Food Engineering Research/Vol.24/No.79/ Autumn & Winter 2025/P: 167-184

Journal Home page: https://fooder.areeo.ac.ir/

Original Research

The Impact of Carboxymethyl Cellulose-Based Edible Coatings Incorporated with Aromatic Violet Flower Extract on the Qualitative Characteristics, Oil Uptake Mitigation, and Acrylamide Concentration in Fried Burgers

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Received: 13 December 2025 **Accepted**: 14 February 2026

http://doi:10.22092/fooder.2026.371751.1444

Abstract

Fried products enjoy widespread popularity and consumption globally; however, their intake poses significant health risks to consumers. This is largely attributable to their elevated oil content and the presence of deleterious compounds, including oxidized lipid derivatives and acrylamide. The objective of this study was to examine the qualitative characteristics, sensory attributes, oxidative stability, and acrylamide content of carboxymethylcellulose (CMC)-based coatings that incorporate aromatic violet flower extract, specifically in the context of fried beef burgers. In order to achieve this objective, varying concentrations of aromatic violet flower extract, specifically 0%, 1%, 2%, 3%, and 4%, were incorporated into a carboxymethyl cellulose (CMC) solution. Subsequently, the burgers were submerged in the formulated coating solutions prior to frying. Subsequently, the burgers were subjected to frying at a temperature of 160 °C for a duration of 5 minutes. Following the frying process, various parameters were assessed, including moisture content, absorbed oil, peroxide and thiobarbituric acid (TBA) indices, droplet size, cooking efficiency, colorimetric indices, textural characteristics, and sensory attributes of the burgers. The findings indicated that the application of coatings derived from carboxymethyl cellulose (CMC), particularly those incorporating violet flower extract, enhances moisture retention, diminishes oil absorption, and reduces acrylamide levels in fried burgers. Furthermore, these coatings markedly improve the oxidative stability of the burgers. A negative correlation was identified between the concentration of the violet flower extract and the oxidative indices of the burgers. Specifically, as the concentration of the violet flower extract in the coating solution increased, there was a corresponding enhancement in antioxidant activity, accompanied by a significant reduction in oxidative indices ($p < 0.05$) Furthermore, the application of the coating to the burgers also enhanced their baking properties by decreasing the cooking loss and improving baking efficiency. The application of coatings on burgers resulted in an increase in the L* index, alongside a decrease in the a* and b* values, as well as the Browning Index (BI), when compared to the control group. Additionally, these coatings led to a significant reduction in the firmness and chewability of the burgers relative to the control ($p < 0.05$) The outcomes from the sensory evaluation demonstrated a high level of consumer acceptance for all burger treatments produced during this study. The results of this study indicate that the application of active edible coatings derived from carboxymethyl cellulose (CMC) infused with aromatic violet flower extract prior to the frying process of meat burgers may enhance the quality characteristics of the final product. Furthermore, this method is associated with a reduction in both oil absorption and the formation of acrylamide in fried burgers.

Keywords: **Acrylamide, Burger, Oxidative Stability, Active Coating, Frying, Aromatic Violet Flower**

http://doi:10.22092/fooder.2026.371751.1444

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Introduction

The advancement of urbanization has significantly intensified consumers' inclination toward the consumption of convenience-oriented food products, particularly ready-to-eat items such as meat burgers(Bahmanyar, F; Hosseini, S.M; Mirmoghtadaie, L; Shojaee-Aliabadi 2021) . Frying is among the most extensively utilized and favored techniques for the preparation of food products, as it effectively enhances the organoleptic properties of the final product (Ananey-Obiri, Matthews, and Tahergorabi 2020). During this process, high heat is applied and the food and oil are exposed to oxygen and moisture, and destructive chemical reactions such as hydrolysis, oxidation, and polymerization occur. During these chemical processes, compounds are produced that are harmful to human health(Nur et al. 2021). Conversely, the frying process results in a significant absorption of oil by food products. This phenomenon raises concerns regarding the health implications associated with the consumption of foods that are high in oil content. Epidemiological evidence indicates that such dietary habits may elevate the risk of various health issues, including cardiovascular diseases, diabetes, and obesity(Guo et al. 2023).

Acrylamide is a carcinogenic compound that forms as a byproduct during the frying process of food, highlighting a significant concern regarding the health implications associated with the consumption of fried food products. During the reaction between amino acids and reducing sugars at elevated temperatures, the formation of acrylamide occurs. Acrylamide is characterized as an unsaturated, hydrophilic compound that possesses an elevated boiling point. Acrylamide possesses the capability to engage in radical reactions with other unsaturated compounds by binding to the double bond present in its molecular structure, thereby facilitating the formation of a polymer. Acrylamide, due to its nature as an electrophilic compound, exhibits reactivity towards nucleophiles through additive reactions, consequently resulting in the modification of proteins and enzymatic structures. Acrylamide has the ability to bind to hemoglobin, thereby disrupting its functional activity. In the human body, acrylamide is metabolized into a more reactive compound known as glycidamide. Glycidamide is recognized as a mutagenic agent that contributes to the carcinogenic process(Perera, Hewavitharana, and Navaratne 2021).

One of the most effective and suitable methods for reducing oil absorption, preventing moisture loss, and preserving the quality of food products is the application of edible coatings. Numerous studies have demonstrated that edible coatings can enhance both the sensory and nutritional qualities of fried products. These coatings effectively preserve the crispiness of such items by inhibiting moisture transfer from the food to the coating, as well as by absorbing moisture from the surrounding environment (Esmaeili et al. 2024). Edible coatings can be constructed from a diverse range of biopolymers, encompassing both carbohydrates and proteins. Carboxymethyl cellulose (CMC) is an economically viable carbohydrate and a hydrophilic polymer. It is widely utilized across multiple sectors of the food industry, as well as serving as a polymer for film formation and as a coating material. Coatings derived from this polymer have the potential to mitigate moisture loss in products, thereby preventing subsequent weight loss. Conversely, these substances serve as a barrier to gas diffusion, inhibit the oxidation of lipids, and restrict microbial growth, thereby contributing to an extended shelf life of food products. The incorporation of functional additives, including antioxidant and antimicrobial agents, into edible coatings facilitates the development of active coatings(El Sheikha, Allam, Elobeid, et al. 2022).

Research indicates that the application of natural antioxidants obtained from diverse plant sources, including essential oils and extracts, can effectively mitigate the formation of acrylamide and other oxidation byproducts in fried foods (Ashrafi et al. 2024). The aromatic violet flower, scientifically designated as Viola odorata and commonly referred to as sweet violet, belongs to the family Violaceae. This plant has a longstanding history of utilization within traditional Persian medicine. This plant has been utilized for the treatment of various medical conditions, including migraines, diabetes, hypertension, and cancer. Additionally, it is employed for the alleviation of muscular strains and functions as a sedative and antipyretic. Furthermore, this plant exhibits notable antioxidant and antimicrobial properties (Nikmanesh, Baghaei, and Mohammadi Nafchi 2023). Aromatic violet flowers possess a diverse array of bioactive constituents, which include triterpenes, flavonoids, phenolic acids, cyclotides, and alkaloids (Zawiślak et al. 2022). The objective of this study was to examine the impact of edible and active coatings formulated with carboxymethyl cellulose, which incorporated varying concentrations of aqueous extracts from the aromatic violet flower, on the qualitative and sensory characteristics, lipid oxidation, and acrylamide formation in fried beef products.

Materials and Methods

Materials

The aromatic violet flower was sourced from the Mazandaran Province of Iran. Carboxymethyl cellulose, along with all other chemicals utilized in the experimental procedures, was sourced from Merck KGaA, Germany.

Preparation of Aromatic Violet Flower Blue Extract

Initially, the aerial portions of the fragrant violet flower were desiccated in a shaded environment. The desiccated plant material was reduced to a fine powder utilizing an electric mill and subsequently subjected to sieving through a mesh with a pore size of 250 μm. For the preparation of the aqueous extract, 300 grams of the powdered material was incorporated into one liter of distilled water. Following a 24-hour period of agitation on a magnetic stirrer, the resultant mixture was filtered using filter paper of grade one. Subsequently, the solvent was removed through evaporation in a rotary evaporator under vacuum conditions maintained at 40°C (Nikmanesh, Baghaei, and Mohammadi Nafchi 2023).

Preparation of Feed Coatings Based on CMC

Carboxymethyl cellulose was solubilized at a concentration of 1 gram per 100 milliliters of deionized water and stirred at a temperature of 60 °C for a duration of 50 minutes. Glycerol, functioning as a plasticizer, was incorporated into the mixture at a concentration of 0.5% The resulting formulation was subjected to continuous stirring at a temperature of 85 °C for a duration of 5 minutes. An aqueous extract of the aromatic violet flower was incorporated into the coating solutions at concentrations of 0%, 1%, 2%, 3%, and 4% (El Sheikha, Allam, Elobeid, et al. 2022).

Preparation of Burger Treatments

The formulation of the burger was composed of 60% veal, 30% onions, 1% salt, 1% spices (specifically pepper and jazubai), and 8% breadcrumbs. To prepare the hamburger, the washed meat was minced utilizing a meat grinder. Subsequently, additional components of the formulation were incorporated and combined thoroughly using a food processor for a duration of 15 minutes. The burger dough was shaped using manual molding techniques, resulting in a diameter of approximately 10 cm. The weight is sixty grams (Farajimehr, H; Khani, M; Rahman 2025). The burgers were submerged in coating solutions at room temperature for a duration of two minutes. Subsequently, any excess solution was removed by placing the burgers on mesh trays for a period of three minutes. The coated burgers were subjected to a freezing process for a duration of 24 hours. Following this period, they were removed from the freezer and allowed to thaw. Subsequently, the burgers were fried in a fryer at a temperature of 160 degrees Celsius for a duration of five minutes. Frying oil was utilized in this study, with a proportion of 20 parts oil to 1 part sample. Upon completion of the frying process and the subsequent removal of excess oil, the burgers were cooled to room temperature prior to undergoing testing (Ashrafi et al. 2024).

Tests on Fried Burgers

Moisture Content Measurement

In order to ascertain the moisture content, samples weighing 2 grams each were subjected to drying in an oven at a temperature of 105 degrees Celsius until a constant weight was achieved. Subsequently, the moisture content of the burgers was calculated using the following equation (F. Liu et al. 2015).

$$(\%) = \frac{\text{Inintial Weight} - \text{Final weight}}{\text{Initial Weight}} \times 100 \quad (1)$$

Measuring the Amount of Oil Absorption

To determine the amount of oil absorbed in the burgers, Soxhlet method and etherpetroleum solvent were used. The operation was performed for 6 hours at 68 °C and the oil of the samples was extracted. The following relationship was used to calculate the percentage of oil absorption (Alaei, M; Rahman, A; Salehifar 2023).

$$\text{Oil Absorption } (\%) = \frac{\text{Oil Weight}}{\textit{Initial Sample Weight}} \times 100 \quad (2)$$

Peroxide Index Measurement

In order to determine the peroxide index, each burger sample weighing 150 grams was combined with 250 milliliters of chloroform for a duration of three minutes, followed by filtration. The resulting peroxide index of the burger samples was subsequently expressed in milliequivalents of oxygen per kilogram of sample(Varmazyar,Elham ; Rahman, Alireza; Hosseinmard 2024) .

Measurement of Thiobarbituric Acid (TBA) Index

In order to determine the TBA index of Burgers, spectroscopy and standard curve of 1,3,3-tetraethoxypropane (TEP) (in the range of 0.06-1 g/mL) concentration were used and the amount of TBA index was reported in terms of mg malondialdehyde per kg of sample (mg MDA/kg). For this purpose, 20 g of burger was first mixed with 950 ml of trichloroacetic acid solution (20%) for 2 minutes and after straining by Whitman filter paper (No. 1), it was added to the strained mixture (5 ml) with 0.01 M TBA solution (in 90% acetic acid). The mixture was incubated at 100 °C for 60 min and after cooling to ambient temperature, the water absorption was recorded by the UV-Vis spectrophotometer at a wavelength of 532 nm (Barbosa et al. 2022).

Measurement of Acrylamide Content

The homogenized burger sample (1.5 g) was mixed with 500 μL of standard acrylamide solution in a centrifugal tube for 10 min and the extraction process was carried out in an ultrasonic bath (60°C). After that, centrifuge was done for 15 minutes (12000 rpm) and then the final extraction was performed with ethyl acetate. The prepared samples were dissolved in ethyl acetate and injected 2 µl of it into a gas chromatography-mass spectroscopy system (GC-MS) equipped with a TG-WAX GC column with dimensions of 0.3 m, 0.25 ×mm, 0.25 × 0.25 µm. Helium gas was used as a carrier gas at a flow rate of 1 mL/min. The temperature of the injection part was 240 °C and the temperature program was in the range of 50-260 °C. The inhibition time of acrylamide is 11 minutes. The standard acrylamide curve was used to determine the acrylamide content of burgers. To draw this curve, acrylamide was used in the range of 5 to 200 µg/kg (Hasan et al. 2021).

$$\text{Cooking Loss (\%)} = \frac{\text{Raw Sample Weigth} - \textit{Cooked Sample Weigth}}{\text{Raw Sample Weigth}} \times 100 \quad (3)$$

$$\text{Cooking Efficiency (\%)} = \frac{\textit{Cooked Sample Weigth}}{\text{Raw Sample Weigth}} \times 100 \quad (4)$$

Color Test

In order to assess the coloration of the burgers, a Minolta colorimeter was employed, allowing for the quantification of color indices, namely L* (brightness), a* (indicating a spectrum from negative greenness to positive redness), and b* (representing a range from negative blue to positive yellowness). The total color difference (ΔE) and the browning index (BI) were computed using the specified equations (Ashrafi et al. 2024).

$$\Delta E = \sqrt[2]{(L*)2 + (a*)2 + (b*)2} \quad (5)$$

$$X = \frac{(a* + 1.75\, L*)}{(5.645L* + a* - 3.012b*)} \quad (6)$$

$$BI = \frac{100\,(X - 0.31)}{0.17} \quad (7)$$

Tissue Parameters

In order to examine the textural characteristics of fried and subsequently cooled burgers at ambient temperature, specifically focusing on texture firmness and chewability, a texture analyzer equipped with a plate probe of 7.5 cm in diameter was utilized. A cylindrical specimen, measuring 1 cm in height and 4 cm in diameter, was excised from the center of the hamburger. Subsequently, a compression test was conducted using a tissue measurement apparatus, employing a probe advancement speed of 5 mm/s, until the sample's height was reduced by 50% of its original dimension (Afshari et al. 2017).

Investigation of Loss and Cooking Efficiency

The equations presented below were employed to ascertain the cooking loss and baking efficiency of the burgers (Najafi, N; Rahman, A; Hosseinmardi 2023).

Sensory Assessment

In order to assess the sensory attributes of fried burgers—including color, texture, flavor, and overall acceptability—a 5-point hedonic scale was employed. This scale ranged from 1 (very undesirable) to 5 (very desirable). The evaluation involved 20 participants, consisting of an equal number of 10 women and 10 men, all within the age range of 25 to 40 years. A minimum score of 3 is deemed acceptable. The samples were presented to the evaluators in coded white plastic containers, distributed randomly, along with bottled mineral water and a sensory evaluation form. Prior to the evaluation, the evaluators were provided with the necessary instructions and explanations regarding the assessment process (Varmazyar,Elham ; Rahman, Alireza; Hosseinmard 2024).

Statistical Analysis of Data

The experiments were conducted with three replicates, and the data were analyzed using SPSS version 22. A completely randomized design was employed, and the data were subjected to one-way analysis of variance (ANOVA) for statistical evaluation. Significant differences among the samples were determined utilizing Duncan's multiple range test at a 95% probability level ($p > 0.05$)

The results are presented as the mean accompanied by the standard deviation.

Results and Discussion

Moisture content of burgers

The moisture content of fried burgers is compared with each other in Table 1 and shows that coating the burgers with CMC-based solutions could lead to better moisture retention in fried burgers compared to the control sample, and the combination of aromatic violet flower extract increased the moisture content of fried burgers. The moisture content of the control burger was 56.82% and its content in the coated burgers was 63.56-66.32%. CMC-based edible coatings are able to prevent water from evaporating rapidly and replacing it with oil during the frying process due to creating a semi-coating layer and trapping water in the polymer matrix (El Sheikha, Allam, Oz, et al. 2022). Plant extracts and their active constituents possess the capability to inhibit the degradation of proteins and lipids, while simultaneously enhancing moisture retention within product matrices. These effects are attributable to their antioxidative properties and the hydrophobic/hydrophilic interactions they facilitate (Khazaei, Esmaiili, and Emam-Djomeh 2016). In accordance with the findings of the current study, previous research has demonstrated that the application of oleogel coatings infused with varying concentrations of thyme essential oil effectively reduced moisture loss in deep-fried chicken nuggets (Oyom et al. 2024). Other researchers successfully employed active coatings derived from chia seed gum, which incorporated nanoemulsions of Aromatic Violet Flower extract, to effectively preserve the moisture content of fried burgers (Ashrafi et al. 2024). Another study demonstrated that the application of active coatings derived from flaxseed mucilage combined with carboxymethyl cellulose (CMC), which incorporates finely encapsulated extracts of burdock root, resulted in improved moisture retention in fried potatoes when compared to the control group (Esmaeili *et al.*, 2024).

Table 1. Moisture, absorbed oil, peroxide and TBA indexes of fried burger treatments

Samples	Moisture (%)	Oil uptake (%)	Peroxide (meq/kg)	TBA (mg MDA/kg)
T0	56.82 ± 0.47 ^{e}	6.19 ± 0.17 ^{a}	5.10 ± 0.04 ^{a}	1.349 ± 0.018 ^{a}
T1	63.56 ± 0.39 ^{d}	4.79 ± 0.11 ^{b}	4.38 ± 0.02 ^{b}	1.175 ± 0.021 ^{b}
T2	64.10 ± 0.42 ^{cd}	4.56 ± 0.14 ^{bc}	4.16 ± 0.02 ^{c}	1.028 ± 0.013 ^{c}
T3	64.87 ± 0.45 ^{bc}	4.30 ± 0.19 ^{cd}	3.25 ± 0.07 ^{d}	0.913 ± 0.024 ^{d}
T4	65.46 ± 0.53 ^{ab}	4.21 ± 0.08 ^{d}	3.10 ± 0.03 ^{e}	0.748 ± 0.010 ^{e}
T5	66.32 ± 0.33 ^{a}	4.13 ± 0.12 ^{d}	2.71 ± 0.02 ^{f}	0.688 ± 0.016 ^{f}

Values represent mean (n=3) ± SD. Different letters in each column represent statistical significant difference at 5% level. T0: control; T1: burger coated with CMC solution; T2: burger coated with CMC solution containing 1% extract; T3: burger coated with CMC solution containing 2% extract; T4: burger coated with CMC solution containing 3% extract; T5: burger coated with CMC solution containing 4% extract

The amount of oil absorbed by the burgers

Table 1 presents a comparative analysis of the oil absorption levels in various fried burger treatments. The control sample exhibited the highest oil absorption rate, measuring 19.6% The application of carboxymethyl cellulose (CMC)-based coatings significantly diminished the amount of oil absorbed by the burgers during the frying process. Furthermore, the incorporation of aromatic violet flower extract into the coating solution, along with an increase in its concentration, resulted in a progressive reduction in oil absorption in the burgers. Specifically, the oil absorption level for the burgers coated with the CMC solution was recorded at 4.79%, whereas the burgers coated with the CMC solution containing the highest concentration of extract (4%) demonstrated an oil absorption of 4.13% Nonetheless, the analysis revealed no statistically significant difference in the quantity of oil absorbed by the coated burgers when compared to the solutions containing extract concentrations ranging from 2% to 4%. Edible coatings primarily function as a physical barrier, inhibiting the direct penetration of oil into the meat matrix. Additionally, these coatings possess the capability to regulate the rapid evaporation of surface water from the product, thereby minimizing the infiltration of oil into the food. Edible coatings can significantly influence mass transfer during the post-frying phase, resulting in a reduction of oil absorption by the food substrate (Xie et al. 2022). The influence of aromatic violet flower extract on the reduction of oil absorption in fried burgers is closely associated with its capacity to enhance moisture retention through a coating mechanism. In accordance with the findings of the present study, additional researchers have effectively employed a coating formulated from soy protein isolate and carboxymethyl cellulose (CMC), which incorporates green tea extract, to diminish the percentage of oil absorption in deep-fried meat products (Guo et al. 2023). Researchers have reported that the application of chitosan-based edible coatings incorporating gallic acid significantly decreased the oil absorption in fried pork meatballs. A previous study has also reported a reduction in oil absorption in deep-fried potatoes through the application of coatings composed of flaxseed mucilage and carboxymethyl cellulose (CMC), which incorporated burdock root extract (Zhang et al. 2024). Other studies have reported that the application of active coatings derived from chia seed gum, which includes Nastaran Kohi extract, significantly diminishes oil absorption in fried burgers (Ashrafi et al. 2024).

Oxidative stability of burgers

The peroxide index serves as a critical parameter for assessing the primary products of lipid oxidation, particularly the presence of hydroperoxides. In the course of lipid oxidation chain reactions, unstable hydroperoxides undergo decomposition, leading to the formation of secondary oxidation products. These secondary products are typically quantified using the thiobarbituric acid (TBA) assay, which serves as a method for measuring the extent of lipid peroxidation (Oyom et al. 2024). In the present study, the oxidative stability of fried veal burgers was assessed through the measurement of the peroxide value and thiobarbituric acid (TBA) levels. The findings are summarized in Table 1. The findings revealed that the control sample exhibited the highest concentrations of peroxide (5.10 meq/kg) and thiobarbituric acid (TBA) reactive substances (1.349 mg MDA/kg). However, the application of coatings based on carboxymethyl cellulose (CMC) prior to the frying process resulted in a significant reduction in both the peroxide index, decreasing to 4.38 meq/kg, and the TBA index, which diminished to 1.175 mg MDA/kg The peroxide and thiobarbituric acid (TBA) indices exhibited a significant decline ($p < 0.05$) Notably, the lowest values for both peroxide and TBA indices were observed in burgers coated with a carboxymethyl cellulose (CMC) solution containing 4% extract, yielding measurements of 2.71 meq/kg and 0.688 mg malondialdehyde (MDA) per kg, respectively. Edible coatings serve to mitigate lipid oxidation by minimizing the penetration of oxygen and restricting the ingress of oil into food during the frying process. Conversely, active edible coatings incorporating plant extracts demonstrate a capacity to inhibit lipid oxidation attributable to their antioxidant properties. These coatings tend to generate a reduced quantity of primary and secondary oxidation products in comparison to uncoated samples (Moghaddasi-Mehrizi et al. 2025) (Moura-Alves et al. 2023). The observed influence of elevated extract levels on the reduction of oxidative indices is correlated with an increase in the concentration of phenolic and bioactive compounds. Subsequent research has indicated that starch-based films incorporating aromatic violet flower extract effectively enhance oxidative stability and diminish both peroxide and TBA indices in chicken fillets. Moreover, the significant antioxidant activity of this extract has been substantiated (Heydarian et al. 2023) (Nikmanesh, Baghaei, and Mohammadi Nafchi 2023). Other research has indicated that the utilization of food coatings formulated from soy protein isolate and carboxymethyl cellulose (CMC), infused with green tea extract, enhances the oxidative stability of fried meat products (Xie et al. 2022). Previous research has indicated that deep-fried pork meatballs coated with an oral and active chitosan-based formulation containing gallic acid exhibit enhanced oxidative stability. Additionally, this treatment has been shown to reduce the levels of oxidative indices associated with the production of deep-fried pork meatballs (Zhang et al. 2024).

Acrylamide content of burgers

The acrylamide concentrations present in various fried burger treatments have been systematically compared, as illustrated in Figure 1. Consistent with expectations, the control sample exhibited the highest concentration of acrylamide, measuring 74.52 The application of coatings derived from carboxymethyl cellulose (CMC) solutions notably reduced the acrylamide content in burgers to 70. 92 Furthermore, the incorporation of aromatic violet flower extract into the coating solution, with a concentration range increased from 1% to 4%, resulted in a progressive reduction of acrylamide levels ($p < 0.05$) Specifically, the burgers coated with the CMC solution containing 4% extract exhibited the lowest acrylamide concentration at 59.25 μg/kg; however, no statistically significant difference was observed when compared to the burgers coated with a solution containing 3% extract, which had an acrylamide level of 62.75. Numerous mechanisms exist through which active edible coatings facilitate a reduction in the formation of acrylamide in fried foods. Edible coatings typically establish a physical barrier on food products, thereby influencing oil penetration and the transfer of heat and moisture. This intervention helps to mitigate surface desiccation, which can exacerbate the Maillard reaction. There appears to be a correlation between decreased oil absorption in fried foods and the generation of detrimental byproducts (Khajeh et al. 2025). A significant pathway for the formation of acrylamide in fried foods is attributed to the oxidation of fats. The application of elevated temperatures, coupled with the degradation of lipids, leads to the formation of acrolein. This compound has the potential to generate acrylic radicals and acrylic acid radicals through oxidative processes. Under optimal conditions, these compounds may serve as intermediates in the synthesis of acrylamide (Lee and Hong 2020). The plant extracts employed in the active coating demonstrate the ability to inhibit oxidation pathways and Maillard reactions, thereby mitigating the presence of mediators that contribute to the formation of acrylamide (Kahkeshani, Saeidnia, and Abdollahi 2015). Phenolic compounds have the potential to engage in reactions with carbonyl species or with precursor amino acids, thereby influencing their availability (Govindaraju et al. 2024). Active edible coatings have the potential to inhibit lipid oxidation by diminishing the permeability of oxygen, which consequently mitigates the formation of acrylamide in fried foods. Other researchers have indicated that the elevated antioxidant activity of protein coatings that incorporate green tea extract significantly mitigates the intensity of acrylamide formation in deep-fried meat products (Gholami, Rahman, and Mostaghim 2017). Other researchers have demonstrated that the utilization of various plant extracts, specifically coriander, black seed, and thyme, can lead to a significant reduction in the production of acrylamide in heated meats, including chicken, turkey, sheep, duck, and fish. In a study conducted by other researchers, the utilization of an active coating composed of chia seed gum, which incorporated nanoemulsions of Aromatic Violet Flower extract, resulted in a substantial reduction in the acrylamide levels present in fried burgers (Ashrafi et al. 2024). In a separate study, the researchers demonstrated that active coatings formulated with flaxseed mucilage and carboxymethyl cellulose (CMC), which incorporated microencapsulated extracts of burdock root, were effective in significantly reducing the formation of acrylamide in French fries (Esmaeili et al. 2024).

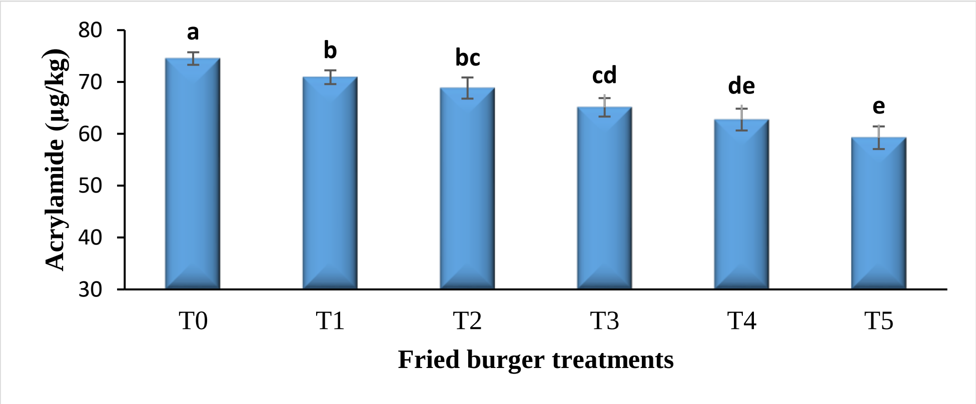

Figure 1. Comparison of acrylamide content of fried burger treatments

*T0: control; T1: burger coated with CMC solution; T2: burger coated with CMC solution containing 1% extract; T3: burger coated with CMC solution containing 2% extract; T4: burger coated with CMC solution containing 3% extract; T5: burger coated with CMC solution containing 4% extract

Characteristics of Cooking Burgers

The sintering parameters examined in this research encompassed the percentage of mass loss and curing efficiency. The corresponding values of these parameters are presented in Table 2. The control sample exhibited the highest cooking loss rate, recorded at 39.77%, alongside the lowest cooking efficiency, which was 62.45% In contrast, the application of coatings based on carboxymethyl cellulose (CMC) significantly mitigated cooking loss and enhanced the cooking efficiency of the burgers relative to the control sample ($p < 0.05$) Notably, an increase in the concentration of aromatic violet flower extract within the coating solutions led to a gradual decrease in cooking loss rates and a corresponding increase in cooking efficiency ($p < 0.05$) The optimal results were observed in burgers coated with a CMC solution that included the highest concentration of extract (4%), yielding a cooking loss rate of 21.74% and a cooking efficiency rate of 78.31% Nevertheless, the analysis revealed no statistically significant difference in the rate of moisture loss and cooking efficiency between the treatment in question and the burger coated with a solution containing 3% of the extract. Enhancing the cooking efficiency and minimizing the cooking loss of burgers, as influenced by the coating process utilizing carboxymethyl cellulose (CMC) solutions infused with violet flower extract, can be ascribed to the coating's capacity to retain moisture and decrease oil absorption during the cooking process. These factors moisture content and oil absorption are critical determinants that exert a substantial influence on the cooking properties of the product (Pourhoseini, M; Rahman 2024) (Bahrami Feridoni and Khademi Shurmasti 2020). Feed coatings can effectively mitigate the rapid absorption of oil during the cooling phase and simultaneously inhibit the swift evaporation of water during this period(Xie et al. 2022). Consequently, these coatings contribute to a reduction in the cooking loss associated with the coated food product. Other researchers, in their investigation, demonstrated that the application of chitosan-based coatings incorporating gallic acid on pork meatballs resulted in a reduction in cooking loss rates for the coated samples compared to their uncoated counterparts (Zhang et al. 2024). The study conducted by other researchers indicated a reduction in the cooking loss percentage and an enhancement in the cooking efficiency of fried burgers, attributed to the application of edible and active coatings derived from chia seed gum that incorporated nanoemulsions of Aromatic Violet Flower extract (Ashrafi et al. 2024). The substantial impact of the coating process on diminutive cooking loss rates in soy burgers has been corroborated by previous studies (Lee and Hong 2020).

Table 2. Cooking properties of fried burger treatments

Samples	Cooking loss (%)	Cooking yield (%)
T0	39.77 ± 0.24 [a]	62.45 ± 0.32 [e]
T1	23.18 ± 0.31 [b]	75.69 ± 0.41 [d]
T2	22.91 ± 0.18 [bc]	76.30 ± 0.47 [cd]
T3	22.46 ± 0.27 [cd]	76.98 ± 0.24 [bc]
T4	22.02 ± 0.33 [de]	77.56 ± 0.36 [ab]
T5	21.74 ± 0.32 [e]	78.31 ± 0.45 [a]

Values represent mean (n=3) ± SD. Different letters in each column represent statistical significant difference at 5% level. T0: control; T1: burger coated with CMC solution; T2: burger coated with CMC solution containing 1% extract; T3: burger coated with CMC solution containing 2% extract; T4: burger coated with CMC solution containing 3% extract; T5: burger coated with CMC solution containing 4% extract

Burger Colors

The visual presentation and coloration of food are critical factors influencing consumer acceptance of the product. The color indices of the fried burgers assessed in this study comprised L*, a*, b*, EΔ, and BI, which were quantified using a calorimeter. The results derived from the analysis of color indices of fried burgers, as presented in Table 3, indicate that the control sample exhibited the lowest L* index value (43.69) along with the highest values for both the a* (14.31) and b* indices (16. 04) Furthermore, the application of coatings formulated with carboxymethyl cellulose (CMC)-based solutions resulted in an elevation of the L* index, concomitantly leading to a statistically significant reduction in the a* and b* indices when compared to the control sample ($p < 0.05$) Additionally, the incorporation of aromatic violet flower extract into the coating solution, particularly when its concentration was increased, corresponded with an enhancement in the intensity of these observed color changes. The incorporation of the extract, along with its elevated concentration in the coating solutions, resulted in a significant enhancement of the overall color variance of the coated burgers in comparison to the control sample. The application of coatings derived from carboxymethyl cellulose (CMC) prior to the frying process, particularly those formulations incorporating varying concentrations of aromatic violet flower extract, has demonstrated a significant reduction in the severity of browning in burgers in comparison to the control group. Specifically, the control sample exhibited the highest browning index (BI) value of 68.76, while the burger coated with the CMC solution containing the highest concentration of the flower extract (4%) recorded the lowest BI value of 45.79 Edible coatings have the potential to alter temperature dynamics and the rate of contact between surface sugars and amines by preserving surface moisture. This preservation contributes to a reduction in the rate of surface drying and the formation of a thermal insulation layer, thereby mitigating the progression of the Maillard reaction. Furthermore, antioxidants have the capacity to modulate or diminish the reactivity of specific mediators involved in the Maillard reaction, thereby leading to a reduction in the formation of brown pigments during the frying process (M.N. Lund and C.A. Ray 2017). Conversely, edible coatings serve to diminish the rate of oxygen penetration and inhibit direct contact between the heated oil and the surfaces of the product. These two factors diminish the oxidative pathways as well as the magnitude of color changes that occur during the cooking process. Furthermore, a decrease in oil consumption mitigates what is commonly referred to as "darkening resultant from lipid combustion (Kurek, Ščetar, and Galić 2017). Plant extracts that are abundant in phenolic compounds demonstrate the ability to inhibit free radicals and reactive oxygen species, thereby mitigating the initiation of lipid peroxidation chain reactions. Lipid peroxidation results in the formation of colored aldehydes and ketones, which can interact with proteins, yielding a darker, brown coloration. Consequently, inhibiting lipid oxidation is instrumental in preserving the brightness of the product's color (Manessis et al. 2020). The oxidation of proteins, along with the conversion of myoglobin to metmyoglobin, can contribute to the darkening or browning of the red hue observed in meat. Plant-derived antioxidants and active coatings have the potential to inhibit this conversion process, thereby preserving the surface color brightness of the product (Y. Liu et al. 2021). In alignment with the findings of the present study, previous research has also indicated that burgers coated with chia seed gum-based coatings, which contain nanoemulsions of Aromatic Violet Flower extract, exhibited lighter and more yellow coloration compared to the control group, as well as a reduced browning index (Ashrafi et al. 2024). In alternative studies, starch-based films infused with aromatic violet flower extract demonstrated a significant reduction in the browning intensity of chicken fillets throughout the storage duration(Nikmanesh, Baghaei, and Mohammadi Nafchi 2023). The substantial impact of edible and active coatings formulated with carboxymethyl cellulose (CMC), incorporating varying concentrations of ethanolic propolis extract, on mitigating the degree of browning in chicken meat has been corroborated in previous studies (Pourhoseini, M; Rahman 2024) (Allam et al. 2022).

Table 3. Color indices of fried burger treatments

Samples	L*	a*	b*	ΔE	BI
T0	43.69 ± 0.56 ^{e}	14.31 ± 0.14 ^{a}	16.04 ± 0.29 ^{a}	-	68.76 ± 0.71 ^{a}
T1	45.24 ± 0.38 ^{d}	12.22 ± 0.19 ^{b}	14.75 ± 0.16 ^{b}	2.90 ± 0.11 ^{e}	50.19 ± 0.65 ^{b}
T2	46.51 ± 0.41 ^{c}	11.50 ± 0.11 ^{c}	14.31 ± 0.20 ^{c}	4.34 ± 0.18 ^{d}	49.24 ± 0.88 ^{bc}
T3	48.10 ± 0.49 ^{b}	11.13 ± 0.17 ^{d}	13.95 ± 0.18 ^{cd}	5.83 ± 0.25 ^{c}	48.62 ± 0.81 ^{c}
T4	48.98 ± 0.48 ^{ab}	10.65 ± 0.19 ^{e}	13.63 ± 0.31 ^{de}	6.87 ± 0.20 ^{b}	47.99 ± 0.77 ^{c}
T5	49.56 ± 0.52 ^{a}	10.08 ± 0.13 ^{f}	13.36 ± 0.25 ^{e}	7.72 ± 0.14 ^{a}	45.79 ± 0.72 ^{d}

Values represent mean (n=3) ± SD. Different letters in each column represent statistically significant difference at 5% level. T0: control; T1: burger coated with CMC solution; T2: burger coated with CMC solution containing 1% extract; T3: burger coated with CMC solution containing 2% extract; T4: burger coated with CMC solution containing 3% extract; T5: burger coated with CMC solution containing 4% extract

Texture Parameters of Burgers

Table 4 presents a comparative analysis of the textural parameters of fried burgers. The results indicated that the control sample exhibited the highest texture firmness (28.28 N) and chewability (13.65 mm) In contrast, the application of CMC-based solutions, both without extract (24.65 N for firmness and 10.88 N.mm for chewability) and with varying concentrations of aromatic violet flower extract (firmness ranging from 22.87 N to 24.12 N and chewability between 9.10 N.mm and 21.88 N.mm), resulted in a statistically significant reduction in both firmness and chewability when compared to the control sample ($p > 0.05$) Edible coatings form a thin layer on the surface of food products, thereby modulating the rates of water evaporation and oil absorption during the frying process. The preservation of internal moisture is essential for enhancing the hydration of the internal tissue, thereby subsequently minimizing both the cutting force required and the stiffness exhibited by the tissue. It also mitigates the excessive desiccation of the crust (Jamalimanesh, K; Rahman, A; Hosseinmardi 2025) (Wang, Z., Ng, K., Warner, R.D., Stockmann, R., & Fang 2023). Plant extracts that are abundant in phenolic compounds have been shown to diminish lipid oxidation and inhibit the formation of by-products resulting from Maillard and oxidation reactions. Lipid oxidation and certain thermal reactions have the potential to induce structural alterations in proteins, thereby contributing to an increase in tissue firmness. The application of antioxidants to mitigate these reactions is associated with the stabilization of tissue and a reduction in its firmness (Singh, Kim, and Lee 2022). In accordance with these findings, research has indicated that the utilization of chitosan-based feed coatings incorporating gallic acid resulted in a reduction of firmness in deep-fried pork meats (Zhang et al. 2024). Additionally, it has been reported that the texture of fried burgers coated with chia seed gum-based coatings, which incorporated nanoemulsions of Aromatic Violet Flower extract, exhibited a softer consistency compared to the uncoated samples (Ashrafi et al. 2024). Research has demonstrated that the application of edible and active coatings infused with essential oils derived from rosemary and oregano results in a softer meat texture when compared to uncoated samples of beef (Vital et al. 2016).

Table 4. Textural parameters of fried burger treatments

Samples	Hardness (N)	Chewiness (N.mm)
T0	28.28 ± 0.44 [a]	13.65 ± 0.36 [a]
T1	24.65 ± 0.51 [b]	10.88 ± 0.43 [b]
T2	24.12 ± 0.48 [b]	10.41 ± 0.29 [bc]
T3	23.74 ± 0.54 [bc]	9.96 ± 0.38 [cd]
T4	23.25 ± 0.29 [c]	9.52 ± 0.24 [de]
T5	22.87 ± 0.56 [c]	9.21 ± 0.27 [e]

Values represent mean (n=3) ± SD. Different letters in each column represent statistical significant difference at 5% level. T0: control; T1: burger coated with CMC solution; T2: burger coated with CMC solution containing 1% extract; T3: burger coated with CMC solution containing 2% extract; T4: burger coated with CMC solution containing 3% extract; T5: burger coated with CMC solution containing 4% extract

Sensory Evaluation of Burgers

The sensory attributes of fried burgers, including color, texture, taste, aroma, and overall acceptability, were assessed using a 5-point hedonic scale. The findings are illustrated in Figure 2. The application of coatings comprising carboxymethyl cellulose (CMC)-based solutions with varying concentrations of aromatic violet flower extract did not yield any significant alterations in the color, flavor, aroma, or overall acceptability of the burgers. However, a noteworthy reduction in the texture score was observed in comparison to the control group. Nevertheless, all the treatments examined in this study demonstrated sensory scores exceeding 4, categorizing them within the "good" range, and exhibited a high level of sensory acceptance (Oyom et al. 2024). In alignment with the findings of the present study, other researchers have indicated that the application of oleogel coatings incorporating thyme essential oil does not negatively impact the sensory characteristics of fried chicken nuggets(Ashrafi et al. 2024). Other studies have demonstrated that the application of active coatings derived from chia seed gum, which incorporate nanoemulsions of Aromatic Violet Flower extract, did not adversely impact the sensory attributes of fried burgers. Furthermore, all treatments exhibited a high level of sensory acceptability. It has been observed that pre-soaking potato slices in turmeric extract prior to the frying process enhances the sensory acceptance of the resulting French fries(Soroushfard, Roufegarinejad, and Soofi 2021).

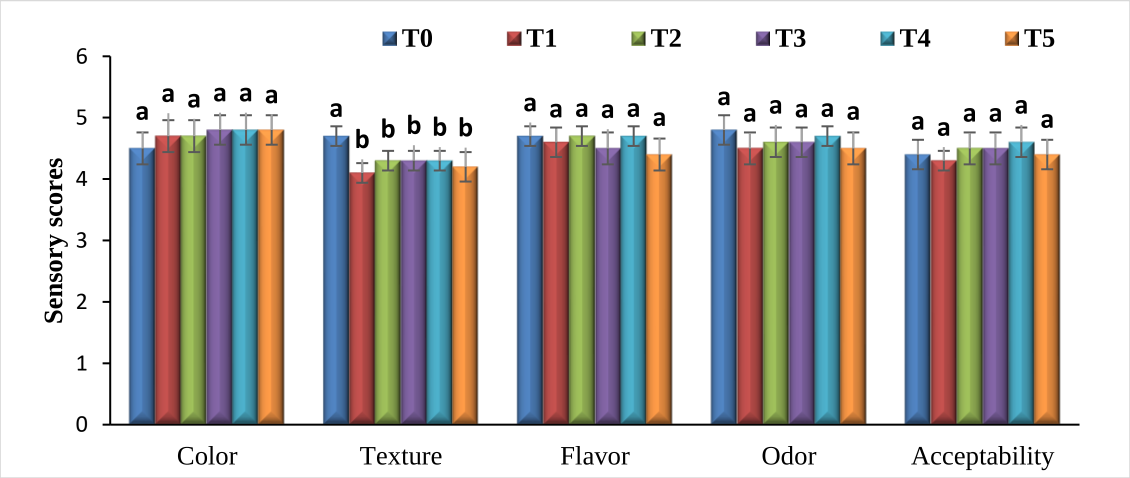

Figure 2. Comparison of sensory scores of fried burger treatments

*T0: control; T1: burger coated with CMC solution; T2: burger coated with CMC solution containing 1% extract; T3: burger coated with CMC solution containing 2% extract; T4: burger coated with CMC solution containing 3% extract; T5: burger coated with CMC solution containing 4% extract

Conclusion

The findings of this study indicated that the application of coatings derived from carboxymethyl cellulose (CMC)-based solutions, particularly those infused with aromatic violet flower extract, resulted in a substantial enhancement of moisture content and a reduction in oil absorption in the coated burgers when compared to the control samples. Furthermore, these treatments significantly improved the cooking properties of the burgers. The application of active coatings has been shown to enhance the oxidative stability of fried burgers while significantly reducing acrylamide levels in comparison to the control sample. Furthermore, an increase in the concentration of the extract within the coating solutions resulted in a marked enhancement of the antioxidant properties of the coatings. The application of a coating to the burgers prior to the frying process resulted in a notable reduction in the browning intensity of the fried burgers when compared to the control group. Furthermore, an increase in the concentration of violet flower extract within the coating solution was found to correlate with a decrease in the production of brown compounds. The textural parameters of fried burgers were significantly influenced by the application of edible coatings. Specifically, the pre-frying coating of the burgers with carboxymethyl cellulose (CMC)-based solutions resulted in a reduction in both firmness and chewability when compared to the control sample. Furthermore, an increasing concentration of violet flower extract in the coating solution was associated with a progressive decline in both firmness and chewability of the coated burgers. The findings from the sensory evaluation indicate that all burger treatments investigated in this study demonstrated high levels of sensory acceptance, accompanied by elevated sensory scores. The findings of this study demonstrate that coatings formulated with carboxymethyl cellulose (CMC) and enriched with aromatic violet flower extract, particularly at a concentration of 4%, are effective in preserving product quality, minimizing absorbed oil content, enhancing oxidative stability, and lowering acrylamide levels in fried meat burgers. Additionally, these coatings contribute to the production of a safer food product without compromising sensory attributes.

Conflict of Interest Statement

The authors declare that there are no conflicts of interest.

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تحقیقات مهندسی صنایع غذایی/جلد ٢٤ / شماره ٧٩/ پاییز و زمستان/١٤٠٤/ ص ١٨٤-١٦٧

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بررسی تأثیر پوشش‌های خوراکی بر پایه کربوکسی متیل سلولز حاوی عصاره گل بنفشه معطر بر خصوصیات کیفی، کاهش جذب روغن و محتوای آکریلامید برگر گوساله سرخ شده

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تاریخ ارسال: ۱۴۰۴/۰۹/۲۲ تاریخ پذیرش: ۱۴۰۴/۱۱/۲۵

چکیده

محصولات سرخ شده با وجود اینکه در سراسر جهان بسیار محبوب و پرمصرف هستند، ولی استفاده از آن‌ها به دلیل محتوای روغن بالا و همچنین حضور ترکیبات مضر شامل محصولات حاصل از اکسیداسیون لیپیدها و همچنین آکریلامید، برای سلامتی مصرف‌کنندگان خطرزا می‌باشد. بنابراین، هدف از این تحقیق بررسی پوشش‌های خوراکی و فعال برپایه کربوکسی‌متیل سلولز (CMC) حاوی عصاره گل‌بنفشه معطر بر خصوصیات کیفی، حسی، پایداری اکسایشی و محتوای آکریلامید برگر گوشت گوساله سرخ شده بود. برای این منظور، سطوح مختلف عصاره گل‌بنفشه معطر شامل ۰، ۱، ۲، ۳ و ٤ درصد به محلول CMC افزوده شده و برگرها قبل از سرخ شدن در محلول‌های پوشش‌دهی آماده شده غوطه‌ور گردیدند. سپس سرخ کردن برگرها در دمای ١٦٠ درجه سلسیوس به مدت ٥ دقیقه انجام گرفته و محتوای رطوبت، روغن جذب شده، اندیس‌های پراکسید و تیوباربیتوریک اسید (TBA)، اُفت و بازده پخت، شاخص‌های رنگی، پارامترهای بافتی و ویژگی‌های حسی برگرها مورد آزمون قرار گرفتند. نتایج نشان داد که پوشش‌دهی برگرها با محلول‌های برپایه CMC، به ویژه محلول‌های حاوی عصاره گل بنفشه، توانست موجب حفظ بهتر رطوبت، کاهش روغن جذب شده و محتوای آکریلامید برگرهای سرخ شده گردد و پایداری اکسایشی برگرها را نیز به طور قابل توجهی بهبود بخشید. بین غلظت عصاره و اندیس‌های اکسایشی برگرها رابطه عکسی مشاهده شد، به طوری که با افزایش سطح عصاره گل بنفشه در محلول پوشش‌دهی، فعالیت آنتی اکسیدانی افزایش یافته و اندیس‌های اکسایشی کاهش معنی‌داری نشان دادند ($p<0.05$). پوشش‌دهی برگرها همچنین خصوصیات پخت را از طریق کاهش میزان اُفت پخت و افزایش بازده پخت بهبود بخشید. پوشش‌دهی برگرها همچنین موجب افزایش شاخص *L و کاهش *a، *b و BI (اندیس قهوه‌ای شدن) در مقایسه با شاهد گردید و سفتی و قابلیت جویدن بافت برگرها را در مقایسه با شاهد به طور معنی‌داری کاهش داد ($p<0.05$). نتایج ارزیابی حسی حاکی از پذیرش بالای کلیه تیمارهای برگر تولیدی در این تحقیق بود. بر طبق این نتایج در کل می‌توان دریافت که پوشش‌دهی برگرهای گوشتی قبل از فرآیند سرخ کردن با پوشش‌های خوراکی فعال برپایه CMC حاوی عصاره گل بنفشه معطر می‌تواند علاوه بر کاهش جذب روغن و محتوای آکریلامید تشکیل شده در برگرهای سرخ شده، بر خصوصیات کیفی این محصولات تأثیر مطلوبی داشته باشد.

کلمات کلیدی: آکریلامید، برگر، پایداری اکسایشی، پوشش فعال، سرخ کردن، گل بنفشه معطر