LWT - Food Science and Technology 88 (2018) 203–209

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Development of a sweet potato starch-based coating and its effect on quality attributes of shrimp during refrigerated storage

Samirah Alotaibi, Reza Tahergorabi*

North Carolina Agricultural and Technical State University, Greensboro, NC, USA

ARTICLE INFO

Keywords:
Sweet potato starch
Thyme essential oil
Shrimp
Quality
Edible coating

ABSTRACT

Shrimp is enjoyed for the uniqueness of its flavor and texture. However, shrimp has limited shelf-life due to biochemical, microbiological or physical changes during postmortem storage. In this study, edible coatings from sweet potato starch (SPS) and variable levels of thyme essential oil (TEO) (0, 2, 4 and 6 g/100 g) were developed to maintain the quality of shrimp during refrigerated storage. Application of SPS-based coating resulted in lower pH ($p < 0.05$). Coated samples activated with TEO had lower counts of bacteria and lipid oxidation ($p < 0.05$) toward the end of storage. Textural and color properties of coated shrimp were generally more acceptable. Sensory scores indicated no significant changes in all samples during storage. The results of this study suggest that the TEO incorporation at 4 g/100 g into SPS- based coating could be useful in extending the shelf life of shrimp meat during refrigerated storage.

1. Introduction

Shrimp is the most popular seafood in the U.S. and the world due to its high nutritional value as well as the distinctive flavor and texture (Mejlholm, Bøknæs, & Dalgaard, 2005). In addition, mercury content of shrimp is relatively lower compared to other seafood (Bragagnolo & Rodriguez-Amaya, 2001). However, shrimp is a quite perishable seafood. The quality of shrimp is influenced by several factors such as method of handling, storage condition, and processing time. The shelf life of shrimp is mostly determined by both microbiological and enzymatic spoilage when stored at refrigerated temperature. Shrimp contains large amounts of free amino acids that are contributed to microbiological spoilage (Yassoralipour, Bakar, Abdul Rahman, Abu Bakar, & Golkhandan, 2013). In addition, shrimp may suffer from black spot (melanosis) due to the activity of polyphenol oxidase (Montville, Matthews, & Kniel, 2012). It has been reported that, 1.2 g/100 g of the lipids that are located just under the shrimp shell are highly unsaturated phospholipids (Bak, Andersen, Andersen, & Bertelsen, 1999). Therefore, lipid oxidation and rancid off-flavors may also occur even under refrigeration or freezing conditions (Montville et al., 2012). As a result, it is necessary to devise a strategy to prevent or slow down quality degradation of shrimp during storage time.

Currently, there is a great interest in the application of natural preservatives in food industry. However, direct application of them has some drawbacks including changes of organoleptic properties, fast release of active compounds and interacting with other food ingredients. These limitations have directed researchers to adopt coating as a method alone or in combination with other methods to increase the shelf-stability of perishable foods such as shrimp. The features of coating application can contribute to maintain the quality of seafood products, and delay spoilage at low temperature with minimum effects on the characteristic of the product (Dursun & Erkan, 2014). Previous studies in our laboratory have demonstrated that antimicrobial films from sweet potato starch (SPS) are effective in reducing pathogens in foods (Issa, Ibrahim, & Tahergorabi, 2017). Sweet potato (*Ipomoea batatas* Lam) is an inexpensive and readily available vegetable that is cultivated extensively for its nutritious value across many regions of the world. Sweet potato is rich in dietary fiber, minerals, vitamins, and antioxidants, such as phenolic acids, anthocyanins, tocopherol, β-carotene, and ascorbic acid (Issa, Ibrahim, & Tahergorabi, 2016). These nutrients may migrate to food if SPS is used as an edible coating and therefore, increases the nutritional value of the product. SPS with a 58–76 g/100 g starch content (on a dry basis), has properties that are similar or better than those of ordinary potato starch (Issa et al., 2017). Therefore, SPS could be a proper candidate to be used for edible coating of food products.

In addition, edible coatings are excellent vehicles for incorporating a wide variety of additives, such as antioxidants and antimicrobial agents. The effect of these additives may result in improvement of food quality and safety. The application of essential oils (EOs) has proven to be an effective preservation method that extends the shelf life of fresh foods (Anyanwu, Alakhrash, & Hosseini, Ibrahim, & Tahergorabi, 2016; Quitral et al., 2009). EOs are aromatic, oily liquids that are obtained

* Corresponding author.
E-mail address: rtahergo@ncat.edu (R. Tahergorabi).

http://dx.doi.org/10.1016/j.lwt.2017.10.022
Received 29 June 2017; Received in revised form 2 October 2017; Accepted 11 October 2017
Available online 12 October 2017

from plant material. According to Tsigarida, Skandamis, & Nychas, 2000; Skandamis & Nychas, 2001, certain oils stand out as better antibacterials than others for meat applications. Thyme (*Thymus vulgaris*) essential oil (TEO) has been found to possess antimicrobial activity *in vitro* against a broad spectrum of bacteria, such as *S. Typhimurium*, *L. monocytogenes* (Singh, Sing, & Bhunia, 2003) *Escherichia coli*, *Pseudomonas fluorescens*, *Staphylococcus aureus*, *Lactobacillus plantarum*, and *Bacillus subtilis*, as well as *Shigella sonnei* and *Shigella flexneri* (Bagamboula, Uyttendaele, & Debevere, 2004). TEO has also been reported to have antioxidative activities comparable to those of α-tocopherol and BHT (Miguel et al., 2004). TEO is considered to present no risk to the health of consumers, has been registered by the European Commission (Burt, 2004), and is generally recognized as safe (GRAS) by the Food and Drug Administration (FDA, 2009). To the best of our knowledge, there is no published report of antimicrobial and antioxidant properties of SPS-based edible coating with TEO that has been tested on shrimp. Therefore, this study was designed to: (1) Investigate physicochemical (texture, color, pH, and lipid oxidation) properties; (2) assess the melanosis and sensory quality; and (3) evaluate the antibacterial activity of the coated shrimp during storage at refrigerated temperature.

2. Material and methods

2.1. Edible coating preparation

The coating solution was prepared according to the previously described method with slight modifications (Ghanbarzadeh & Almasi, 2011). An aqueous solution of SPS was prepared by dissolving 50 g of SPS in 1000 ml distilled deionized H_2O, moderately stirred at room temperature, and then heated to 80 °C for 30 min. After gelatinization, glycerol (Fisher Scientific, Fair Lawn, New Jersey) was added as a plasticizer at a concentration of 2 g/100 g (*w/w*, on dry basis of the weight of starch) and the resulting dispersion was subjected to further mixing for 5 min. Then, TEO (*Thymus Vulgaris*, New Direction Aromatics, Mississauga, ON, Canada), previously mixed with Tween 80 (Fisher Scientific, Fair Lawn, NJ, USA) (0.25 g/g of essential oil) to help create a uniform and stable distribution, was incorporated into the coating solution at several concentrations (0, 2, 4, and 6 g/100 g *v/v* on the basis of neat film solution). Samples were then homogenized at 20,000 rpm for 5 min using a laboratory homogenizer (Homogenizer, OMNI International, Kenneswa, GA, USA), after being degassed using an ultrasonic bath (Branson sonifier, Model 3800, Danbury, CT, USA).

2.2. Treatment of shrimp samples

Medium size, beheaded, unpeeled, and deveined frozen shrimp were purchased from a local grocery and delivered to laboratory by using a cold box. Frozen shrimp had been treated with phosphate according to the information provided at the label of product. Shrimp samples were thawed at refrigerator temperature (4 °C) before application of the coating solutions. Shrimp samples were randomly assigned to five lots consisting of one control lot (un-coated) and four lots treated with the following coating solutions: SPS coating and SPS coating with TEO, final concentrations of 0.0, 2.0, 4.0, or 6.0 g/100 g (v/v) with a shrimp/solution ratio of 1:2 (w/v) at 4 °C for 15 min. The shrimp were gently swirled in the coating solution using a sterile glass rod to ensure complete contact of the shrimp with the coating solution. Shrimp were removed and allowed to drain for 5 min on a pre-sterilized metal net under a biological containment hood. After draining of the excess coating solution, samples were placed into sterile Petri plates. All the plates were stored at 4 °C and triplicate samples were taken at days 1, 4, and 8 for physico-chemical, antibacterial, sensory, and melanosis assessments.

2.3. Determination of pH

The measurement of pH was performed by the method described by Alakhrash, Anyanwu, and Tahergorabi (2016) with slight modifications. Shrimp meat (2 g) was homogenized with 10 vol of deionized water for 1 min using a homogenizer (OMNI International, Kenneswa, GA, USA). The homogenate was kept at room temperature for 5 min. The pH was determined using a hand-held pH meter (Oakton, Vernon Hills, Il, USA).

2.4. Texture properties

Texture profile analysis (TPA) was measured using a texture analyzer (Model TA-XT2, Texture Analyzer, Texture Technologies Corp., Scarsdale, NY, USA) according to the method described by Tahergorabi, Beamer, Matak, and Jaczynski (2013). The result of force-time curves for TPA was defined by Bourne (2002), which includes hardness, cohesiveness, springiness, gumminess, chewiness, and resilience. The TPA is an empirical test which can be directly related to overall acceptance or hedonic ratings (Kim, Park, & Yoon, 2005).

2.5. Color properties

The color properties of coated shrimp were determined using a Minolta Chroma Meter CR-400/410 colorimeter (Konica Minolta Co. Ltd., Osaka, Japan), calibrated with a white calibration plate ($L^* = 97.57$, $a^* = -1.08$ and $b^* = 1.25$) supplied by the manufacturer that was placed in the slot of the instrument (Tahergorabi, Beamer, Matak, & Jaczynski, 2011). According to the CIE (Commission Internationale d'Eclairage of France) color system, the L* (lightness), a* (red to green), and b* (yellow to blue) tristimulus color values were determined (Lanier, 1992).

2.6. Lipid oxidation

Using the 2-thiobarbituric acid reactive substance (TBARS) assay of malondialdehyde (MDA) the oxidative rancidity of coated shrimp was measured as described by Tahergorabi et al. (2013). The calculation of TBARS values was determined by using a molar absorptivity of MDA (156,000 M^{-1} cm^{-1}) and results reported as mg MDA/kg of sample.

2.7. Aerobic plate count

All samples were subjected to microbiological analysis. A total of 1 g of shrimp muscles was added into peptone water (0.1 g/100 g), then the samples were homogenized for 1 min, samples were then serially diluted in 9 ml peptone water (0.1 g/100 g). The aerobic plate counts were enumerated by spread-plating of 1 ml of sample solution on sterile Petri-plates containing Plate Count Agar (Difco Laboratories, Detroit, MI, USA). Plates were incubated for 24 h at 35 ± 1 °C (Caballero, Alles, Le, Mozola, & Rice, 2015).

2.8. Melanosis assessment

A 10-point scoring test was used to evaluate black spots on the surface of shrimp. The melanosis was rated from 0 to 10. If there is no black spot on the surface of shrimp then it was rated as zero (0) while 10 indicating that 80–100 g/100 g of the shrimp's surface is covered by black spots (Nirmal & Benjakul, 2009).

2.9. Sensory evaluation

Over 100 untrained panelists volunteered to evaluate the shrimps stored in refrigerator on days 1 and 8. Raw samples which were labeled by random three digit codes were placed on trays and served to the panelists. Panelists were asked to score appearance, odor, and texture

using a nine-point scale, where 9 was the highest quality score, 1 was the lowest, and 5 was acceptable level (Tsironi, Dermesonlouoglou, Giannakourou, & Taoukis, 2009). Prior to testing, participants were assigned to a private evaluation station and instructed to read an informational handout and consent form approved by the Institutional Review Board at NC A & T State University (IRB number: 15–0197).

2.10. Statistical analysis

Each experiment was performed three times, independently ($n = 3$). For each experiment, the mean and standard deviation of the result was recorded; then an analysis of variance using two-way ANOVA was done (SAS version 16.0, SAS Institute, Cary, North Carolina, USA). Differences in the mean values of the results of repeated experiments were calculated using Tukey's test, and the criterion for labeling a difference as significant was $p < 0.05$.

3. Results and discussion

3.1. Changes in pH

Changes in pH value of uncoated and coated shrimp are shown in Fig. 1. The initial pH of control sample ranged from 8.94 to 9.35 before the application of edible coatings, which was close to the initial pH value for shrimp reported by Gonçalves and Junior (2009). They reported that the reason for higher pH in the shrimp sample is due to use of phosphate before the freezing process. Similarly, in our study, frozen shrimp samples had been treated with phosphate according to the information provided at the label of product. Phosphate is added to shrimp before freezing as a cryoprotectant. It also helps to increase water binding by increasing the pH (Gonçalves & Junior, 2009). The edible coating of SPS with different concentrations of TEO application onto the surface of the shrimp resulted in the decrease of pH values of the samples, as compared to the control sample. Particularly, 6 g/100 g TEO resulted in the lowest pH values during 8 days of storage. Lower pH in coated samples might be related to the potential of the coatings to decrease microbial growth and inhibit the activity of the endogenous proteases to different degrees (Souza et al., 2010). Further, the hydrophobic constituents of the EOs are capable of gaining access to the periplasm of bacteria through the proteins of the outer membrane. The increase in membrane permeability provokes a release of the cell constituents, a decrease in ATP production in the cells and a decrease of the intracellular and extracellular pH (Zinoviadou, Koutsoumanis, & Biliaderis, 2009). Mu, Chen, Fang, Mao, and Gao (2012) treated Pacific white shrimp with Cinnamaldehyde which is the major component of bark extract of cinnamon (*Cinnamomum verum*), and well known for its antioxidant and antimicrobial properties. They reported that, the pH values of samples treated with cinnamaldehyde were lower than in the control sample after 2 days of storage ($p < 0.05$). The samples treated with 1 and 5 g kg^{-1} cinnamaldehyde had pH values of 7.77 and 7.43, respectively, at the end of storage ($p < 0.05$). Bacterial growth could be controlled by decreasing the pH value of coated shrimp, which helps extend the shelf life of shrimp samples (Farajzadeh, Motamedzadegan, Shahidi, & Hamzeh, 2016). At low pH, the hydrophobicity of the EO increases, enabling it to more easily dissolve in the lipids of the cell membrane of target bacteria and prevent their growth (Juven, Kanner, Schved, & Weisslowicz, 1994). In this study, the result of pH and bacterial count were supportive of each other.

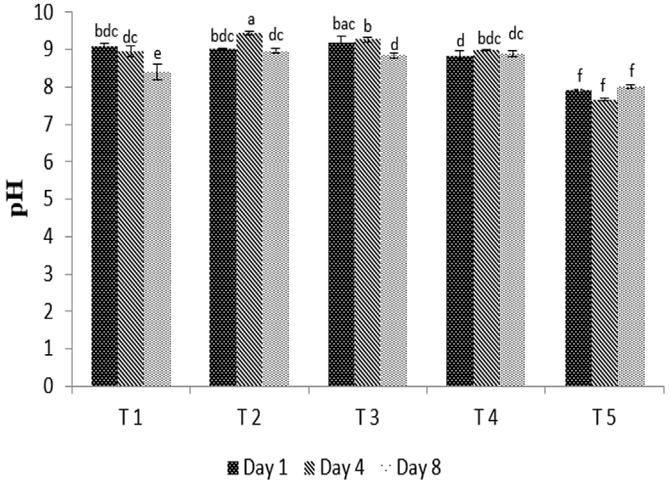

Fig. 1. Changes of pH values for coated and uncoated shrimp samples stored at refrigerated temperature (4 ± 1 °C) for 8 days.
T1: uncoated; T2: Sweet potato starch-based coating; T3: Sweet potato starch based-coating with 2 g/100 g thyme essential oil; T4: Sweet potato starch based-coating with 4 g/100 g thyme essential oil; T5: Sweet potato starch based-coating with 6 g/100 g thyme essential oil.
Data are given as mean values ± standard deviation ($n = 3$). Different letters on the top of data bars indicate significant differences (Tukey's Test, $p < 0.05$) between mean values.

3.2. Texture profile analysis

Six factors are determined using texture profile analysis (TPA) including hardness, springiness, cohesiveness, gumminess, chewiness, and resilience. Table 1 show the effect of SPS-based coating on the texture of shrimp. In general, a higher hardness was found in SPS-based coated shrimp, compared with the uncoated sample except for day 1. The hardness value significantly decreased ($p < 0.05$) for uncoated samples after four days of storage. However, this value slightly increased towards the end of storage. Diaz-Tenorio, Garcia-Carreno, and Pacheco-Aguilar (2007) suggested that the differences in hardness might be related to different protein structure of shrimp. Myofibrillar protein might also be affected by ice crystals during the frozen storage. This could be translated to the quality of the shrimp as well as the consumer acceptance. Generally, the lower values for uncoated sample might be related to proteolytic activity of endogenous or microbial proteinases and collagenase. However, incorporation of TEO resulted in higher hardness values throughout the storage time. The lower bacterial population is correlated with higher hardness values of SPS-based coated shrimp containing TEO. No significant difference ($p > 0.05$) was observed for resilience, cohesiveness, gumminess, springiness and chewiness of control and SPS-based coated shrimp samples during the storage time. This indicates that coating had no effect on shrimp except for TPA hardness during storage time.

3.3. Instrumental color

The tristimulus color values of shrimp samples are shown in Table 2. In biodegradable films and coatings, color is an important property because it could influence consumer purchasing decision (Bourtoom & Chinnan, 2008). Tristimulus color values (L*, a* and b*) were used to determine the color properties of uncoated and coated shrimp. The L* value has a range from 0 (black) to 100 (white). The a* value is another scale that measures redness (+60) to greenness (−60) values. The b* scale is a measure of the yellowness (positive values) to blueness (negative values). The L* value significantly increased in the treatment with different concentration (2, 4, or 6 g/100 g) of thyme essential oil. The enhancement of L* value has been attributed to the light scattering that results from the emulsion created when oil is mixed with an edible coating. Similarly, Jouki, Yazdi, Mortazavi, and Koocheki (2014) reported that incorporation of thymol particularly at higher concentrations lead to an increase of the whiteness of fried shrimp. However, the L* value of all the samples decreased significantly during the storage period. At the end of storage, the decrease of the L* value with time for the coated shrimp was slower than the control. The same result was reported by Alparslan et al. (2017) who used gelatin and orange peel essential oil in the coating solution and showed a

Table 1
Textural profile analysis of coated and uncoated shrimp samples stored at refrigerated temperature (4 ± 1 °C) for 8 days.

Days	Treatments				
	T 1	T 2	T 3	T 4	T 5
	Hardness (N)				
1	46.17 ± 1.93^{ba}	35.50 ± 2.01^{d}	46.41 ± 1.74^{ba}	48.51 ± 1.47^{a}	43.94 ± 1.54^{ba}
4	25.66 ± 2.37^{e}	35.74 ± 0.58^{d}	41.54 ± 1.09^{bc}	42.80 ± 0.29^{bc}	41.48 ± 1.52^{bc}
8	38.53 ± 2.71^{dc}	34.29 ± 1.08^{d}	42.40 ± 1.96^{bc}	45.56 ± 1.99^{ba}	45.55 ± 1.02^{ba}
	Resilience				
1	0.18 ± 0.01^{c}	0.31 ± 0.03^{a}	0.20 ± 0.01^{c}	0.20 ± 0.01^{c}	0.20 ± 0.01^{c}
4	0.21 ± 0.04^{bc}	0.24 ± 0.02^{bac}	0.21 ± 0.04^{ba}	0.23 ± 0.01^{bac}	0.22 ± 0.03^{bc}
8	0.19 ± 0.04^{c}	0.20 ± 0.03^{c}	0.21 ± 0.03^{bc}	0.24 ± 0.03^{bac}	0.29 ± 0.03^{ba}
	Cohesiveness				
1	0.34 ± 0.02^{de}	0.27 ± 0.04^{e}	0.36 ± 0.01^{dc}	0.35 ± 0.0^{d}	0.34 ± 0.01^{de}
4	0.34 ± 0.01^{de}	0.48 ± 0.03^{a}	0.38 ± 0.06^{bdc}	0.41 ± 0.01^{bdac}	0.37 ± 0.03^{dc}
8	0.34 ± 0.05^{de}	0.47 ± 0.02^{a}	0.37 ± 0.02^{dc}	0.46 ± 0.03^{ba}	0.44 ± 0.02^{bac}
	Springiness				
1	0.54 ± 0.03^{edcf}	0.61 ± 0.06^{ebdcf}	0.74 ± 0.02^{ba}	0.51 ± 0.03^{edf}	0.50 ± 0.01^{f}
4	0.51 ± 0.03^{edf}	0.66 ± 0.08^{bac}	0.63 ± 0.12^{ebdac}	0.64 ± 0.04^{bdac}	0.67 ± 0.01^{dac}
8	0.47 ± 0.01^{ef}	0.63 ± 0.02^{ebdacf}	0.62 ± 0.02^{ebdacf}	0.75 ± 0.03^{a}	0.74 ± 0.04^{da}
	Gumminess				
1	12.11 ± 0.96^{a}	10.98 ± 1.76^{a}	12.92 ± 2.69^{a}	12.31 ± 0.03^{a}	11.43 ± 0.70^{a}
4	17.84 ± 1.20^{a}	12.95 ± 1.65^{a}	13.53 ± 1.20^{a}	12.20 ± 0.07^{a}	12.77 ± 0.66^{a}
8	14.54 ± 0.50^{a}	13.86 ± 1.64^{a}	11.22 ± 0.51^{a}	12.98 ± 0.47^{a}	12.14 ± 0.87^{a}
	Chewiness				
1	6.47 ± 0.85^{ba}	6.51 ± 0.37^{ba}	7.66 ± 0.22^{ba}	7.76 ± 1.48^{ba}	6.73 ± 0.74^{ba}
4	8.36 ± 1.07^{a}	6.53 ± 0.95^{ba}	7.53 ± 0.93^{ba}	8.76 ± 0.69^{a}	7.21 ± 1.47^{ba}
8	6.63 ± 0.21^{ba}	5.69 ± 0.04^{b}	7.33 ± 0.42^{ba}	7.99 ± 0.64^{a}	7.85 ± 0.55^{ba}

T1: uncoated; T2: Sweet potato starch-based coating; T3: Sweet potato starch based-coating with 2 g/100 g thyme essential oil; T4: Sweet potato starch based-coating with 4 g/100 g thyme essential oil; T5: Sweet potato starch based-coating with 6 g/100 g thyme essential oil.
Data are given as mean values ± standard deviation (n = 3). Different letters within the same row indicate significant differences (Tukey's Test, $p < 0.05$) between mean values.

decrease of the L* value during storage time. Incorporation of different concentrations of thyme oil caused a significant increase of b* values. This could be attributed to pigmentation of TEO. However, storage time did not have any effect on color changes. Similarly, Ozturk (2015) observed an increase in the b* value of sucuk treated with TEO compared with control treatment. Farajzadeh et al. (2016) reported that

Table 2
Color properties of coated and uncoated shrimp samples stored at refrigerated temperature (4 ± 1 °C) for 8 days.

Days	Treatments				
	T 1	T 2	T 3	T 4	T 5
	L* (lightness)				
1	41.71 ± 0.65^{ced}	45.70 ± 1.00^{ebd}	46.23 ± 0.89^{cb}	50.38 ± 1.28^{b}	62.58 ± 1.10^{a}
4	40.92 ± 2.29^{ed}	46.52 ± 2.74^{cb}	46.68 ± 1.48^{b}	52.99 ± 2.33^{b}	62.62 ± 0.30^{a}
8	38.78 ± 1.15^{e}	46.13 ± 1.62^{cbd}	45.53 ± 1.16^{cbd}	50.20 ± 1.68^{b}	61.17 ± 0.18^{a}
	a* (redness-greenness)				
1	−1.21 ± 0.71^{d}	2.35 ± 0.44^{a}	1.49 ± 0.22^{ba}	1.23 ± 0.12^{ba}	−0.48 ± 0.07^{dc}
4	0.55 ± 0.08^{bc}	1.19 ± 0.22^{ba}	2.27 ± 0.15^{a}	1.47 ± 0.39^{ba}	−0.45 ± 0.02^{dc}
8	1.62 ± 0.97^{ba}	2.03 ± 0.22^{a}	1.86 ± 0.12^{a}	1.47 ± 0.35^{ba}	−0.54 ± 0.03^{dc}
	b* (yellowness-blueness)				
1	−2.19 ± 0.62^{d}	−2.50 ± 1.12^{c}	5.62 ± 0.19^{ba}	5.67 ± 0.28^{ba}	5.31 ± 0.15^{b}
4	1.06 ± 0.88^{c}	1.56 ± 0.38^{c}	6.78 ± 0.16^{a}	5.29 ± 0.05^{b}	5.54 ± 0.41^{ba}
8	1.59 ± 0.28^{c}	1.83 ± 0.18^{c}	6.43 ± 0.32^{ba}	6.24 ± 0.18^{ba}	5.73 ± 0.26^{ba}

T1: uncoated; T2: Sweet potato starch-based coating; T3: Sweet potato starch based-coating with 2 g/100 g thyme essential oil; T4: Sweet potato starch based-coating with 4 g/100 g thyme essential oil; T5: Sweet potato starch based-coating with 6 g/100 g thyme essential oil.
Data are given as mean values ± standard deviation (n = 3). Different letters within the same row indicate significant differences (Tukey's Test, $p < 0.05$) between mean values.

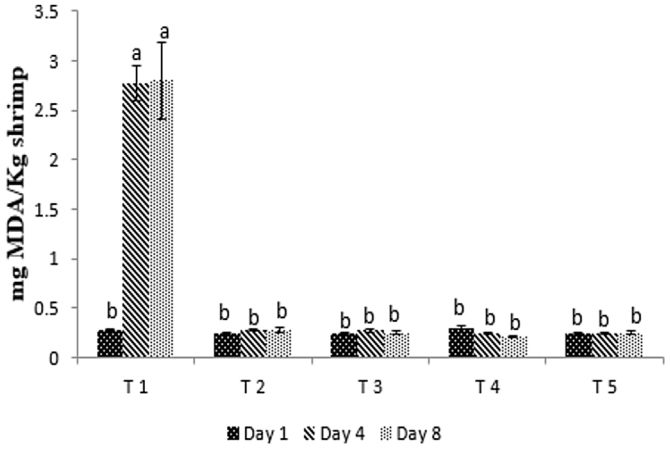

Fig. 2. Thiobarbituric acid reactive substances (TBARS) values of coated and uncoated shrimp samples stored at refrigerated temperature (4 ± 1 °C) for 8 days.
T1: uncoated; T2: Sweet potato starch-based coating; T3: Sweet potato starch based-coating with 2 g/100 g thyme essential oil; T4: Sweet potato starch based-coating with 4 g/100 g thyme essential oil; T5: Sweet potato starch based-coating with 6 g/100 g thyme essential oil.
Data are given as mean values ± standard deviation (n = 3). Different letters on the top of data bars indicate significant differences (Tukey's Test, $p < 0.05$) between mean values.

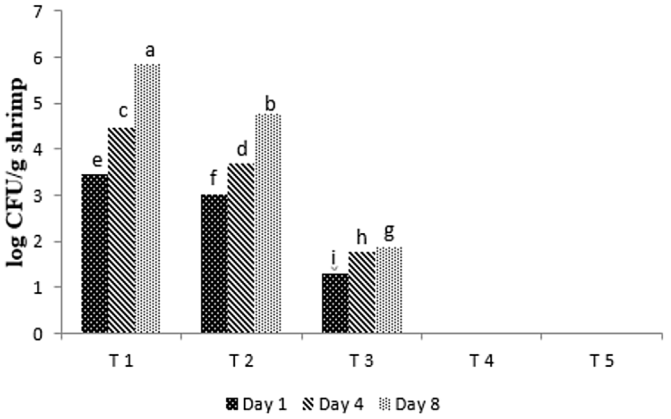

Fig. 3. Aerobic plate counts (APC) for coated and uncoated shrimp samples stored at refrigerated temperature (4 ± 1 °C) for 8 days.
T1: uncoated; T2: Sweet potato starch-based coating; T3: Sweet potato starch based-coating with 2 g/100 g thyme essential oil; T4: Sweet potato starch based-coating with 4 g/100 g thyme essential oil; T5: Sweet potato starch based-coating with 6 g/100 g thyme essential oil.
Data are given as mean values ± standard deviation (n = 3). Different letters on the top of data bars indicate significant differences (Tukey's Test, $p < 0.05$) between mean values.

coating could help to preserve the color values throughout the storage period.

3.4. TBARS values

TBARS values of the shrimp without and with SPS-based coating are illustrated in Fig. 2. Initial TBARS value of shrimp meat without coating was 0.32 mg MDA/kg. It increased by the end of refrigerated storage ($p < 0.05$). The raise in TBARS value might be contributed to unsaturated fatty acids oxidation and the partial dehydration of shrimp. TBARS values for all treatments in the present study did not reach the limit value for perceived undesirable rancid flavor and odor reported in the literature for fish. Up to 5 mg MDA/kg has been reported as the maximum level of TBARS which indicates the good quality of aquatic food products. However, even up to 8 mg MDA/kg is considered safe to eat for seafood products (Tahergorabi, Beamer, Matak, & Jaczynski, 2012). In the present study, TBARS for all of the samples were much lower than the proposed limit.

However, the lower TBARS values were noticeable when SPS-based coating with or without TEO were used. An edible coating can impede the entry of gases, moisture, and other substances, resulting in a reduced rate of oxidation (Bravin, Peressini, & Sensidoni, 2006). Further, TEO exhibits very strong free radical-scavenging ability and inhibits lipid oxidation induced by both Fe^{2+}/ascorbate and Fe^{2+}/H_2O_2 (Bozin, Mimica-Dukic, Simin, & Anackov, 2006). The primary aroma compounds in thyme include 1,8-cineole, thymol, carvacrol, and α-terpineol (Lee, Umano, Shibamoto, & Lee, 2005). Carvacrol and thymol each have one aromatic ring and one −OH group, 1-terpineol has one −OH group, while *p*-cymene has one aromatic group. The presence of aromatic groups and the number of −OH groups appears to coincide with the antioxidant potential of these compounds. Our results seem to agree with those reported by Khazaei, Esmaiili, and Emam-Djomeh (2016), who reported that using an edible coating rich with thymol is efficient to prevent early lipid oxidation. Therefore, SPS-based coating could be a viable solution to prevent lipid oxidation over the time of storage.

3.5. Aerobic plate counts

Seafood provides a good niche for growth of different microorganisms. Counts of bacterial population in coated and uncoated control samples are shown in Fig. 3. The results showed that there was a significant difference between control (uncoated) samples and coated samples ($p < 0.05$). APC increased significantly in uncoated samples and reached to 5.85 log CFU/g at the end of storage time. However, coating treatment containing 2 g/100 g of TEO resulted in almost 4 log CFU/g reduction compared to the uncoated samples. Moreover, by increasing the percentage of TEO to 4 g/100 g or 6 g/100 g, the APC was undetectable. On the other hand, uncoated samples had faster bacterial growth than those of coated with SPS only. No bacteria were detectable for T4 and T5, which had 4 g/100 g and 6 g/100 g thyme oil, respectively. Thyme essential oil showed the ability to inhibit the growth of the bacteria of coated shrimp during the storage time. The same result was reported by Emiroğlu, Yemiş, Coşkun, and Candoğan (2010), who tested soy edible films incorporated with different concentrations of thyme and oregano essential oils on fresh ground beef patties. TEO was completely inhibitive on *S. aureus* growth in the samples. Erkan, Tosun, Ulusoy, and Üretener (2011) treated bluefish (*Pomatomus saltatrix*) with thyme oil during storage at 2 °C. They reported that, lipid oxidation, and microbial growth in the oil treated samples were lower than control groups and as a result the shelf life of treated samples increased by 3–4 days compare to control samples. Essential oils can damage microbial cells by several mechanisms: damaging a cell membrane's phospholipid bilayer, disturbing enzyme systems, altering genetic material, and oxidative degradation of unsaturated fatty acids to form lipid hydroperoxide (Ruiz-Navajas, Viuda-Martos, Sendra, Perez-Alvarez, & Fernández-López, 2013). From these results it may be concluded that the SPS coating incorporated with thyme oil has a significant advantage in inhibiting the growth of bacteria.

3.6. Sensory evaluation

Table 3 shows the sensory scores of coated and uncoated shrimp. In general, the sensory properties of the shrimp samples were not affected by coating or storage time. Seafood products normally develop strong fishy, rancid and putrid odor due to spoilage and shrimp is no exception. These undesirable odors are easily detected by sensory panelists. However, in our study, even control samples did not develop any putrid odors. This might be because shrimp samples were stored directly in the refrigerator without a plastic bag. The same trend was true for appearance and texture of shrimp samples throughout the storage time. However, TEO incorporation resulted in numerically slightly better

Table 3
Sensory properties of coated and uncoated shrimp samples stored at refrigerated temperature (4 ± 1 °C) for 8 days.

Days	Treatments				
	T 1	T 2	T 3	T 4	T 5
	Appearance				
1	7.3 ± 0.49[a]	7.2 ± 0.84[a]	7.5 ± 1.05[a]	7.5 ± 0.71[a]	7.4 ± 1.74[a]
8	7.7 ± 1.03[a]	7.3 ± 0.82[a]	8.3 ± 0.96[a]	7.8 ± 0.5[a]	7.5 ± 0.58[a]
	Odor				
1	7.3 ± 0.49[a]	7.8 ± 0.45[a]	7.3 ± 1.03[a]	7.5 ± 0.71[a]	7.4 ± 1.2[a]
8	7.7 ± 2.16[a]	7.5 ± 0.55[a]	7.0 ± 1.41[a]	7.3 ± 0.96[a]	7.8 ± 0.5[a]
	Texture				
1	7.4 ± 0.79[a]	7.4 ± 0.55[a]	7.0 ± 1.79[a]	7.0 ± 1.41[a]	7.2 ± 2.14[a]
8	7.3 ± 1.03[a]	7.7 ± 0.52[a]	6.8 ± 0.50[a]	7.0 ± 0.82[a]	7.3 ± 0.5[a]

T1: uncoated; T2: Sweet potato starch-based coating; T3: Sweet potato starch based-coating with 2 g/100 g thyme essential oil; T4: Sweet potato starch based-coating with 4 g/100 g thyme essential oil; T5: Sweet potato starch based-coating with 6 g/100 g thyme essential oil.
Data are given as mean values ± standard deviation (n = 3). Different letters within the same row indicate significant differences (Tukey's Test, $p < 0.05$) between mean values.

Table 4
Melanosis of coated and uncoated shrimp samples stored at refrigerated temperature (4 ± 1 °C) for 8 days.

Days	Treatments				
	T 1	T 2	T 3	T 4	T 5
	Melanosis				
1	0.0 ± 0.0[b]	0.0 ± 0.0[b]	0.0 ± 0.0[b]	0.0 ± 0.0[b]	0.0 ± 0.0[b]
8	2.0 ± 0.0[a]	0.0 ± 0.0[b]	0.0 ± 0.0[b]	0.0 ± 0.0[b]	0.0 ± 0.0[b]

T1: uncoated; T2: Sweet potato starch-based coating; T3: Sweet potato starch based-coating with 2 g/100 g thyme essential oil; T4: Sweet potato starch based-coating with 4 g/100 g thyme essential oil; T5: Sweet potato starch based-coating with 6 g/100 g thyme essential oil.
Data are given as mean values ± standard deviation (n = 3). Different letters within the same row indicate significant differences (Tukey's Test, $p < 0.05$) between mean values.

characteristic of sensory properties. This can be related to the intrinsic sensory characteristics of thyme oil, which improve the acceptability of the product for the consumer. Similarly, Alparslan et al. (2017) reported that orange essential oil gives a pleasant aroma and odor to shrimp samples which were scored higher by panelists. These results are in agreement with those of Ouattara, Sabato, and Lacroix (2001), who found that an antimicrobial coat with irradiation did not affect the sensory attributes of shrimp.

3.7. Melanosis assessment

Table 4 displays the changes in the melanosis score of coated and uncoated shrimp during storage time. The results showed that there is a significant difference between uncoated (control) samples on day 8 and coated samples ($p < 0.05$). Melanosis is started by the polyphenol oxidase enzyme (naturally present in shrimp), which oxidizes phenols into quinones. Although the quinones are colorless, they polymerize non-enzymatically to form black pigments (Arancibia Lopez-Caballero, Gómez-Guillén, & Montero, 2015). No distinct melanosis was revealed for the coated shrimp during storage. This may be attributed to SPS incorporated with TEO functional properties. Results of this study were similar to Simpson, Gagne, Ashie, & Noroozi, 1997, who found that using an edible coating based on chitosan could delay the appearance of black spots in shrimp (*Pandalus borealis*). The results of sensory and melanosis were supportive of each other.

4. Conclusions

In this study, a sweet potato starch-based coating with thyme essential oil could reduce microbial growth, melanosis, TBARS values and loss of firmness of shrimp samples during eight days of storage compared to uncoated samples. This suggests that sweet potato starch-based coating with thyme essential oil could be a viable solution to maintain the quality and reduce the losses of shrimp meat. However, it is recommended to analyze the nutritional value of the coated shrimp with sweet potato starch and thyme essential oil during storage time since these ingredients may migrate to the products.

Acknowledgements

This work was supported, in part, by the Agriculture Research Program and the Department of Family and Consumer Sciences at North Carolina Agriculture and Technical State University, Greensboro, N.C., USA, through the USDA Evans-Allen Project No. NC.X-290-5-15-170-1.

References

Alakhrash, F., Anyanwu, U., & Tahergorabi, R. (2016). Physicochemical properties of Alaska pollock (*Theragra chalcograma*) surimi gels with oat bran. *LWT - Food Science and Technology, 66*, 41–47.
Alparslan, Y., Metin, C., Yapıcı, H. H., Baygar, T., Günlü, A., & Baygar, T. (2017). Combined effect of orange peel essential oil and gelatin coating on the quality and shelf life of shrimps. *Journal of Food Safety and Food Quality, 68*(3), 53–80.
Anyanwu, U., Alakhrash, F., Hosseini, S. V., Ibrahim, S. A., & Tahergorabi, R. (2016). Effect of bay (*Laurus nobilis L.*) essential oil on surimi gels nutritionally enhanced with salmon and flaxseed oils. *Journal of Aquatic Food Product Technology, 4*(26), 1–16.
Arancibia, M. Y., Lopez-Caballero, M. E., Gómez-Guillén, M. C., & Montero, P. (2015). Chitosan coatings enriched with active shrimp waste for shrimp preservation. *Food Control, 54*, 259–266.
Bagamboula, C. F., Uyttendaele, M., & Debevere, J. (2004). Inhibitory effect of thyme and basil essential oils, carvacrol, thymol, estragol, linalool and p-cymene towards *Shigella sonnei* and *S. flexneri*. *Food Microbiology, 21*(1), 33–42.
Bak, L. S., Andersen, A. B., Andersen, E. M., & Bertelsen, G. (1999). Effect of modified atmosphere packaging on oxidative changes in frozen stored cold water shrimp (Pandalus borealis). *Food Chemistry, 64*(2), 169–175.
Bourne, M. C. (2002). *Food texture and viscosity: Concept and measurement*Food science and technology international series; Food science and technology international series(2nd ed.). San Diego: Academic Press. http://site.ebrary.com/id/10186461.
Bourtoom, T., & Chinnan, M. S. (2008). Preparation and properties of rice starch–chitosan blend biodegradable film. *LWT-Food Science and Technology, 41*(9), 1633–1641.
Bozin, B., Mimica-Dukic, N., Simin, N., & Anackov, G. (2006). Characterization of the volatile composition of essential oils of some Lamiaceae spices and the antimicrobial and antioxidant activities of the entire oils. *Journal of Agricultural and Food Chemistry, 54*(5), 1822–1828.
Bragagnolo, N., & Rodriguez-Amaya, D. B. (2001). Total lipid, cholesterol, and fatty acids

of farmed freshwater prawn *(Macrobrachium rosenbergii)* and wild marine shrimp *(Penaeus brasiliensis, Penaeus schimitti, Xiphopenaeus kroyeri)*. *Journal of Food Composition and Analysis, 14*(4), 359–369.
Bravin, B., Peressini, D., & Sensidoni, A. (2006). Development and application of polysaccharide–lipid edible coating to extend shelf-life of dry bakery products. *Journal of Food Engineering, 76*(3), 280–290.
Burt, S. (2004). Essential oils: Their antibacterial properties and potential applications in foods—a review. *International Journal of Food Microbiology, 94*(3), 223–253.
Caballero, O., Alles, S., Le, Q. N., Mozola, M., & Rice, J. (2015). Validation of the NeoFilm for yeast and mold method for enumeration of yeasts and molds in select foods. *Journal of AOAC International, 98*(3), 798–805.
Diaz-Tenorio, L. M., Garcia-Carreno, F. L., & Pacheco-Aguilar, R. A. M.Ó. N. (2007). Comparison of freezing and thawing treatments on muscle properties of whiteleg shrimp *(Litopenaeus vannamei)*. *Journal of Food Biochemistry, 31*(5), 563–576.
Dursun, S., & Erkan, N. (2014). The effect of edible coating on the quality of smoked fish. *Italian Journal of Food Science, 26*(4), 370.
Emiroğlu, Z. K., Yemiş, G. P., Coşkun, B. K., & Candoğan, K. (2010). Antimicrobial activity of soy edible films incorporated with thyme and oregano essential oils on fresh ground beef patties. *Meat Science, 86*(2), 283–288.
Erkan, N., Tosun, Ş. Y., Ulusoy, Ş., & Üretener, G. (2011). The use of thyme and laurel essential oil treatments to extend the shelf life of bluefish (*Pomatomus saltatrix*) during storage in ice. *Journal of Consumer Protection and Food Safety, 6*(1), 39–48.
Farajzadeh, F., Motamedzadegan, A., Shahidi, S. A., & Hamzeh, S. (2016). The effect of chitosan-gelatin coating on the quality of shrimp *(Litopenaeus vannamei)* under refrigerated condition. *Food Control, 67*, 163–170.
Food and Drug Administration (FDA) (2009). *Guidance for industry: Guide to minimize microbial food safety hazards of leafy greens.* Available online http://www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments/ProduceandPlanProducts/ucm174200.htm#intro, Accessed date: 25 April 2017.
Ghanbarzadeh, B., & Almasi, H. (2011). Physical properties of edible emulsified films based on carboxymethyl cellulose and oleic acid. *International Journal of Biological Macromolecules, 48*(1), 44–49.
Gonçalves, A. A., & Junior, C. S. G. G. (2009). The effect of glaze uptake on storage quality of frozen shrimp. *Journal of Food Engineering, 90*(2), 285–290.
Issa, A., Ibrahim, S. A., & Tahergorabi, R. (2016). Sweet potato starch/clay nanocomposite Film: New material for emerging biodegradable food packaging. *MOJ Food Processing & Technology, 3*(3), 00073. http://dx.doi.org/10.15406/mojfpt.2016.03.00073.
Issa, A., Ibrahim, S. A., & Tahergorabi, R. (2017). Impact of sweet potato starch-based nanocomposite films activated with thyme essential oil on the shelf-life of baby spinach leaves. *Foods, 6*(6), 43.
Jouki, M., Yazdi, F. T., Mortazavi, S. A., & Koocheki, A. (2014). Quince seed mucilage films incorporated with oregano essential oil: Physical, thermal, barrier, antioxidant and antibacterial properties. *Food Hydrocolloids, 36*(16), 9–19.
Juven, B. J., Kanner, J., Schved, F., & Weisslowicz, H. (1994). Factors that interact with the antibacterial action of thyme essential oil and its active constituents. *Journal of Applied Bacteriology, 76*, 626–631.
Khazaei, N., Esmaiili, M., & Emam-Djomeh, Z. (2016). Effect of active edible coatings made by basil seed gum and thymol on oil uptake and oxidation in shrimp during deep-fat frying. *Carbohydrate Polymers, 137*, 249–254.
Kim, B. Y., Park, J. W., & Yoon, W. B. (2005). Rheology and texture properties of surimi gels. In J. W. Park (Ed.). *Surimi and surimi seafood* (pp. 491–582). (2nd ed.). Boca Raton (FL): Taylor and Francis Group.
Lanier, T. (1992). Measurement of surimi composition and functional properties. In T. C. Lanier, & C. M. Lee (Eds.). *Surimi technology* (pp. 123–163). New York: Marcel Dekker, Inc.
Lee, S. J., Umano, K., Shibamoto, T., & Lee, K. G. (2005). Identification of volatile components in basil (*Ocimum basilicum L.*) and thyme leaves (*Thymus vulgaris L.*) and their antioxidant properties. *Food Chemistry, 91*(1), 131–137.
Mejlholm, O., Bøknæs, N., & Dalgaard, P. (2005). Shelf life and safety aspects of chilled cooked and peeled shrimps *(Pandalus borealis)* in modified atmosphere packaging. *Journal of Applied Microbiology, 99*(1), 66–76.
Miguel, G., Simoes, M., Figueiredo, A. C., Barroso, J. G., Pedro, L. G., & Carvalho, L. (2004). Composition and antioxidant activities of the essential oils of *Thymus caespititius, Thymus camphoratus* and *Thymus mastichina*. *Food Chemistry, 86*(2), 183–188.
Montville, T. J., Matthews, K. R., & Kniel, K. E. (2012). *Food microbiology: An introduction* (3rd ed.). .
Mu, H., Chen, H., Fang, X., Mao, J., & Gao, H. (2012). Effect of cinnamaldehyde on melanosis and spoilage of Pacific white shrimp (*Litopenaeus vannamei*) during storage. *Journal of the Science of Food and Agriculture, 92*(10), 2177–2182.
Nirmal, N. P., & Benjakul, S. (2009). Melanosis and quality changes of Pacific white shrimp (Litopenaeus vannamei) treated with catechin during iced storage. *Journal of Agricultural and Food Chemistry, 57*(9), 3578–3586.
Ouattara, B., Sabato, S. F., & Lacroix, M. (2001). Combined effect of antimicrobial coating and gamma irradiation on shelf life extension of pre-cooked shrimp (*Penaeus spp*.). *International Journal of Food Microbiology, 68*(1), 1–9.
Ozturk, I. (2015). Antifungal activity of propolis, thyme essential oil and hydrosol on natural mycobiota of sucuk, a Turkish fermented sausage: Monitoring of their effects on microbiological, color and aroma properties. *Journal of Food Processing and Preservation, 39*(6), 1148–1158.
Quitral, V., Donoso, M. L., Ortiz, J., Herrera, M. V., Araya, H., & Aubourg, S. P. (2009). Chemical changes during the chilled storage of Chilean jack mackerel (Trachurus murphyi): Effect of a plant-extract icing system. *LWT-Food Science and Technology, 42*(8), 1450–1454.
Ruiz-Navajas, Y., Viuda-Martos, M., Sendra, E., Perez-Alvarez, J. A., & Fernández-López, J. (2013). In vitro antibacterial and antioxidant properties of chitosan edible films incorporated with *Thymus moroderi* or *Thymus piperella* essential oils. *Food Control, 30*(2), 386–392.
Simpson, B., Gagne, N., Ashie, I., & Noroozi, E. (1997). Utilization of chitosan for preservation of raw shrimp (*Pandalus borealis*). *Food Biotechnology, 11*(1), 25–44.
Singh, N., Singh, R. K., & Bhunia, A. K. (2003). Sequential disinfection of Escherichia coli O157: H7 inoculated alfalfa seeds before and during sprouting using aqueous chlorine dioxide, ozonated water, and thyme essential oil. *LWT-Food Science and Technology, 36*(2), 235–243.
Skandamis, P. N., & Nychas, G. J. (2001). Effect of oregano essential oil on microbiological and physico-chemical attributes of minced meat stored in air and modified atmospheres. *Journal of Applied Microbiology, 91*(6), 1011–1022.
Souza, B. W., Cerqueira, M. A., Ruiz, H. A., Martins, J. T., Casariego, A., Teixeira, J. A., et al. (2010). Effect of chitosan-based coatings on the shelf life of salmon (Salmo salar). *Journal of Agricultural and Food Chemistry, 58*(21), 11456–11462.
Tahergorabi, R., Beamer, S. K., Matak, K. E., & Jaczynski, J. (2011). Effect of isoelectric solubilization/precipitation and titanium dioxide on whitening and texture of proteins recovered from dark chicken-meat processing by-products. *LWT - Food Science and Technology, 44*(4), 896–903.
Tahergorabi, R., Beamer, S. K., Matak, K. E., & Jaczynski, J. (2012). Isoelectric solubilization/precipitation as a means to recover protein isolate from striped bass (*Morone saxatilis*) and its physicochemical properties in a nutraceutical seafood product. *Journal of Agricultural and Food Chemistry, 60*(23), 5979–5987.
Tahergorabi, R., Beamer, S. K., Matak, K. E., & Jaczynski, J. (2013). Chemical properties of ω-3 fortified gels made of protein isolate recovered with isoelectric solubilisation/precipitation from whole fish. *Food Chemistry, 139*(1–4), 777–785.
Tsigarida, E., Skandamis, P., & Nychas, G. J. (2000). Behaviour of Listeria monocytogenes and autochthonous flora on meat stored under aerobic, vacuum and modified atmosphere packaging conditions with or without the presence of oregano essential oil at 5 C. *Journal of Applied Microbiology, 89*(6), 901–909.
Tsironi, T., Dermesonlouoglou, E., Giannakourou, M., & Taoukis, P. (2009). Shelf life modelling of frozen shrimp at variable temperature conditions. *LWT-Food Science and Technology, 42*(2), 664–671.
Yassoralipour, A., Bakar, J., Abdul Rahman, R., Abu Bakar, F., & Golkhandan, E. (2013). Effect of different temperatures on the free amino acids, physico-chemical and microbial changes during storage of Barramundi (*Lates calcarifer*) fillets. *Advance Journal of Food Science and Technology, 5*(7), 822–828.
Zinoviadou, K. G., Koutsoumanis, K. P., & Biliaderis, C. G. (2009). Physico-chemical properties of whey protein isolate films containing oregano oil and their antimicrobial action against spoilage flora of fresh beef. *Meat Science, 82*(3), 338–345.