represent Mean ± SD of three experiments. Zero time: 30 min. after outer coat dryness.
Means within the same row (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).
Means within the same column (ABCD) followed by different superscript letters are significantly different ($P \leq 0.05$).
4.0-5.0 very good (VG), 3.1-3.9 good (G), 2.1-3.0 Acceptable (A), 1.1-2.0 Unacceptable (U), 0.0-1.0 spoiled (S).

Regarding the drip loss (%), **Table (2)** showed that all of the treated groups even with plain CMC recorded a significant lower drip loss (%) indicating a higher water holding capacity and improved meat quality. Although gradual increase in the drip loss (%) in all the examined samples, it is obvious that plain CMC treated group exhibited significantly lower drip loss than the other fortified CMC treated samples initially, followed by significant increase in drip loss up to the 7th day of storage. On the other hand, CMC-AG, among the fortified CMC treated samples, revealed more potent water holding capacity represented by lower drip loss along the storage period than those recorded in CMC-OG and CMC-MG treated groups, respectively.

Table (2). Drip loss (%) of chicken fillet group samples in cold storage (4±1ºC).

	C	CMC	CMC+AG	CMC+MG	CMC+OG
Zero day	--	--	--	--	--
2nd day	5.3±0.01^{Da}	4.5±0.02^{Fb}	4.8±0.02^{Hc}	5.6±0.01^{Ga}	5.4±0.02^{Ga}
3rd day	8.5±0.02^{Ca}	6.5±0.03^{Ebc}	6.8±0.01^{Gc}	7.5±0.02^{Fb}	7.1±0.01^{Fbc}
4th day	12.8±0.02^{Ba}	8.3±0.01^{Db}	8.1±0.02^{Fd}	8.5±0.02^{Ed}	8.2±0.01^{Ec}
5th day	15.7±0.01^{Aa}	11.2±0.01^{Cb}	9.7±0.01^{Ee}	10.8±0.02^{Dd}	10.4±0.01^{Dc}
6th day	--	13.2±0.02^{Ba}	11.6±0.02^{Dc}	12.2±0.01^{Cc}	11.8±0.01^{Cb}
7th day	--	14.4±0.03^{Aa}	12.6±0.01^{Cc}	13.1±0.02^{Bc}	12.4±0.02^{Bb}
8th day	--	--	13.4±0.01^{Bb}	14.8±0.01^{Aa}	14.5±0.03^{Aa}
9th day	--	--	--	--	15.1±0.02^{A}

Means within the same row (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).
Means within the same column (ABCD) followed by different superscript letters are significantly different ($P \leq 0.05$).

The cooking loss of chicken fillet **(Table, 3)** increased progressively during refrigerated storage in all experimental groups, indicating a gradual reduction in water-holding capacity with time. The control samples consistently exhibited the highest cooking loss throughout storage, reflecting greater moisture and fat exudation during cooking. In contrast, while coated samples showed significantly lower cooking loss, CMC coatings providing noticeable improvement over the control. Initially, plain CMC treated samples showed lower cooking loss than the combined treatments followed by sudden increasing throughout the storage period. Also, comparison between the combined CMC coatings showed that CMC-AG revealed significant lower cooking loss in first five days of storage than the other fortified CMC treated groups; however, at the end of the experiment, treated group with CMC-OG showed the lowest cooking loss %, followed by CMC-AG and CMC-MG, respectively.

Table (3). Cooking loss (%) of chicken fillet group samples.

	C	CMC	CMC+AG	CMC+MG	CMC+OG
Zero day	22.4 ± 0.8^{Fa}	18.8 ± 0.5^{Gd}	19.3 ± 0.6^{Fc}	19.8 ± 0.7^{Gb}	19.9 ± 0.5^{Fb}
2nd day	23.1 ± 0.9^{Ea}	18.4 ± 0.5^{Fd}	19.9 ± 0.6^{Ec}	20.4 ± 0.8^{Fb}	20.2 ± 0.6^{EFb}
3rd day	24.0 ± 1.0^{Da}	19.1 ± 0.3^{Ee}	19.6 ± 0.6^{Ed}	21.1 ± 0.8^{Eb}	20.1 ± 0.7^{Fc}
4th day	25.2 ± 1.1^{Ca}	20.7 ± 0.8^{Dc}	20.1 ± 0.7^{Ee}	21.9 ± 0.9^{Db}	20.3 ± 0.6^{EFd}
5th day	26.4 ± 1.2^{Ba}	21.6 ± 0.9^{Cb}	20.7 ± 0.8^{Dd}	21.5 ± 1.0^{Db}	21.0 ± 0.7^{Ec}
6th day	--	24.7 ± 1.0^{Ba}	22.6 ± 0.8^{Cc}	23.0 ± 1.1^{Cb}	21.9 ± 0.9^{Dd}
7th day	--	26.2 ± 1.1^{Aa}	25.0 ± 0.9^{Bb}	25.2 ± 1.2^{Bb}	22.6 ± 1.0^{Cc}
8th day	--	--	26.9 ± 1.2^{Aa}	26.5 ± 1.1^{Ab}	23.5 ± 1.0^{Bc}
9th day	--	--	--	--	24.8 ± 1.0^{A}

Means within the same row (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).
Means within the same column (ABCD) followed by different superscript letters are significantly different ($P \leq 0.05$).

Conversely, cooking yield **(Table, 4)** showed an inverse trend to cooking loss, declining gradually with storage time in all treatments. Control samples recorded the lowest cooking yield at all storage intervals, whereas plain CMC-coated fillets exhibited higher yields in the first three days of storage followed by significant lowering throughout the rest of the storage period. The incorporation of natural gums with CMC further enhanced cooking yield. Among the treatments, CMC-OG achieved the highest cooking yield, followed by CMC-MG and CMC-AG, confirming the effectiveness of composite edible coatings in improving the technological quality of refrigerated chicken fillets.

Table (4). Cooking yield (%) of chicken fillet group samples.

	C	CMC	CMC+AG	CMC+MG	CMC+OG
Zero day	77.6 ± 0.7^{Ac}	81.2 ± 0.5^{Ab}	80.7 ± 0.6^{Ab}	80.2 ± 0.5^{Ab}	80.1 ± 0.5^{Aa}
2nd day	76.9 ± 0.6^{Bd}	81.6 ± 0.6^{Ac}	80.1 ± 0.7^{Bb}	79.6 ± 0.6^{Bc}	79.8 ± 0.5^{Aa}
3rd day	76.0 ± 1.4^{Ce}	80.9 ± 0.4^{Bd}	80.4 ± 0.8^{Bc}	78.9 ± 0.6^{Cb}	79.9 ± 0.7^{Aa}
4th day	74.8 ± 1.2^{Dd}	79.3 ± 0.5^{Cc}	79.9 ± 0.9^{Cb}	78.1 ± 0.8^{Da}	79.7 ± 0.4^{ABa}
5th day	73.6 ± 1.5^{Ed}	78.4 ± 0.9^{Dc}	79.3 ± 1.1^{CDb}	78.5 ± 0.7^{Da}	79.0 ± 0.3^{Ba}
6th day	--	75.3 ± 1.2^{Ec}	77.4 ± 0.8^{Db}	77.0 ± 1.1^{Ea}	78.1 ± 1.2^{Ca}
7th day	--	73.8 ± 1.1^{Fc}	75.0 ± 1.2^{Eb}	74.8 ± 1.2^{Fa}	77.4 ± 1.1^{Da}
8th day	--	--	73.1 ± 1.0^{Fb}	73.5 ± 0.9^{Ga}	76.5 ± 1.0^{Ea}
9th day	--	--	--	--	75.2 ± 1.2^{F}

Means within the same row (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).
Means within the same column (ABCD) followed by different superscript letters are significantly different ($P \leq 0.05$).

Regarding the bacteriological quality indicators, the recorded results of aerobic plate count (APC), coliform, Psychrotrophs and *Staph. aureus* counts in **Tables (5-8)** showed a significant reduction in the treated groups even with plain CMC alone or in combination with the other investigated fortifications.

Table (5) showed that the treated groups (CMC-OG) kept their APC within the acceptable limit (<5 log CFU/g according to the Egyptian standard "**EOS, 1651:2019**") up to nine days of refrigeration, whereas, plain CMC treated group exceeded that limit after the 7th. Although, CMC-AG and CMC-MG treated groups showed significant antibacterial effects, CMC-OG treatment showed the most potent antibacterial effect. While the control group exceeded the acceptable limit after the 5th day of storage revealing that the examined treatments could enhance the bacteriological quality with relative extended shelf life of chicken fillet during refrigeration.

Table (5). Aerobic plate count (log CFU/g) of chicken fillet samples in cold storage (4±1^{O}C).

	C	CMC	CMC+AG	CMC+MG	CMC+OG
Zero day	$3.86±0.03^{Da}$	$3.86±0.03^{Da}$	$3.86±0.03^{Ca}$	$3.86±0.03^{Da}$	$3.86±0.03^{Ca}$
2nd day	$3.92±0.01^{Da}$	$3.72±0.02^{Eb}$	$3.68±0.01^{Db}$	$3.44±0.02^{Fb}$	$3.41±0.02^{Eb}$
3rd day	$4.20±0.02^{Ca}$	$3.80±0.04^{Db}$	$3.56±0.02^{Ec}$	$3.25±0.01^{Gc}$	$3.28±0.01^{Fc}$
4th day	$4.72±0.01^{Ba}$	$3.88±0.01^{Db}$	$3.44±0.02^{Fd}$	$3.41±0.01^{Fc}$	$3.20±0.02^{Fd}$
5th day	$4.88±0.03^{Aa}$	$4.44±0.05^{Cb}$	$3.51±0.02^{Ed}$	$3.65±0.02^{Ec}$	$3.10±0.01^{Ge}$
6th day	> 5.0	$4.68±0.01^{Ba}$	$3.88±0.1^{Cc}$	$4.05±0.01^{Cb}$	$3.55±0.04^{Dd}$
7th day	-- (S)	$4.82±0.02^{Aa}$	$4.32±0.02^{Bb}$	$4.23±0.04^{Bc}$	$3.97±0.01^{Cd}$
8th day	-- (S)	-- (S)	$4.78±0.03^{Aa}$	$4.61±0.02^{Ab}$	$4.34±0.02^{Bc}$
9th day	-- (S)	-- (S)	-- (S)	-- (S)	$4.73±0.02^{A*}$

Means within the same row (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).
Means within the same column (ABCD) followed by different superscript letters are significantly different ($P \leq 0.05$).
* Superscript star within the same row between two groups means significant difference by T test ($P \leq 0.05$).

APC limit log CFU/g according to **(EOS 1651, 2019)**

Regarding the coliform bacterial count **(Table, 6)**, as an indicator of fecal contamination, the fortified CMC treated groups revealed initial reduction regardless the type of fortification followed by gradual increase up to eight days of storage for CMC-AG and CMC-MG treated groups, while for nine days of storage for CMC -OG treated group to exceed the acceptable limit (2 log CFU/g). On the other hand, plain CMC treated group kept its acceptable count for seven days of storage; whereas, the control group was unacceptable after the 5th day of storage.

Regarding the bacteriological and serotyping of the coliform isolates, *E. coli, K. oxytoca* and *K. ozaenae* were the most prevalent strains. Moreover, *E. coli* serotyping revealed detection of *E. coli* O_{25}:K_{11} and O_{44}:K_{74} serotypes.

Table (6). Coliform count (log CFU/g) of chicken fillet samples in cold storage (4±1^{O}C).

	C	CMC	CMC+AG	CMC+MG	CMC+OG
Zero day	1.66±0.02^{Da}	1.66±0.02^{Da}	1.66±0.02^{Ca}	1.66±0.02^{Ba}	1.66±0.02^{Ca}
2nd day	1.72±0.01^{Ca}	1.48±0.02^{Fc}	1.59±0.01^{Db}	1.56±0.02^{BCb}	1.48±0.02^{Dc}
3rd day	1.78±0.02^{Ca}	1.57±0.04^{Eb}	1.42±0.01^{Ec}	1.44±0.01^{Cc}	1.31±0.01^{Ed}
4th day	1.88±0.01^{Ba}	1.65±0.01^{Db}	1.38±0.02^{Ec}	1.25±0.01^{Dd}	1.38±0.02^{Ec}
5th day	1.94±0.01^{Aa}	1.78±0.03^{Cb}	1.52±0.01^{Dc}	1.42±0.01^{Cc}	1.47±0.01^{Dc}
6th day	>2.0	1.82±0.01^{Ba}	1.67±0.02^{Cb}	1.57±0.02^{BCc}	1.52±0.02^{Dc}
7th day	-- (S)	1.96±0.01^{Aa}	1.74±0.01^{Bb}	1.68±0.02^{Bc}	1.60±0.01^{Cd}
8th day	-- (S)	-- (S)	1.88±0.01^{Aa}	1.89±0.03^{Aa}	1.77±0.02^{Bb}
9th day	-- (S)	-- (S)	-- (S)	-- (S)	1.82±0.03^{A}

Means within the same row (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).
Means within the same column (ABCD) followed by different superscript letters are significantly different ($P \leq 0.05$).

Coliform limit log CFU/g according to **(EOS 1651, 2019)**
While, Psychrotrophs **(Table, 7)** are not listed in the Egyptian recommended standards, it is, also, showed a significant reduction in the count/g; where the CMC-OG treated group revealed the lowest count at the end of the experiment (1.93 log CFU/g).

Table (7). Psychrotrophs count (log CFU/g) of chicken fillet samples in cold storage (4±1^{O}C).

	C	CMC	CMC+AG	CMC+MG	CMC+OG
Zero day	1.69±0.01^{Ea}	1.69±0.01^{Ea}	1.69±0.01^{Ea}	1.69±0.01^{Da}	1.69±0.01^{Ca}
2nd day	1.90±0.01^{Da}	1.77±0.03^{Db}	1.65±0.02^{Ec}	1.48±0.02^{Ed}	1.77±0.02^{Bb}
3rd day	2.04±0.03^{Ca}	1.84±0.04^{Cb}	1.60±0.02^{Ec}	1.60±0.01^{Dc}	1.82±0.01^{Bb}
4th day	2.11±0.01^{Ba}	1.95±0.01^{Bb}	1.77±0.02^{Dc}	1.77±0.01^{Cc}	1.72±0.02^{Bc}
5th day	2.20±0.01^{Aa}	2.00±0.03^{ABb}	1.90±0.01^{Cc}	1.84±0.01^{Bd}	1.67±0.01^{Ce}
6th day	-- (S)	2.07±0.02^{Aa}	2.00±0.01^{Ba}	1.95±0.01^{ABab}	1.60±0.01^{Db}
7th day	-- (S)	2.14±0.03^{Aa}	2.07±0.02^{Bab}	2.04±0.02^{Aab}	1.80±0.01^{Bb}
8th day	-- (S)	-- (S)	2.17±0.03^{Aa}	2.10±0.02^{Aa}	1.90±0.01^{Ab}
9th day	-- (S)	-- (S)	-- (S)	-- (S)	1.93±0.01^{A}

Means within the same row (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).
Means within the same column (ABCD) followed by different superscript letters are significantly different ($P \leq 0.05$), S: Apparently spoiled

Referring to the recorded results in **Table (8),** the treated chicken fillet with fortified CMC coating showed significant reduction in the *Staph. aureus* count along the storage period in reference to the control group; where, the *Staph. aureus* count (log CFU/g) still within acceptable limit (< 3 log CFU/g) up to the 9th day of storage for the treated samples with CMC+OG to be the most effective treatment against *Staph. aureus* as a Gram-positive food-borne bacteria, followed by CMC+MG and CMC+AG treated groups, respectively. Moreover, the treated samples with plain CMC, also, showed potential to inhibit the *S. aureus* multiplication in comparison with the control group, however, there was no obvious reduction in the *S. aureus* count along the storage time.

It is worth noting that the bacteriological identification of the isolated coagulase-positive Staphylococcus spp. from the examined control samples revealed detection of *S. aureus* and *S. pseudintermedius* strains.

Table (8). *Staphylococcus aureus* count (log CFU/g) of chicken fillet samples in cold storage (4±1^{O}C).

	C	CMC	CMC+AG	CMC+MG	CMC+OG
Zero day	2.06±0.01^{Ea}	2.06±0.01^{Fa}	2.06±0.01^{Ea}	2.06±0.01^{Ca}	2.06±0.01^{Ca}
2nd day	2.31±0.01^{Da}	2.23±0.01^{Ea}	1.86±0.01^{Fb}	1.82±0.01^{Db}	1.69±0.01^{Dc}
3rd day	2.53±0.02^{Ca}	2.29±0.03^{Eb}	1.71±0.01^{Gc}	1.67±0.01^{Ec}	1.52±0.01^{Ed}
4th day	2.68±0.02^{Ba}	2.43±0.02^{Db}	1.90±0.03^{Fc}	1.60±0.02^{Ed}	1.48±0.04^{Fe}
5th day	2.79±0.03^{Aa}	2.69±0.01^{Cb}	2.13±0.02^{Dc}	1.89±0.01^{Dd}	1.37±0.02^{Ge}
6th day	> 3.0 (S)	2.75±0.01^{Ba}	2.37±0.01^{Cb}	2.14±0.03^{Cc}	1.76±0.01^{Dd}
7th day	-- (S)	2.86±0.03^{Aa}	2.69±0.02^{Bb}	2.52±0.01^{Bb}	1.92±0.01^{CDc}
8th day	-- (S)	-- (S)	2.88±0.01^{Aa}	2.79±0.01^{Ab}	2.33±0.01^{Bc}
9th day	-- (S)	-- (S)	-- (S)	-- (S)	2.68±0.01^{A}

Means within the same row (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).
Means within the same column (ABCD) followed by different superscript letters are significantly different ($P \leq 0.05$). S: Apparently spoiled

For determination of *S. aureus* biofilm potentiality, PCR detection of biofilm regulating genes (*icaA, icaD*, *spa* and *fnb*A) were determined in some strains isolated from the fillet samples without treatment. **Table (9) and Fig. (1 and 2)** showed that *ica*A gene was absent in all of the examined isolates, while *ica*D gene was detected in 80.0%; whereas *spa* and *fnb*A genes were detected in 40.0% of the examined isolates, respectively.

Table (9). Prevalence of the examined genes in the examined *S. aureus* isolates (n=5)

Sample code	*ica*A	*ica*D	*Spa*	*fnb*A
1	-	+	+	-
2	-	-	+	+
3	-	+	-	+
4	-	+	-	-
5	-	+	-	-
Positive ratio (%)	0	80	40	40

ica gene: Intercellaular adhesion protein, *spa* gene: Staphylococcal protein A, *fbn*A: fibronectin-binding protein A

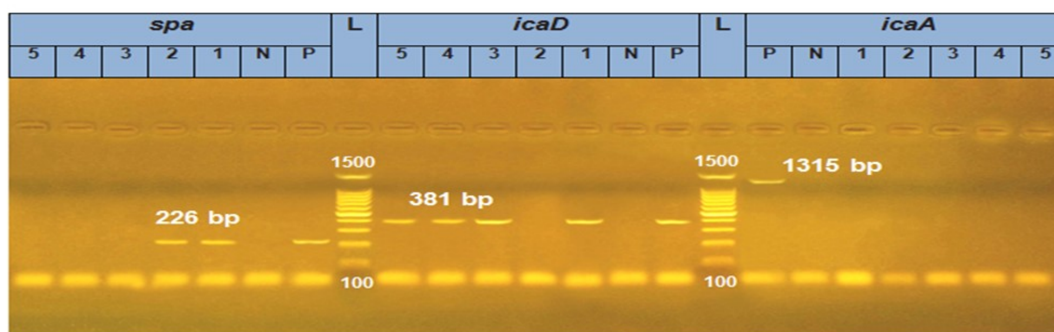

Fig. (1): Molecular detection of biofilm potentiating genes of *S. aureus* isolates (n=5) using agarose gel electrophoresis.
L: 100 bps DNA StepLadder. P: positive control. N: negative control, For *icaA* gene: Lanes 1 through 5 provide negative results, For *icaD* gene: Lanes 1, 3, 4 and 5 provide positive results, while Lane 2 provides negative result,
For *spa* gene: Lanes 1 and 2 provide positive results, while Lanes 3, 4 and 5 provide negative results.

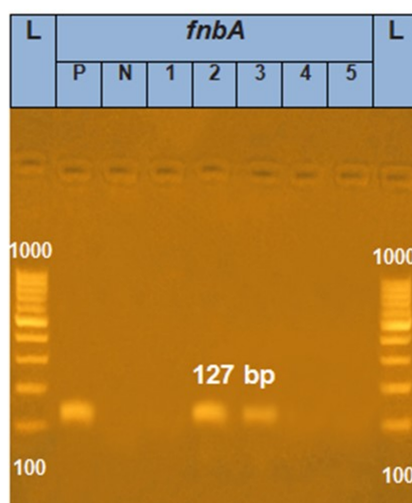

Fig. (2): Molecular detection of *fnb*A gene of *Staph. aureus* isolates (n=5) using agarose gel electrophoresis.
L: 100 bps DNA StepLadder.
Lane P: Positive control
Lane N: negative control
Lanes 1, 4 and 5: negative for *fnb*A gene
Lanes 2 and 3: Positive for *fnb*A gene

The anti-biofilm effect of the tested treatments revealed that the fortified CMC coating showed a potent anti-biofilm effect appeared as white colony with weak biofilm potency against *E. coli* O_{44}:K_{74}, *E. coli* O_{25}:K_{11} and *S. aureus*; while moderate effect was recorded against *K. ozaenae and K. oxytoca*. On the other hand, *S. pseudintermedius* showed resistance to Arabic gum, whereas mastic and olibanum gums had a potent effect **(Table, 11)**.

Table (10). Anti-biofilm effect of the used treatments

Microorganism	Criteria	C	CMC	CMC-AG	CMC-MG	CMC-OG
E. coli **O44:K74**	**Colony color**	Black	Black	White	White	White
	Biofilm potency	Strong	Strong	Weak	Weak	Weak
E. coli **O25:K11**	**Colony color**	Pink	Pink	White	White	White
	Biofilm potency	Moderate	Moderate	Weak	Weak	Weak
K. ozaenae	**Colony color**	Metallic black	Metallic black	Pink	Pink	Pink
	Biofilm potency	Strong	Strong	Moderate	Moderate	Moderate
K. oxytoca	**Colony color**	Metallic black	Metallic black	Pink	Pink	Pink
	Biofilm potency	Strong	Strong	Moderate	Moderate	Moderate
Staph. aureus	**Colony color**	Pink	Pink	White	White	White
	Biofilm potency	Moderate	Moderate	Weak	Weak	Weak
Staph. pseudinter-medius	**Colony color**	Black	Black	Black	White	White
	Biofilm potency	Strong	Strong	Strong	Weak	Weak

The recorded pH values in **Fig. (3)** indicated that all of the treated chicken fillet groups showed a relative pH stability in comparison to the control group; however, it begun to record a significant variation since the 3rd day of storage where the plain CMC treated group showed higher pH value than the other treated groups with the fortified CMC coating. Continuous gradual increase in the pH values were recorded along the storage period in all of the examined groups. While the control group exceeded the acceptable limit (6.4) at the 6th day, CMC treated group hold its chemical quality for seven days, while the fortified CMC treated groups kept their acceptability up to 9 days of storage even the pH is considerably on the edge of spoilage (> 6.2).

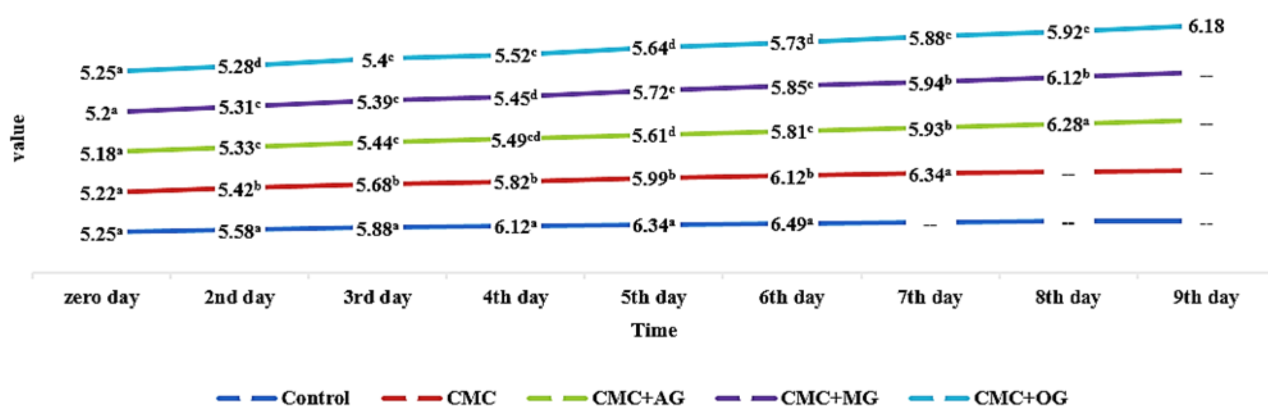

Fig. (3). pH values of the examined chicken fillet groups

Means within the same day (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).

As a correlational with pH, and as indicators for lipid and protein stability, all the treated chicken fillet samples kept their TBA and TVN **(Tables 11 and 12)** levels within the acceptable limits in relatively longer time than the control group.

Table (11). Thiobarbituric acid (TBA) values (mg malonaldehyde/Kg) of the examined chicken fillet groups

	C	CMC	CMC+AG	CMC+MG	CMC+OG
Zero day	0.28 ± 0.01^{Ea}	0.28 ± 0.01^{Ea}	0.28 ± 0.01^{Ga}	0.28 ± 0.01^{Ga}	0.28 ± 0.01^{Fa}
2nd day	0.36 ± 0.01^{Da}	0.33 ± 0.01^{Ea}	0.32 ± 0.01^{Fab}	0.31 ± 0.01^{Fab}	0.31 ± 0.01^{EFab}
3rd day	0.48 ± 0.01^{Ca}	0.38 ± 0.01^{Eb}	0.35 ± 0.01^{Fb}	0.37 ± 0.01^{Ec}	0.34 ± 0.01^{Eb}
4th day	0.57 ± 0.01^{Ba}	0.46 ± 0.01^{Db}	0.39 ± 0.01^{Ed}	0.40 ± 0.01^{Dc}	0.37 ± 0.01^{Ed}
5th day	0.79 ± 0.01^{Aa}	0.58 ± 0.01^{Cb}	0.48 ± 0.01^{Dc}	0.45 ± 0.01^{CDc}	0.41 ± 0.01^{DEd}
6th day	> 0.9	0.69 ± 0.01^{Ba}	0.55 ± 0.01^{Cb}	0.49 ± 0.01^{Cc}	0.46 ± 0.01^{Dc}
7th day	> 0.9	0.81 ± 0.01^{Aa}	0.67 ± 0.01^{Bb}	0.61 ± 0.01^{Bc}	0.52 ± 0.01^{Cd}
8th day	> 0.9	> 0.9	0.78 ± 0.01^{Aa}	0.74 ± 0.01^{Aa}	0.66 ± 0.01^{Bb}
9th day	> 0.9	> 0.9	> 0.9	> 0.9	0.78 ± 0.01^{A}

Means within the same row (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).
Means within the same column (ABCD) followed by different superscript letters are significantly different ($P \leq 0.05$).
0.9 mg malonaldehyde/Kg: The maximum permissible limit according to the Egyptian standard for TBA **(EOS 1651, 2019)**

It is worth noting that significant difference was recorded between the obtained values of the treated groups with CMC-AG, CMC-MG and CMC-OG; with mean values of 0.78, 0.74 and 0.66 for TBA (mg malonaldehyde/Kg), and 18.3, 17.8 and 14.3 (mg/100g) for TVN at the 8th day of storage, respectively. However, they showed a significant enhancement in the chemical and keeping quality consequently in comparison with either the control untreated group or the CMC treated group.

Table (12). Total volatile nitrogen (TVN) values (mg/100g) of the examined chicken fillet groups

	C	CMC	CMC+AG	CMC+MG	CMC+OG
Zero day	4.8 ± 0.01^{Ea}	4.8 ± 0.01^{Ga}	4.8 ± 0.01^{Ha}	4.8 ± 0.01^{Ga}	4.8 ± 0.01^{Ia}
2nd day	7.5 ± 0.02^{Da}	6.5 ± 0.01^{Fb}	5.7 ± 0.01^{Gc}	5.3 ± 0.01^{Gd}	5.5 ± 0.01^{Hc}
3rd day	10.8 ± 0.01^{Ca}	7.8 ± 0.01^{Eb}	7.1 ± 0.01^{Fc}	6.7 ± 0.01^{Fd}	6.8 ± 0.01^{Gd}
4th day	13.9 ± 0.02^{Ba}	9.4 ± 0.01^{Db}	8.9 ± 0.01^{Ec}	7.9 ± 0.01^{Ed}	7.6 ± 0.01^{Fd}
5th day	18.2 ± 0.03^{Aa}	12.6 ± 0.01^{Cb}	11.3 ± 0.01^{Dc}	10.4 ± 0.01^{Dd}	9.91 ± 0.01^{Ee}
6th day	> 20	15.3 ± 0.01^{Ba}	13.4 ± 0.01^{Cb}	11.6 ± 0.01^{Cc}	10.5 ± 0.01^{Dd}
7th day	> 20	18.7 ± 0.01^{Aa}	15.8 ± 0.01^{Bb}	15.3 ± 0.01^{Bb}	12.8 ± 0.01^{Cc}
8th day	> 20	> 20	18.3 ± 0.01^{Aa}	17.8 ± 0.01^{Ab}	14.3 ± 0.01^{Bc}
9th day	> 20	> 20	> 20	> 20	16.74 ± 0.01^{A}

Means within the same row (abcd) followed by different superscript letters are significantly different ($P \leq 0.05$).
Means within the same column (ABCD) followed by different superscript letters are significantly different ($P \leq 0.05$).
20 mg/100g: The maximum permissible limit according to the Egyptian standard for TVN **(EOS 1651, 2019)**

Discussion

Chicken meat is a vital global protein source, prized for its high nutritional value including lean protein, essential amino acids, B vitamins, and minerals, making it an essential milestone in the global food sector. However, its high water activity and nutrient richness render it highly perishable, prone to rapid microbial spoilage and lipid oxidation, underscoring the need for effective preservation to ensure food safety and minimize economic losses **(Edris *et al.*, 2013).**

Recent preservation techniques feature edible coatings with carboxymethyl cellulose (CMC) fortification, often combined with different functional fortification forming thin biopolymer films that adhere to food surfaces for barrier protection **(Ali *et al.*, 2023)**. These coatings either applied by dipping or spraying may incorporate functional agents such as Arabic gum (*Acacia Senegal), mastic gum (Pistacia lentiscus*) and olibanum gum (*Boswellia sacra*) for more slowing deterioration during refrigerated storage. Studies demonstrated that CMC-fortified films have the ability to extend shelf life by reducing drip loss, pH fluctuations, microbial growth and TVN buildup, while maintaining physicochemical stability **(Abdelkhalek *et al.*, 2024)**.

Targeted effects include enhanced sensory attributes with minimal impact on color and odor, though slight odor and taste improvements occur at optimal concentrations; bacteriological benefits show reduced bacterial counts; chemically, they reduce lipid oxidation and protein degradation **(Hu *et al.*, 2025)**.

Referring to the obtained results in **Tables (1 to 4)**, significant enhancement in the sensory and physical characters of the treated chicken fillet groups was recorded that was represented by lower drip loss and higher cooking yield indicating higher water holding capacity, and keeping higher overall acceptability scores than the control group during refrigeration storage. As was shown, the treated fillet samples with CMC alone kept their acceptability up to six days of storage; while for eight days in CMC-AG and CMC-MG, and for nine days in CMC-OG treated groups indicating a significant effect of the used fortification for keeping longer shelf-life and wholesome.

The obtained findings may be referred to the tightly closed fortified CMC coating that provides favorable aroma and texture, accompanied as an oxygen and oil barrier properties to the product **(Rad *et al.*, 2021).** Moreover, permission of the active compounds in the fortification materials of AG, MG and OG migration through the casing into the product may delay the unfavorable changes that may occur leading to extended sensory acceptability for longer shelf-life than plain CMC by incorporating bioactive compounds that provide superior antioxidant activity, reducing lipid peroxidation and maintaining fresh odor, color, and texture during storage. In addition, the gums fortify CMC's hydrophilic matrix with emulsifying and film-forming synergies, improving moisture retention and oxygen barrier function, which preserves structural integrity and juiciness critical for texture acceptability over time **(Mohamed *et al.*, 2020 and Azevedo *et al.*, 2022)**.

Regarding the water holding capability of the treated chicken fillet samples, the treated chicken fillets exhibited a clear improvement in technological quality compared with the control, as evidenced by significantly lower drip loss **(Table, 2),** cooking loss **(Table, 3)** and consequently, higher cooking yield **(Table, 4)**. These effects were observed in all CMC-based treatments, either alone or fortified with natural gums, indicating that the primary mechanism is related to enhanced water-holding capacity of the muscle matrix. In contrast, the control samples lacked any protective hydrocolloid network, allowing free and immobilized water to be easily expelled during refrigerated storage and thermal processing, which explains their higher drip and cooking losses and lower final yield **(Gaurav *et al.*, 2023)**.

The present findings demonstrated clear differences in cooking loss among the four treatments, with chicken fillet samples treated with CMC alone exhibiting the lowest cooking loss, followed by CMC reinforced with gum arabic, while samples treated with CMC combined with olibanum and mastic gums showed progressively higher moisture losses at the first few days of the experiment followed by gradual enhancement in the treated samples with fortified CMC along the rest of the storage period.

The initial superior performance of CMC alone can be attributed to its ability to form a stable, continuous gel network that effectively immobilizes water within the muscle matrix during heating. In contrast, the incorporation of gum arabic, despite its hydrophilic nature, resulted in increased cooking loss due to the formation of weakly bound water fractions and partial disruption of the CMC–protein network, leading to reduced thermal stability **(Tornberg, 2005)**. CMC likely interacts with myofibrillar proteins, increasing protein–water interactions and viscosity of the intercellular spaces, thereby limiting water migration and exudation during storage and heating **(Zhou *et al.*, 2023)**. The highest cooking losses observed in mastic- and olibanum-treated samples are mainly associated with their resinous and partially hydrophobic composition, which promotes phase separation, interferes with polymer–protein interactions, and accelerates muscle fiber shrinkage during thermal processing. These mechanisms facilitate water migration and exudate release upon cooking **(Xiong *et al.,* 2015 and Dickinson, 2018)**.

However, fortification of CMC with arabic gum, mastic gum, or olibanum gum resulted in a synergistic enhancement of water retention and cooking yield for advanced storage time that may be attributed to their potent antimicrobial and antioxidant effects **(Abdelkhalek *et al.*, 2024)**. This synergism can be attributed, also, to the formation of a more complex and cohesive hydrocolloid–protein matrix, where the combined polymers improve gel strength, thermal stability, and water entrapment. The mixed hydrocolloid systems likely reduce protein denaturation and shrinkage during heating, which in turn minimizes the expulsion of water and soluble components, explaining the lower cooking loss and higher yield compared with CMC alone **(Shakir *et al.*, 2022).**

Among the fortified treatments, CMC plus olibanum gum achieved the most pronounced improvement, followed by CMC plus mastic gum and then CMC plus arabic gum that came in line with the recorded results of **Abdelkhalek *et al.* (2024)** who suggested that olibanum gum likely contributed the highest water-binding and gel-forming capacity due to its resinous polysaccharide structure and higher molecular complexity, enabling stronger interactions with both water and muscle proteins that results in a tighter network that effectively immobilizes water during storage and cooking. In addition, mastic gum showed a moderate effect, possibly related to its partial hydrophobic character, which may enhance structural integrity but slightly limit water affinity compared with olibanum. Arabic gum, while highly soluble and effective as an emulsifier, forms weaker gels, explaining its comparatively lower—but still superior to CMC alone—performance.

Food quality, safety, and freshness are now highly prized. However, the main element affecting food safety is food packaging. Standard food packaging is frequently made of polymers like polyethylene, polypropylene, polystyrene, or polyethylene terephthalate without any additional functionality **(Shaikh *et al.*, 2021**).

Regarding the bacteriological quality indicators, data from **Tables (5-8)** indicated notable decreases in key bacteriological metrics such as aerobic plate count (APC), coliforms, psychrotrophs, and *S. aureus* counts in all treated samples, including those with plain CMC or alongside other fortifications, relative to the control group; where all the treated groups kept the bacteriological counts (log CFU/g) within the acceptable limit, up to approximately seven days for plain CMC, and eight days for CMC-AG and CMC-MG, while for nine days in CMC-OG treated chicken fillet to meet the Egyptian regulatory standards **(EOS 1651, 2019)** indicating higher safety and keeping quality of the treated groups, and superiority of OG over the other CMC fortifications of the current study.

In this study two serotypes of *E. coli* were isolated which differ in production of β-D-glucuronidase enzyme that appeared as pale blue colonies for *E. coli* O_{44}:K_{74} while *E. coli* O_{25}:K_{11} appeared as dark blue colonies. These serotypes known as food poisoning *E. coli*; where O_{44}:K_{74} and O_{25}:K_{11} serotypes have been known to be enterotoxigenic **(Ahrens *et al.*, 1988),** that were previously isolated from different broiler flocks and in retail meat samples **(Gad *et al.*, 2025).** In addition, the biochemical tests result revealed detection of *K. ozaenae* and *K. oxytoca* beside the *E. coli* isolation that

came in agree with the recorded results of **Fielding *et al.* (2012)** and **Tanni *et al.* (2025)** who detected *K. ozaenae* and *K. oxytoca* in poultry meat. Presence of such pathogens indicates fecal contamination and poor hygienic conditions that may possess a public health hazards.

Furthermore, the bacteriological investigations revealed isolation of *Staph. aureus* and *S. pseudintermedius* as coagulase positive staphylococci posing a public health hazards, as a significant poor hygienic indicator, referring to enterotoxin secretions and potential human infections **(Roghaiyeh akbari *et al.*, 2025).**

Biofilm formation in *Staph. aureus* is a multifactorial process regulated by both polysaccharide-dependent and protein-mediated mechanisms, in which the *ica* operon and *spa* gene play key but distinct roles. The *ica* operon, particularly *icaA* and *icaD*, is responsible for the synthesis of polysaccharide intercellular adhesin (PIA), a major component of the classical biofilm matrix. While *icaA* encodes N-acetylglucosaminyl transferase, *icaD* acts as an essential cofactor that enhances enzymatic activity and stabilizes PIA production **(Arciola *et al.*, 2015)**.

Regarding the molecular studying of the biofilm potentiators of the isolated *Staph. aureus* strains, **Table (9) and Figs. (1 and 2)** showed that *ica*A gene was absent in all of the examined isolates, while *ica*D gene was detected in 80.0%; whereas *spa* and *fnbA* genes were detected in 40.0% of the examined isolates that indicated potentiality of the isolated strains to form aggressive biofilm shield posing a long-term possible contamination of chicken meat products.

In the current study, the absence of detectable *icaA* in all *Staph. aureus* isolates, despite the presence of *icaD* in 80% of samples, suggests that polysaccharide-dependent biofilm formation may be incomplete, down regulated, or genetically altered in these strains. This finding indicates a possible shift away from the canonical *icaA*-driven PIA pathway toward alternative biofilm strategies **(Nasr *et al.*, 2012).**

The failure to detect *icaA* may be attributed to several factors, including gene deletion, sequence variation at primer-binding regions leading to PCR failure, or transcriptional repression of the *ica* operon under the prevailing environmental or stress conditions of the study **(Rohde *et al.*, 2004).** Additionally, *Staph. aureus* is known to form biofilms via *ica*-independent mechanisms, particularly through surface and secreted proteins such as protein A, encoded by the *spa* gene **(Merino *et al.*, 2009 and Suryanditha *et al.*, 2018)**. So, the detection of *spa* in 40% of isolates supports the contribution of protein-mediated adhesion and biofilm development, especially in strains lacking functional PIA synthesis. Protein A promotes initial attachment to host tissues and abiotic surfaces by binding immunoglobulins and host matrix proteins, thereby facilitating biofilm initiation and maturation.

In addition, bacterial biofilms that consist of microbial communities encased in a protective extracellular polymeric matrix that adheres to food processing surfaces, rendering them highly resistant to sanitizers and enabling persistent contamination of meat products. This resistance promotes cross-contamination by foodborne pathogens leading to food spoilage, shortened shelf life, outbreaks of foodborne illnesses, and costly recalls **(Anjum Reem *et al.*, 2025)**.

While investigating the anti-biofilm effect of the experimental treatments on congo-red agar, the results showed that Carboxymethyl cellulose (CMC) has no anti-biofilm action which agreed with **Bao *et al.* (2022)** who recorded that CMC has limited or no inherent anti-biofilm effect. However, it is widely used as a carrier or a base material for composites with other antimicrobial and anti-biofilm agents, which then show significant efficacy against bacterial biofilms.

The fortified CMC coating demonstrated a strong anti-biofilm effect against *E. coli* O_{44}:K_{74}, *E. coli* O_{25}:K_{11}, and *Staph. aureus*, while a moderate effect was noted against *K. ozaenae* and *K. oxytoca*, according to the anti-biofilm effect of the tested treatments. However, mastic and olibanum gums had a strong effect, while *Staph. pseudintermedius* shown resistance to Arabic gum **(Table, 10)**.

The recorded antibacterial effect of the used treatments even with CMC alone or fortified CMC with AG, MG or OG may be referred to that CMC, alone, exhibits mild antibacterial

effects through its physical barrier properties, forming a dense hydrophilic film on meat surfaces that limits oxygen enterance, water activity, and nutrient diffusion essential for bacterial proliferation, thereby reducing bacterial growth. In addition, this semi-permeable matrix disrupts microbial attachment and biofilm formation by altering surface hydrophobicity and creating an anhydrous microenvironment unfavorable to psychrotrophs and other biofilm forming bacteria. Additionally, CMC's anionic carboxymethyl groups may chelate divalent cations in bacterial cell walls, mildly destabilizing membranes without direct biocidal action **(Wang *et al.*, 2025).**

Fortification with gums enhances CMC's antibacterial role via synergistic emulsification and film reinforcement, where their polysaccharides boost adhesion and moisture retention, indirectly suppressing microbial enzymes that degrade meat proteins and release growth-promoting peptides **(Karnwal *et al.*, 2025).**

Regarding the bioactive compounds, AG contributes bioactive arabinogalactans with prebiotic-like inhibition of pathogens through competitive exclusion and acidification of the coating microenvironment. This combination sustains lower pH and total viable counts longer than CMC alone by amplifying physical exclusion of spoiling microorganisms **(Sun *et al.*, 2021).** On the same line, MG and OG, also, impart potent antibacterial mechanisms to fortified CMC via terpenoids (e.g., α-pinene in MG, boswellic acids in OG) that rupture bacterial cell membranes, inhibit efflux pumps, and disrupt quorum sensing in Staphylococcus and coliforms, causing cytoplasmic leakage and metabolic arrest **(Abdelkhalek *et al.*, 2024)**. These resinous bioactives exhibit hydrophobicity, enhancing the coating's oxygen barrier and scavenging reactive oxygen species that encourage microbial resilience. The overall mechanism involves hydrophobic interactions, penetrating lipid bilayers, protein denaturation, and DNA binding **(Abdelkhalek *et al.*, 2024 and Wang *et al.*, 2025)**.

Chemical stability is fundamental to meat quality because it reflects the rate of lipid oxidation, protein degradation, and pigment changes that determine flavor, color, texture, and shelf life **(Domínguez *et al.*, 2019)**. Referring to the current results, **Figure (2)** illustrates that all the treated fillet groups exhibited greater pH stability relative to the control. Although significant divergence emerged from the third day of storage, with the CMC-treated group displaying higher pH values than those treated with fortified CMC coatings, a progressive pH increase occurred across all groups throughout refrigeration; where the control surpassed the acceptability threshold (6.4) by the day six, while the CMC-treated group maintained pH values acceptable for eight days, and fortified CMC groups preserved acceptability up to nine days, despite approaching spoilage limits.

Notably, a significant variation was observed among the treated groups containing CMC–AG, CMC–MG, and CMC–OG. On the 8th day of storage, the recorded mean TBA values **(Table, 11)** were 0.78, 0.74, and 0.66 mg malonaldehyde/kg, respectively, while the corresponding TVN values **(Table, 12)** reached 18.3, 17.8, and 14.3 mg/100 g. Despite these differences, all three treatments demonstrated a marked improvement in chemical stability and overall keeping quality when compared with both the untreated control group and the group treated with CMC alone.

It is worth noting that, plain CMC maintains chemical attributes like pH, TVN, and TBA values in treated chicken fillets can be attributed to form a hydrophilic barrier that restricts oxygen diffusion and water activity, thereby slowing microbial metabolism and enzymatic proteolysis that elevate pH and TVN through ammonia release from protein breakdown. Its anionic groups chelate pro-oxidant metals, mildly inhibiting lipid peroxidation and delaying TBA rise from malonaldehyde formation during refrigerated storage. This physical and mild chemical stabilization extends freshness beyond controls, but allows gradual increases due to limited bioactive scavenging **(Schuh *et al.*, 2013).**

Through synergistic bioactive reinforcement, fortified CMC with AG, MG, or OG performs better than plain CMC. MG and OG are well known for their high content of terpenoids (such as α-pinene and boswellic acids) that effectively scavenge free radicals, chelate ions, and disrupt microbial lipoxygenases, thereby suppressing lipid oxidation and TBA escala-

tion; moreover, AG's arabinogalactans, also, improve emulsification and pH buffering via acidic polysaccharides, limiting amine production and TVN accumulation.

The current recorded results came in agreement with those of **Abdelkhalek *et al.* (2024)** who recorded significantly improved sensory quality of fortified CMC coated fish fillet with longer shelf-life up to 12 days of storage, additionally the investigated treatments could reduce the psychrotrophic and coliform bacteria below the detection limit in the 8th day of storage, while APC and *Staph. aureus* showed initial reductions up to the 4th day of the experiment followed by gradual increasing up to the 14th day where the fortified CMC-AG showed the most potent antibacterial effect than the other treatments; **Elmarzouqi *et al.* (2024)** who recorded a significant enhancement in the sensory and bacteriological quality of beef kofta treated with olibanum gum (2.0%) that kept their sensory acceptability up to 12 days of storage; accompanied by significant bacteriostatic effect on *Staph. aureus* and *E. coli;* and **Messinese *et al.* (2024)** who concluded that increasing film density, adhesion, reducing gas exchange, and hydrolytic reactions of these gums provide smoother pH curves, reduced TVN/TBA peaks, and acceptability that lasts to fifteen days of storage.

Variation between the previously recorded results and the current findings may be attributed to the type of treatment, kind of application, storage conditions and the initial bacterial loads.

Although strong significant variation was not recorded between the used gums, they showed a potent effect as sensory enhancer, antibacterial effect and anti-oxidant effect possess a potential wholesome of the treated chicken fillet samples. The lack of significant differences in the efficacy among AG, MG, and OG-fortified CMC coatings on chicken fillets stems from their comparable bioactive profiles and synergistic interactions within the CMC matrix, which collectively achieve threshold reductions in bacterial loads which may be attributed to that all the three gums share polyphenolic, terpenoid, and resinous compounds (e.g., arabinogalactans in AG, α-pinene in MG, boswellic acids in OG) that disrupt microbial membranes, inhibit quorum sensing, and enhance physical barriers against spoilers like psychrotrophs and Staphylococcus, saturating the antimicrobial effect at applied concentrations and masking individual potency differences. This equivalence is further evidenced by uniform anti-biofilm outcomes against *E. coli* serotypes and *Staph. aureus* in **Table 10**, where fortified groups exhibited potent inhibition (white colonies, weak potency) comparable to each other, prioritizing overall shelf-life extension over nuanced disparities.

Conclusion

In conclusion, the application of carboxymethyl cellulose (CMC) edible coatings, particularly when fortified with Arabic gum, mastic gum, or olibanum gum, significantly enhanced the preservation of refrigerated chicken fillets compared to untreated controls and plain CMC, extending sensory acceptability, water holding capacity, bacteriological safety, and chemical stability up to eight days for fortified CMC with AG and MG, and to nine days for fortified CMC with OG. Treated groups maintained the bacterial counts within limits, alongside pH stability (<6.4), low TBA (<0.90 mg malonaldehyde/kg), and TVN (<20.0 mg/100g), while the control group spoiled by the day 6. Moreover, these natural gum fortifications demonstrated potent anti-biofilm effects against key pathogens like *E. coli* serotypes and *Staph. aureus*, underscoring their potential as eco-friendly alternatives for improving meat shelf life and food safety in line with Egyptian standards. In addition, presence of *ica*D, *fnbA* and *spa* genes positive *S. aureus* isolates revealed biofilm forming potential of foodborne *S. aureus*.

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