Evaluating the quality of fried whiteleg shrimp (*Litopenaeus vannamei*) filets coated with quince seed gum containing encapsulated cinnamon extract

Aghababaei F.[1]; Jouki M.[1]; Mooraki N.[1*]

Received: October 2023 Accepted: February 2024

Abstract

This study aims to examine the impact of applying a coating composed of quince seed gum and cinnamon extract on the reduction of oil absorption and oxidation in white Pacific shrimp during the frying process. This study dealt with the formulation of edible coatings incorporating quince gum seed at concentrations of 0.5% and 1%, along with encapsulated cinnamon extract at varying concentrations of 0%, 0.1%, 0.5%, and 1%. These coatings were applied to filets to enhance quality preservation throughout the frying process. Statistical analyses were conducted using SPSS version 26 software. The coatings formulated with 1% quince seed gum and 1% encapsulated cinnamon extract demonstrated superior performance throughout the testing duration. Notably, the moisture loss in fried shrimp diminished significantly when compared to the uncoated control samples. Further, the most pronounced reduction in fat oxidation was also recorded in the above-mentioned samples. The samples that were coated exhibited enhanced juiciness and improved texture post-frying, while the incorporation of the coating resulted in a darker hue and increased brightness of the samples. The findings indicated that the application of the highest quantity of quince seed gum, along with the maximum level of encapsulated cinnamon extract utilized in this study, significantly inhibited the formation of primary compounds associated with fat oxidation. Furthermore, it also reduced the production of secondary compounds when compared to the control samples, demonstrating the most effective preservation method for maintaining moisture in the samples.

Keywords: Deep frying, Coating, Oil absorption, Aquaculture food products.

1- Department of Food Science and Technology, North Tehran Branch, Islamic Azad University, Tehran, Iran

*Corresponding author's E-mail: Nargess_Mooraki@Yahoo.com

Introduction

Shrimps rank among the most favored seafood varieties, being integral to the traditional cuisines of numerous countries due to their exceptional flesh quality, palatable flavor, nutritional benefits, and straightforward cooking methods (Li *et al.*, 2022). The Pacific White Shrimp, scientifically known as Litopenaeus vannamei, stands as the predominant species in aquaculture, significantly contributing to global production, which is projected to reach approximately 4.0 million metric tons in 2023 (FAO, 2024). Due to its considerable market value, L. vannamei has established itself as one of the most economically significant seafood commodities in international trade (Li *et al.*, 2021). The high sensitivity of seafood to high processing temperatures is attributed to the presence of unsaturated fatty acids. Although shrimp muscle contains a lower lipid percentage relative to other sources of edible meats, it boasts a fatty acid profile that is notably rich in unsaturated fatty acids. According to Li *et al.* (2021), the common strain of pacific shrimp contains 38.11±0.39 (g/100g wet weight), 17.48±0.09, and 44.14±0.38, ∑PUFA, ∑MUFA, and ∑SFA, respectively. This characteristic presents a significant benefit of including shrimp in the diet. However, it is crucial to exercise caution during the processing and cooking stages, particularly throughout frying, to preserve the quality of the product (Carrión-Granda *et al*., 2016).

A widely used technique to mitigate excessive oil absorption during deep-fat frying and to produce low-fat fried foods is the application of hydrocolloid coatings (Bouchon *et al.*, 2003). Deep frying represents a method of dehydration utilized within various food processing techniques. The process involves heat transfer which results in the denaturation of proteins, gelatinization of starches, and the evaporation of moisture. This leads to the development of a crispy and brittle crust, typically measuring between 1 and 2 mm in thickness, along with the attainment of an appealing coloration. Given the critical role of surface characteristics in influencing oil absorption, the application of food coatings is regarded as an effective strategy to minimize oil uptake during the frying process. Coated food items enjoy significant popularity owing to their visual appeal, crunchy texture, vibrant color, as well as enticing aroma and flavor. The qualitative attributes of these products are significantly affected by the rheological properties of the coating materials. The application of a coating on the surface diminishes its porosity and inhibits the absorption of oil into the food. Besides reducing oil absorption, this also minimizes moisture loss. Key attributes of coating compounds include their capacity to form films, thermal stability, characteristics related to the transfer of oil and moisture, as well as their nutritional and sensory qualities. The application of hydrocolloids as a coating technique has emerged as the predominant approach for minimizing oil absorption in the majority of research conducted over the past ten years.

Mucilage and natural polysaccharides, particularly those derived from plant seeds, exhibit distinctive techno-functional characteristics, such as water holding capacity (WHC) and emulsifying properties. These attributes render them highly suitable for application in meat processing, particularly during frying, where they can effectively bind to fats and contribute to a reduction in overall lipid content (Noshad *et al.,* 2017; Eghbaljoo *et al.*, 2022; Gao *et al.*, 2024). Quince (*Cydonia oblonga*) seeds, characterized by their brown coloration and oval shape, measure approximately 7 mm in length and 5 mm in width. Quince seed mucilage (QCM) is a biomaterial composed from glucuronic acid and xylose, specifically a glucuronoxylan-based substance. This polysaccharide hydrogel, known as glucuronoxylan, is both cost-effective and biocompatible (Hussain *et al.*, 2019). These seeds exhibit a rapid absorption of water, resulting in the formation of a viscous and flavorless liquid.

Cinnamon is derived from the bark of trees belonging to the Cinnamomum genus, which is classified as a tropical perennial plant. This species is widely acknowledged for its potential as a source of essential oils and various phenolic compounds, including flavonoids, phenolic aldehydes and acids, coumarins, and proanthocyanidins (Rahayu *et al.*, 2022). Various studies have investigated the impact of potent antioxidant found in cinnamon extract on lipid oxidation and the stability of meat products during the processes of deep frying and subsequent storage (Award *et al.*, 2022; Shoqairan *et al.*, 2023; Zhou *et al.*, 2023; Shahid *et al.*, 2018; su *et al.*, 2007). In contemporary practices, the incorporation of functional compounds in their free and encapsulated form within food packaging represents a significant advancement in food technologies. The process of microencapsulation enhances the antioxidant, antibacterial, and sensory attributes of the extract.

The application of mucilage and plant-derived hydrocolloids, in conjunction with extracts exhibiting strong antioxidant properties, has garnered significant attention in research aimed at minimizing oil absorption during frying and enhancing quality parameters. A considerable number of these studies have specifically concentrated on assessing their effectiveness in shrimp fillets (Khazaei *et al.,* 2016; Attar *et al.*, 2018; Sharifimehr *et al.*, 2019; Shahidi and Hossain, 2022; Mehraie *et al.*, 2023). The existing scientific literature does not address the mitigation of quality degradation in shrimp through the application of active coatings derived from quince seed gum that incorporates micro-encapsulated cinnamon extract during frying. This study aimed to explore the impact of these active coatings on moisture retention, lipid oxidation, colorimetry and textural changes of fried shrimp.

Materials and methods

Ingredients

The ingredients included: pacific shrimp and quince fruit (purchased from local market in Tehran Province), cinnamon extract (GiayahKala refine plant Co.), vegetable oil (Saman), water.

Sample Preparation

Mucilage extraction from quince seeds

The seeds underwent a sifting process utilizing a fabric sieve to eliminate any extraneous materials. Mucilage was generated by dispersing the dried seeds in distilled water for one hour at a temperature of 45°C, maintaining a water-to-seed ratio of 1:20. This was followed by a stirring phase lasting 12 minutes at a constant speed of 1100 rpm with the aid of a stirrer. Subsequently, the seed kernels and insoluble non-carbohydrate substances were separated using a fabric sieve, with this process repeated three to four times, after which the mucilage was collected (Jouki *et al.*, 2014). The measurement of seed gum concentration was conducted utilizing a refractometer (Atago, Japan), yielding a value of 1.328.

Antioxidant capacity assay of cinnamon extract

Cinnamon extract was acquired from GiayahKala refine plant Company. The antioxidant activities were assessed to evaluate the inhibition of free radicals following a modified version of the method established by Brand-Williams *et al.* (1995). A methanolic solution of DPPH was prepared daily, consisting of 0.002 g of DPPH dissolved in 50 cc of methanol, and stored in a dark container. Specifically, 1 mL of the extract was thoroughly blended with 9 mL of methanol and subsequently introduced into the DPPH solution at a 1:3 ratio. The mixture was then stirred well and allowed to sit in the dark for 30 minutes. The absorbance was measured at 517 nm using a spectrophotometer, as described by Brand-Williams *et al.* (1995). The percentage of inhibition was calculated using the following formula:

$$\%I = \frac{A_B - A_S}{A_B} \times 100$$

Where, A_B is the absorbance number of the control sample and A_S denotes the absorbance of the standard sample, and a numerical value of 65/41% was obtained from the measurement of cinnamon antioxidant capacity.

Preparation of microcapsules

Microcapsules encapsulating cinnamon extract were synthesized utilizing a layer-by-layer deposition technique. A 1% (v/v) solution of Tween 80 was prepared, serving as an emulsifier in conjunction with oil at a ratio of 1:5:5 relative to the extract. Subsequently, this mixture was incorporated into seed gum in varying proportions. The separation and homogenization of the capsules were achieved through ultrasound treatment at a power of 900 watts for 5 minutes. The resulting emulsion was then subjected to freezing at -18°C for 24 hours, after which it was transferred to a freeze dryer (Element Scanvac) set at -49°C and dried over a period of 48 hours (Alipoorfard *et al.*, 2020). Following the methodology outlined by

Jouki and Khazaei (2022), with minor modifications, the resultant capsules were stored in moisture-resistant plastic bags until the preparation of the paste coating. This procedure continued until 2 g of dry powder was obtained from each experimental group.

Preparation of fried shrimps

Cultivated white pacific shrimp with a typical weight of 2 kg was purchased from the local market and transported to the research facility in cold temperatures. After washing with tap water, the shrimp was filleted and coated with quince seed gum containing different levels of miroencapsulated cinnamon extract according to Table 1, and deep fried with liquid oil at 160°C for 1 Minute.

Table 1: Specification of experimental groups.

T	quince seed gum	encapsulated cinnamon extract
1control	0%	0%
T1	0.5%	0%
T2	0.5%	0.1%
T3	0.5%	0.5%
T4	0.5%	1%
T5	1%	0%
T6	1%	0.1%
T7	1%	0.5%
T8	1%	1%

Compositional analysis

The moisture levels of shrimps were assessed prior to and following the frying process, while adhering to the established protocol (AOAC, 1990). Specifically, the shrimps were subjected to drying in a hot air oven maintained at a temperature of 105±3°C for 24 hours. The percentage of moisture, calculated based on the wet weight, was determined by comparing the initial weight of the samples before drying with their weight after the drying process. The quantification of TBA was conducted using a colorimetric technique alongside a spectrophotometer and a reagent, prepared by dissolving 200 mg of TBA in 100 ml of 1-butanol solvent following filtration. This procedure followed the methodology established by Krick *et al.*, (1991), with the results expressed in milligrams of malondialdehyde per kilogram of fried fillets. The peroxide index was assessed through titration with sodium thiosulfate following the extraction of crude fat, which involved maintaining 15 g of fillet in a chloroform and methanol mixture for a duration of 24 hours (Bligh and Dyer, 1959).

Physical analysis

A texture analyzer (M350-10CT) featuring a 500 N load cell was employed to assess the hardness of shrimp samples (Sharifimehr *et al.*, 2019). Additionally, a Hunterlab colorimeter was utilized to evaluate the color attributes (L*=brightness, a*=redness, b*= yellowness) of both the coatings and the fried samples (Shojaei-Aliabadi *et al*., 2023).

Statistical analysis

Statistical analysis was performed utilizing SPSS statistical software version 26, with the Kolmogorov-Smirnov (K-S) test applied to evaluate the distribution at a significance threshold of $p<0.05$. For datasets demonstrating a normal distribution, One-Way Analysis of Variance (ANOVA) along with Duncan's post hoc test were implemented, again at a significance level of $p<0.05$. In contrast, when the data did not conform to a normal distribution, the Kruskal-Wallis test was employed to examine differences among the experimental groups.

Results

Compositional analysis

Moisture

The initial assessment of moisture content experimental groups was conducted utilizing the Smirnov-Kolmogorov test to evaluate the data distribution. The analysis revealed that the data followed a normal distribution ($p=0.09$), thereby justifying the application of the One-way ANOVA test to compare the eight experimental groups at a significance level of $p<0.05$. The findings illustrated in Figure 1 indicate a significant difference in moisture levels among the samples ($p=0.00$), with the T8 sample exhibiting the highest moisture content, while the control sample recorded the lowest (Fig. 1).

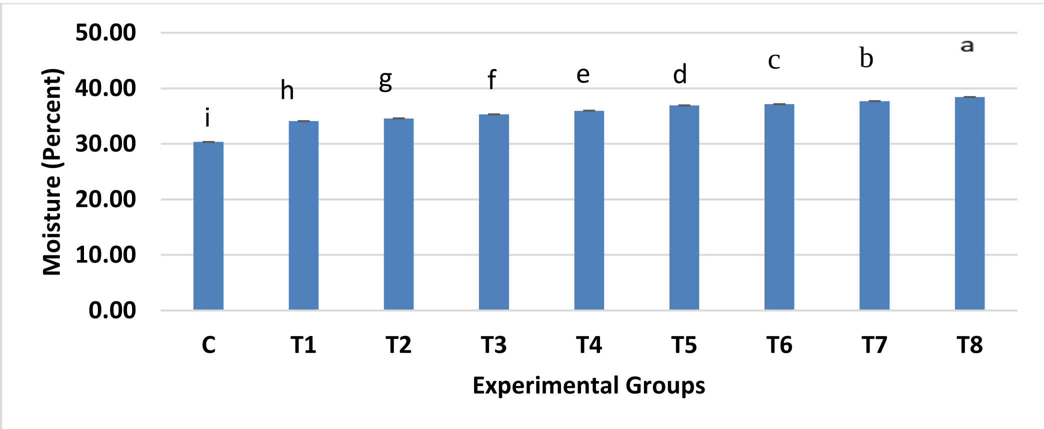

Figure 1: The moisture content of the experimental groups (significance indicated by superscripts at *p*<0.05).

TBARS value

The data concerning TBARS, which serves as a measure of aldehyde formation and indicates the stability or rancidity of lipids, demonstrated a normal distribution. As displayed in Figure 2, there exists a statistically significant difference in the levels of TBARs across the samples ($p=0.00$). It is noteworthy that the control sample exhibited the highest values, whereas the T4 and T8 samples presented the lowest values, respectively.

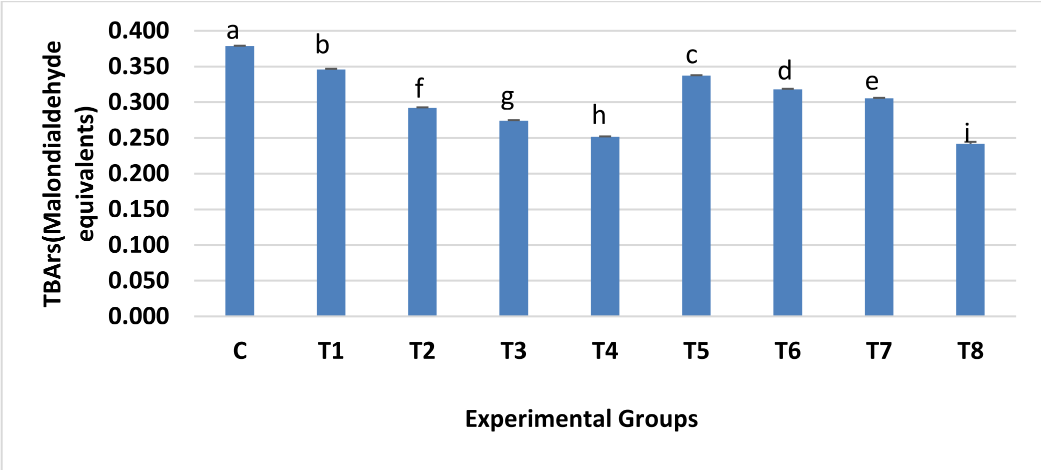

Figure 2: The TBARs content of the experimental groups (significance indicated by superscripts at *p*<0.05).

Peroxide value

The peroxide values exhibited a distribution resembling a normal curve (p=0.76). The data illustrated in Figure 3 indicate a statistically significant variation in peroxide values among the experimental groups (p=0.00). Notably, the control sample displayed the highest peroxide values, while the T_4 and T_8 samples recorded the lowest values, respectively.

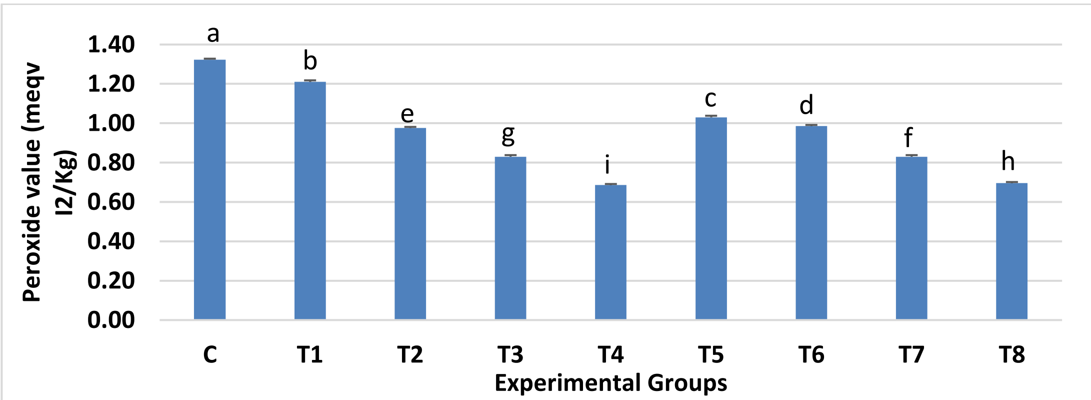

Figure 3: The peroxide value of the experimental groups (significance indicated by superscripts at *p*<0.05).

Physical analysis

Color

The L* values observed in the fried shrimp samples did not conform to a normal distribution pattern. As illustrated in Figure 4a, there is a statistically significant variation among the samples (p=0.002). The samples T_4 and T_5 exhibited the highest L* values, while the T_1 samples recorded the lowest values. The findings illustrated in Figure 4b indicate a significant variation in L* values across the coat (mucilage contained microcapsules enclose cinnamon extract) samples, with a statistical significance of p=0.007. The T_4 sample exhibited the highest recorded values.

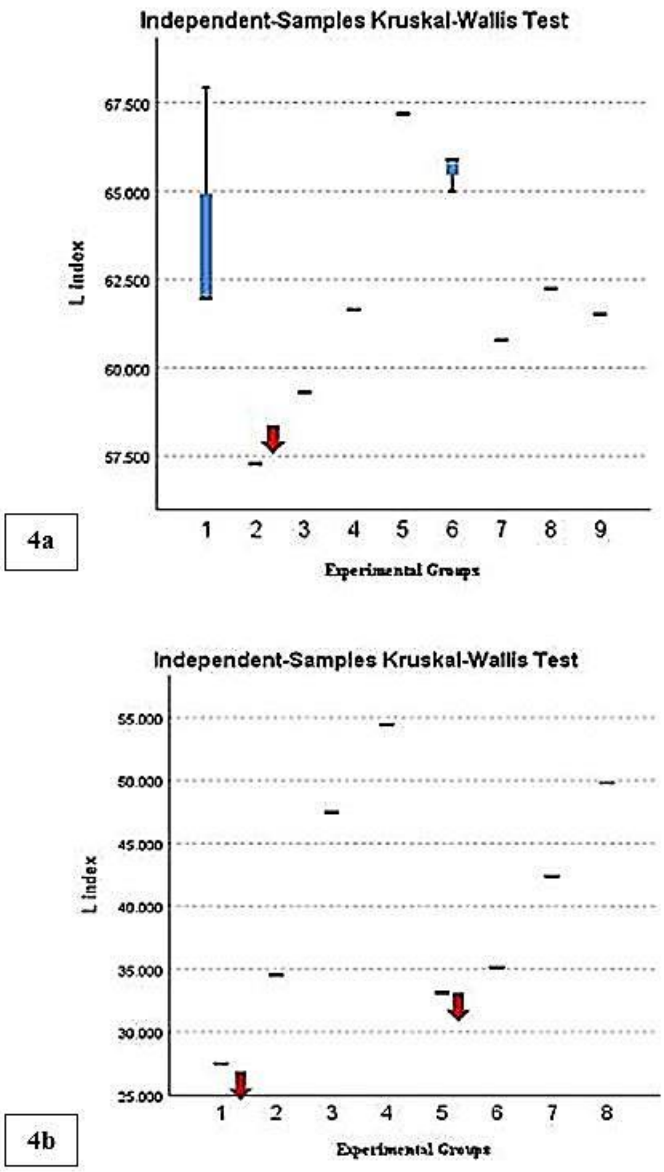

Figure 4: (a): L* changes of the fried samples; (b): L* changes of coat samples (red arrow indicates the factors that are causing significant differences at *p*<0.05).

The distribution of the a* and b* components related to fried samples exhibited characteristics of normal distribution curves. The findings illustrated in Figures 5 and 6 indicate a statistically significant difference among the samples concerning the variations in a* and b* components (p=0.00). The sample T_6 recorded the highest level of redness, while T_5 exhibited the lowest index value. Conversely, the control sample demonstrated the highest level of yellowness, with T_1 showing the lowest index value. The values obtained from the produced coat samples followed a normal distribution pattern. As statistically significant difference was observed in the a* values of the coating samples (p=0.00). The T_2 revealed the highest level of green spectrum, whereas the control group had the lowest index value.

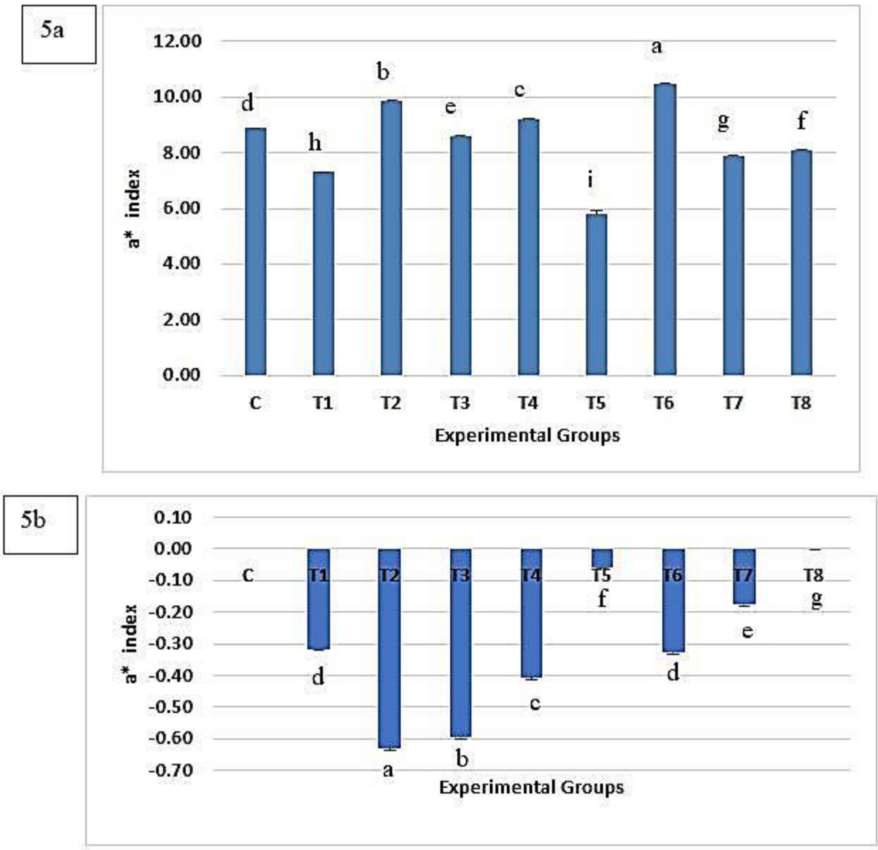

Figure 5: (a): The a* changes of the fried samples; (b): a* changes of coat samples (significance indicated by superscripts at *p*<0.05).

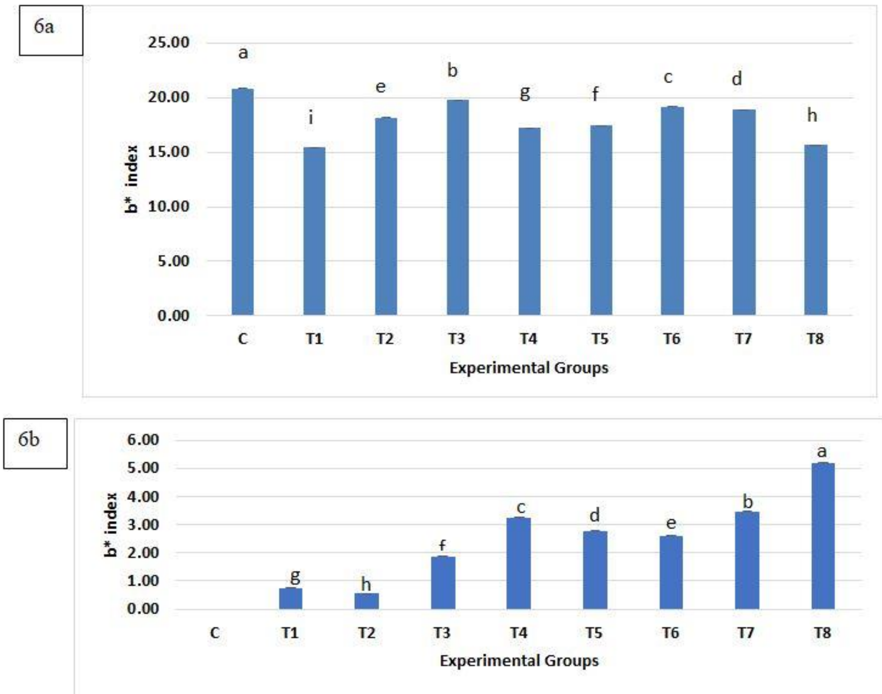

Figure 6: The b* changes of the fried samples; (b): b* changes of coat samples (significance indicated by superscripts at *p*<0.05).

Additionally, Figure 6b reveals a significant difference in the values of the samples (p=0.00), with the T_8 sample exhibiting the greatest degree of yellowness, in contrast to the control cover sample, which recorded the lowest index value.

Texture

The data outlined in Table 2 indicate that the control sample exhibits the highest measurements of adhesion, hardness, and springiness, whereas treatment 8 demonstrates the lowest values in these parameters.

Table 2: The textural characteristics of samples following the frying process.

	Adhesiveness	Hardness	Springness
C	0.307	0.261	0.091
T1	0.196	0.180	0.859
T2	0.130	0.176	0.896
T3	0.099	0.147	0.897
T4	0.094	0.140	0.897
T5	-0.1045	0.132	0.877
T6	-0.1088	0.117	0.878
T7	-0.105	0.089	0.888
T8	-1.218	0.067	0.783

Discussion

The findings indicated that the treatment with the highest proportion of coating and microcapsule extract exhibited the greatest moisture retention. An increase in the gum concentration from 0.5% to 1% across the initial four treatments to the subsequent series resulted in a notable enhancement in moisture levels. The superior efficacy of seed gum at a 1% concentration contributed to a reduction in moisture loss and oil absorption, attributed to the heightened viscosity of the gum. However, variations in the amounts of cinnamon extracts within the coatings did not significantly influence the moisture retention of fried shrimp. The findings align with those reported by Jouki and Khazaei (2022), who demonstrated that the incorporation of 1% oregano or thyme essential oil into the films did not significantly influence their moisture content. They also revealed that the presence of seed gum plays a crucial role in retaining moisture within the nugget matrix and in sealing the pores, which results in reduced moisture loss from the food during processing. Furthermore, the elevated vapor pressure of the retained moisture leads to a decline in the amount of oil that permeates the food structure. Khazaei *et al.* (2016) demonstrated that incorporating basil gum as a hydrocolloid at a concentration of 1% led to a 13.9% reduction in moisture loss in fried shrimp, which in turn resulted in a 34.5% reduction in fat absorption in the samples. Furthermore, Kim *et al.* (2011) found that a 0.9% concentration of guar gum solution enhanced the moisture content in fried potato slices. Gums are entities characterized by a high concentration of hydroxyl groups, which enable them to effectively retain moisture, exhibiting a significant water-holding capacity

(WHC) (Khezerlou *et al.,* 2021; Gao *et al.,* 2024).

In order to assess the impact of the active coatings applied on the oxidation of lipids in shrimp during frying, measurements of the peroxide value and the thiobarbituric acid reactive substances were conducted. These metrics indicate the levels of oxidation products generated during the initial and subsequent phases of the oxidation process, respectively (Juntachote *et al.,* 2007). The peroxide value showed a statistically significant increase in all samples following the frying process. The amount of peroxide value for the coated samples was lower than for the control sample (uncoated). It also showed that the use of coatings prepared from gum and encapsulated cinnamon extract effectively prevented the increase of oxidation in shrimp during the frying process. According to earlier findings by Kim *et al.* (2011), the application of hydrocolloid coatings markedly diminished both the heat transfer coefficient and oil absorption. This reduction may explain the slower rate of oxidation observed in coated shrimp compared to their uncoated counterparts. The findings from the current study indicate that during the oxidation changes in shrimp following the frying process, samples T_4 and T_8 exhibited the lowest levels of peroxide and thiobarbituric acid indices. This suggests that, in addition to the presence of gum, an elevated concentration of encapsulated extract plays a significant role in mitigating oxidation. Conversely, samples 1 and 5, which contained nomicroencapsulated extract, demonstrated lower thiobarbituric acid and peroxide values compared to the control sample; however, they still recorded higher values than the other tested samples. Jouki and Khazaei (2022) found that the application of seed gum coating and carvacrol microcapsules on nuggets effectively diminished oxidation during the frying process. The findings regarding oil absorption in the samples suggest that the observed decline in oxidation in the coated-fried nugget samples can be attributed to a reduction in oil absorption. This outcome aligns with the anticipated effects of QSG (an active paste coating that incorporates quince seed gum) in lowering oil absorption, as well as the antioxidant properties of carvacrol microcapsules. A study revealed that nanoemulsions of cinnamon essential oil were integrated into composite coatings composed of chitosan, tragacanth, and polyvinyl alcohol (PVA). Chicken fillets that were coated with the cinnamon essential oil-enriched formulation revealed enhanced preservation of their cooking quality. Importantly, the application of this edible coating resulted in diminished water loss throughout the cooking process, and sensory evaluation confirmed that it did not negatively impact the inherent flavor profile of the chicken (Azadi *et al.,* 2023)

The present study employed a temperature exceeding 160°C, a condition under which peroxides can break down into secondary oxidation products (Robards *et al*., 1988). The thiobarbituric acid (TBA) assay is commonly utilized as an effective measure for assessing the secondary compounds generated during this process. This method is particularly relevant for evaluating fat oxidation, as it correlates directly with the concentration of malondialdehyde produced during the oxidation of lipids. Research conducted by Sioen *et al*. (2006) indicated that oxidation products emerge at temperatures exceeding 150°C in the presence of oxygen. In the current study, the measured concentrations of peroxide and thiobarbituric acid were found to be lower than the acceptable thresholds. Huss *et al.* (1995) established that a peroxide value ranging from 10 to 20 milliequivalents per kilogram of fat is considered acceptable. Significantly, the thiobarbituric acid test revealed that the malondialdehyde levels in the coated samples were lower than those in the uncoated control samples. The current study has indicated that the minimal oxidation observed in samples treated with active coatings incorporating 1% cinnamon extract, along with gum concentrations of 1% and 0.5%, can be attributed to the antioxidant characteristics of the cinnamon extract. Plant-derived secondary metabolites, including phenolic compounds and flavonoids, exhibit significant capabilities to neutralize free radicals, which are ubiquitous across various plant parts, including leaves, fruits, seeds, roots, and skins. Phenolic compounds, prevalent in both consumable and non-consumable sources, are known for their diverse biological effects, particularly their antioxidant properties.

The frying process reduces the hardness of the nugget samples. This effect can be related to the temperature of the frying process, which causes protein degradation and cell damage on the surface (Min and Ahn 2005). As Chen *et al*. (2019) stated, following oil uptake, the most important quality parameter to accept or reject fried products is texture, especially crispy crust. Sahin *et al*. (2005) reported that the addition of different gum types could reduce moisture loss by 10% in chicken nugget samples during the deep-frying process, and the hardness of the nuggets diminished when the moisture loss decreased. Han and Bertram (2017) stated that dietary fiber may reduce tissue hardness by disturbing the protein–protein and water-protein networks. The soft and moist interior along with the porous crispy crust provides increased palatability to foods (Akdeniz *et al.*, 2006).

The current study has found that incorporating an active coating with quince seed gum substantially influences texture characteristics. The fried shrimp samples that were not coated exhibited greater toughness compared to the other samples. This increased hardness in the uncoated samples is likely attributable to a greater loss of moisture during the frying process. Among all the fried shrimps, the control sample, which was uncoated, demonstrated the highest level of hardness. The fried samples featuring an active coating composed of seed gum and 1% encapsulated cinnamon extract, exhibited the lowest hardness levels, likely attributable to enhanced moisture retention within these samples. Additionally, the application of an active coating containing gum and encapsulated cinnamon extract on the shrimp resulted in improved springiness.

Usawakesmanee *et al.* (2008) conducted a study indicating that fried shrimp samples coated with 6% methyl cellulose revealed reduced shear strength compared to untreated shrimp. Their findings demonstrated that these coated samples retained a greater amount of moisture than the control group did. Similarly, Sahin *et al.* (2005) found that incorporating various types of gum could diminish moisture loss by as much as 10% in chicken nugget samples during deep frying, with a corresponding decline in the hardness of the nuggets as moisture loss was minimized.

In the colorimetric analysis conducted by Khazaei *et al*. (2016), it was observed that both brightness and yellowness exhibited an increase with higher concentrations of thymol. The treatments that were coated with a combined suspension of Shirazi Gadomeh seed gum and methyl cellulose at various concentrations demonstrated the lowest L* component values when compared to the control treatment. Furthermore, Yadgari *et al.* (2020) reported that the application of hydrocolloids as a coating led to a reduction in the L* component of the coated treatments relative to the control. Note that the findings from the colorimetric tests in the current study revealed slight discrepancies when compared to the results of the aforementioned research. Baik and Mittal (2005) demonstrated that variations in the redness index are more pronounced at elevated frying temperatures, eventually stabilizing and conforming to an exponential function. Furthermore, an increase in the moisture content results in a lighter coloration of French fry samples during the deep-frying process. In another study, tilapia fillets (*Oreoschromis niloticus*) that were coated with a Guar gum formulation incorporating thyme essential oil demonstrated a more gradual rise in pH levels, diminished brightness, decreased redness, and heightened yellowness when compared to the control samples (Ruelas-Chacon *et al.*, 2020). The lighter hue observed in fried hamburgers can be attributed to the alteration and increase in moisture levels, coupled with a reduction in fat content, which subsequently influences the extent of the Maillard reaction, leading to its reduction (Farajzadeh *et al.* 2013).

Conclusion

Gums, recognized for their techno-functional properties, are increasingly utilized in meat processing and preservation. Their remarkable gel-forming capabilities allow various types of gums to act as effective barrier, which can lead to a decline in fat consumption among consumers. Furthermore, the addition of gums improves the textural attributes of meat products, thus increasing their market appeal. Note that typical additives found in gum-based composite coatings, such as extracts derived from plants, can significantly impact the quality of meat products. The results of the present research indicated that the use of active coatings containing 1% of seed gum and 1% of encapsulated cinnamon extract had the greatest effect on inhibiting the formation of primary compounds resulting from fat oxidation as well as the production of secondary compounds in comparison with control samples. The use of quince seed gum along with 1% of encapsulated cinnamon extract in the coating has improved the texture of fried shrimp samples.

References

Akdeniz, N., Sahin, S. and Sumnu, G., 2006. Functionality of batters containing different gums for deep-fat frying of carrot slices. *Journal of Food Engineering*, 75(**4**), pp.522-526. https://doi.org/10.1016/j.jfoodeng.2005.04.035

Alipoorfard, F., Tavakolipour, J.M.H., 2020. Application of sodium chloride and quince seed gum pretreatments to prevent enzymatic browning, loss of texture and antioxidant activity of freezedried pear slices. J Food Sci Technol 57:3165–3175. https://doi.org/10.1007%2Fs13197-020-04265-0

AOAC (Association of Official Analytical Chemists), 1990. Official Methods of Analyses of Association of Analytical Chemist, fifteenth ed. AOAC, Washington.

Attar, B., Seyed Alangi, S.Z. and Jorjani, S., 2018. The effect of Xanthan gum added to the coated breaded shrimp (*Litopenaeusvannamei*) on oil uptake, nutritional quality indices and sensory properties. *Iranian Food Science and Technology Research Journal*, 14(**1**), 107-118. https://doi.org/10.22067/ifstrj.v1396i0.56879

Awad, A.M., Kumar, P., Ismail-Fitry, M.R., Jusoh, S., Ab Aziz, M.F. and Sazili, A.Q., 2022. Overview of plant extracts as natural preservatives in meat. *Journal of Food Processing and Preservation*, 46(**8**), e16796. https://doi.org/10.1111/jfpp.16796

Azadi, A., Rafieian, F., Sami, M. and Rezaei, A., 2023. Investigating the effects of chitosan/tragacanth gum/polyvinyl alcohol composite coating incorporated with cinnamon essential oil nanoemulsion on safety and quality features of chicken breast fillets during storage in the refrigerator. *International Journal of Biological Macromolecules* 253, 126481. https://doi.org/10.1016/j.ijbiomac.2023.126481

Baik, O.D. and Mittal, G.S., 2005. Heat and moisture transfer and shrinkage simulation of deep-fat tofu frying. *Food Research International*, 38(**2**), 183-191. DOI:10.1016/j.foodres.2004.10.003

Bligh, E.G. and Dyer, W.J., 1959. A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, 37, 911-917. DOI:10.1139/o59-099.

Bouchon, P., Aguilera, J. and Pyle, D., 2003. Structure oil-absorption relationships during deep-fat frying. *Journal of Food science*, 68(**9**), 2711-2716. DOI:10.1111/j.1365-2621.2003.tb05793.x

Brand-Williams, W. Cuvelier and M. Berset, C., 1995. Use of a free radical method to evaluate antioxidant activity. *LWT-Food Science and Technology*, 28, 25–30. https://doi.org/10.1016/S0023-6438(95)80008-5

Carrión-Granda, X., Fernández-Pan, I., Jaime, I., Rovira, J. and Maté, J.I.,

2016. Improvement of the microbiological quality of ready-to-eat peeled shrimps (*Penaeus vannamei*) by the use of chitosan coatings. *International Journal of Food Microbiology*, 232, 144-149, ISSN 0168-1605, https://doi.org/10.1016/j.ijfoodmicro.2016.05.029. DOI:10.1016/j.ijfoodmicro.2016.05.029

Chen, L., Ma, R., Zhang, Z., Huang, M., Cai, C., Zhang, R., McClement, D.V., Tian, Y., Jin, Z., 2019. Comprehensive investigation and comparison of surface microstructure of fractionated potato starches. *Food Hydrocolloids*, V. (89) pp. 11-19, ISSN 0268-005X, https://doi.org/10.1016/j.foodhyd.2018.10.017.

Eghbaljoo, H., Karimi Sani, I., Alizadeh Sani, M., Rahati, S., Mansouri, E., Molaee-Aghaee, E., Fatourehchi, N., Kadi, A., Arab, A., Sarabandi, Kh., Samborska, K. and Jafari, S.M., 2022. Advances in plant gum polysaccharides; Sources, techno-functional properties, and applications in the food industry - A review. *International Journal of Biological Macromolecules*, V. (222) B, pp. 2327-2340, ISSN 0141-8130, https://doi.org/10.1016/j.ijbiomac.2022.10.020.

Farajzadeh, Z., Rahimi, E., Hojjatoleslamy, M. and Molavi, H., 2013. Production of low fat hamburger using hydrocolloid coatings, Journal of Food Hygiene, Vol. 2, No 8, Winter 2013.(In Persian).

Food and Agriculture Organisation of the United Nation (FAO), 2024. GLOBFISH, Information and Analysis in Markets and Trade of Fisheries and Aquaculture Products.

Gao, X., Pourramezan, H., Ramezan, Y., Roy, S., Zhang, W., Assadpour, E., Zou, J. and Jafari, S.M., 2024. Application of gums as techno-functional hydrocolloids in meat processing and preservation: A review. *International Journal of Biological Macromolecules*, 268(**1**), 131614, ISSN 0141-8130, https://doi.org/10.1016/j.ijbiomac.2024.131614.

Han, M. and Bertram, H.C., 2017. Designing healthier comminuted meat products: Effect of dietary fibers on water distribution and texture of a fat-reduced meat model system. *Meat Sci*., 133, 159–165. DOI: 10.1016/j.meatsci.2017.07.001

Huss, H.H., Jeppesen, V.F., Johansen, Ch. and Gram, L., 1995. Biopreservation of fish products-a review of recent approaches and results. *J Aquat Food Prod Technol*., 4(**2**), 5-26. https://doi.org/10.1300/J030v04n02_02

Hussain, M.A., Muhammad, G., Haseeb, M.T. and Tahir, M.N., 2019. Quince seed mucilage: a stimuli-responsive/smart biopolymer. *Funct Biopolym*, 1-22. DOI:10.1007/978-3-319-95990-0_19

Jouki, M. and Khazaei, N., 2022. Effects of active batter coatings enriched by quince seed gum and carvacrol microcapsules on oil uptake and quality loss of nugget during frying. *Journal of Food Science and Technology*, 59(**3**), pp.1104-1113. https://doi.org/10.1007%2Fs13197-021-05114-4

Jouki, M., Yazdi, F.T., Mortazavi, S.A., Koocheki, A. and Khazaei, N., 2014. Effect of quince seed mucilage edible films incorporated with oregano or thyme essential oil on shelf life extension of refrigerated rainbow trout fillets. *International journal of Food Microbiology*, 174, pp.88-97. https://doi.org/10.1016/j.ijfoodmicro.2014.01.001

Juntachote, T., Berghofer, E., Siebenhandl, S. and Bauer, F., 2006. The antioxidative properties of holy basil and galangal in cooked ground pork.

Meat Science, 72, 3, 446-456. https://doi.org/10.1016/j.meatsci.2005.08.009

Khazaei, N., Esmaiili, M. and Emam-Djomeh, Z., 2016. Application of active edible coatings made from basil seed gum and thymol for quality maintenance of shrimp during cold storage. *Journal of the Science of Food and Agriculture*, 97(**6**), 1837-1845. https://doi.org/10.1016/j.carbpol.2015.10.084

Khezerlou, A., Zolfaghari, H., Banihashemi, S.A., Forghani, S. and Ehsani, A., 2021. Plant gums as the functional compounds for edible films and coatings in the food industry: A review. *Polymer Advance Technologies*, 32, 2306–2326. https://doi.org/10.1002/pat.5293

Kim, D., Pe., Lima, J., Bae, I.Y., Lee, H.G. and Lee, S., 2011. Effect of hydrocolloid coatings on the heat transfer and oil uptake during frying of potato strips. *Journal of Food Engineering*, 102, 317–320. http://dx.doi.org/10.1016/j.jfoodeng.2010.09.005

Kirk, R. S., Sawyer, R., & Pearson, D. 1991. *Pearson's composition and analysis of foods* (9. ed). Longman Scientific and Technical. ISBN: 9780470216934, 047021693X

Li, X., Wang, Y., Li, H., Jiang, X., Ji, L., Liu, T. and Sun, Y., 2021. Chemical and quality evaluation of Pacific white shrimp Litopenaeus vannamei: Influence of strains on flesh nutrition. *Food Science and Nutrition*, 9, 5352–5360. https://doi.org/10.1002/fsn3.2457.

Li, D.Y., Li, N., Dong, X.H., Tan, Z.F., Na, Z.K., Liu, X.Y. and Zhou, DY., 2022. Effect of phytic acid combined with lactic acid on color and texture deterioration of ready-to-eat shrimps during storage, *Food Chemistry*, 396, 133702, ISSN 0308-8146, https://doi.org/10.1016/j.foodchem.2022.133702.

Mehraie, A., Khanzadi, S., Hashemi, M. and Azizzadeh, M., 2023. New coating containing chitosan and Hyssopus officinalis essential oil (emulsion and nanoemulsion) to protect shrimp (Litopenaeus vannamei) against chemical, microbial and sensory changes. *Food Chemistry: X*, 19, 100801. https://doi.org/10.1016/j.fochx.2023.100801

Min, B. and Ahn, D.U., 2005 Mechanism of lipid peroxidation in meat and meat products-A review. *Food Sci Biotechnol*, 14, 152–163.

Noshad, M., Nasehi, B. and Anvar, A.A., 2017. Effect of active edible coating made by quince seed mucilage and green tea extract on quality of fried shrimps: Physicochemical and sensory properties. *Nutr. Food Sci. Res*. 4, 31–36. http://dx.doi.org/10.29252/nfsr.4.4.5

Rahayu, D.U.C., Hakim, R.A., Mawarni, S.A. and Satriani, A.R., 2022. Indonesian cinnamon (*Cinnamomum burmannii*), extraction, flavonoid content, antioxidant activity, and stability in the presence of ascorbic acid. *Cosmetics*, 9, 57. https://doi.org/10.3390/cosmetics9030057.

Robards, K., Kerr, A.F. and Patsalides, E., 1988. Rancidity and its measurement in edible oils and snack foods. *Analyst*, 113, 213–222. DOI:10.1039/an9881300213

Ruelas-Chacon, X., Aguilar-González, A., de la Luz Reyes-Vega, M., Peralta-Rodríguez, R.D., Corona-Flores, J., Rebolloso-Padilla, O.N. and Aguilera-Carbo, A.F., 2020. Bioactive protecting coating of guar gum with thyme oil to extend shelf life of tilapia (*Oreoschromis niloticus*) fillets. *Polymers*, 12, 3019. https://doi.org/10.3390/polym12123019

Sahin, S., Sumnu, G. and Altunakar, B., 2005. Effects of batters containing different gum types on the quality of deep-fat fried chicken nuggets. *J Sci Food Agric*, 85, 2375–2379. DOI:10.1002/jsfa.2258

Shahid, M.Z., Saima, H., Yasmin, A., Nadeem, M.T., Imran, M. and Afzaal, M., 2018. Antioxidant capacity of cinnamon extract for palm oil stability. *Lipids in Health and Disease*, 17, pp.1-8. https://doi.org/10.1186/s12944-018-0756-y

Shahidi, F. and Hossain, A., 2022. Preservation of aquatic food using edible films and coatings containing essential oils: A review. *Critical Reviews in Food Science and Nutrition*, 62(**1**), 66-105. DOI:10.1080/10408398.2020.1812048

Sharifimehr, S., Soltanizadeh, N. and Goli, S.A.H., 2019. Physicochemical properties of fried shrimp coated with bio-nano-coating containing eugenol and *Aloe vera*. *Lwt*, 109, 33-39. https://doi.org/10.1016/j.lwt.2019.03.084.

Shojaee-Aliabadi, S., Hosseini, H., Mohammadifar, M.A., Mohammadi, A., Ghasemlou, M., Ojagh, S.M., Hosseini, S.M. and Khaksar, R., 2013. Characterization of antioxidant-antimicrobial κ-carrageenan films containing Satureja hortensis essential oil. *International Journal of Biological Macromolecules*, 52, 116–124. https://doi.org/10.1016/j.ijbiomac.2012.08.026

Shoqairan, Y.I., Darwish, H.K., Hamami, M. ., Al-Juhaimi, F.Y., Ahmed, I.A.M. and Babiker, E.E., 2023. The influence of cinnamon powder on the antioxidant and antimicrobial properties of beef burger during refrigerated storage. *LWT, 188,* 115422. DOI:10.1016/j.lwt.2023.115422

Sioen, I., Haak, L., Raes, K., Hermans, C., De Henauw, S., De Smet, S. and Van Camp, J., 2006. Effects of pan-frying in margarine and olive oil on the fatty acid composition of cod and salmon. *Food Chemistry*, 98, 609-617. https://doi.org/10.1016/j.foodchem.2005.06.026

Su, L., Yin, J.J., Charles, D., Zhou, K., Moore, J. and Yu, L., 2007. Total phenolic contents, chelating capacities, and radical-scavenging properties of black peppercorn, nutmeg, rosehip, cinnamon and oregano leaf. *Food Chem.*, 100, 990–7. https://doi.org/10.1016/j.foodchem.2005.10.058

Usawakesmanee, W., Chinnan, M.S., Wuttijumnong, P., Jangchud, A. and Raksakulthai, N., 2008. Effect of edible coating ingredients incorporated into predusting mix on moisture content, fat content and consumer acceptability of fried breaded product. *Songklanakarin Journal of Science and Technology*, 30, 25-34.

Yadegari, M., Esmaeil Zadeh Kenari R. and Hashemi S.J., 2020. Investigation the effect of separate and mutual interactions of alyssum homolocarpum seed and methylcellulose gums on qualitative properties of fried potato. *Journal of Innovation in Food Science and Technology*, 11, 4 , 89-101. (In Persian).

Zhou, Q., He, D., Yu, H., Yang, J., Wu, K., Duan, X., Wu, X., and Han, X., 2023. Increased antioxidant and antimicrobial activities of lemongrass and cinnamon essential oils with tea polyphenols and its application in the preservation of marine fish. *International Journal of Food Science and Technology*, 58(**7**), 3996-4008. DOI:10.1111/ijfs.16177.