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Chemical, sensory and shelf life evaluation of sliced salmon treated with salts of organic acids

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Abstract

This study was carried out to evaluate the shelf life, chemical quality and sensory attributes of salmon slices treated by dipping in 2.5% aqueous solution of sodium acetate (NaA), sodium lactate (NaL), or sodium citrate (NaC) during refrigerated storage at 1 °C. The chemical analyses demonstrated significant reduction in *K* value, hypoxanthine (Hx) concentration, total volatile base nitrogen (TVB-N), and trimethylamine (TMA) in treated salmon slices when compared with the control. Sensory scores of treated salmon were in a typical category for appearance, juiciness and tenderness compared with the control. Only minor changes in the sensory attributes were recognized by few panellists in NaA- and NaL-treated samples. A shelf life of 12, 12 and 15 days has been estimated for salmon treated with NaL, NaC, and NaA, respectively, versus 8 days for control. The salts of organic acids can therefore be used as safe preservatives for fish under refrigerated storage.

Keywords

Sliced salmon; Chemical quality; Sensory attributes; Shelf life; Sodium acetate; Lactate; Citrate

1. Introduction

Fish is one of the most highly perishable food products. During handling and storage, quality deterioration of fresh fish rapidly occurs and limits the shelf life of the product. Shelf life is defined as the period of time, under defined conditions of storage, for which a food product remains safe and fit for use. In other words, during this period, it should retain its desired sensory, chemical, physical, functional or microbiological characteristics (IFST, 1993). The quality of fish degrades, due to a complex process in which physical, chemical and microbiological forms of deterioration are implicated. Enzymatic and chemical reactions are usually responsible for the initial loss of freshness whereas microbial activity is responsible for the obvious spoilage and thereby establishes product shelf life (Gram & Huss, 1996).

Many indices have been used for the assessment of fish quality during storage. Such indices comprise changes in the microbial population (Gram & Huss, 1996; Hozbor, Saiz, Yeannes, & Fritz, 2006), chemical changes, including adenosine triphosphate (ATP) breakdown products (such as hypoxanthine; Hx concentration and *K* value) (Dalgaard, 2000; Ehira & Uchiyama, 1987; Ryder, 1985; Saito, Aria, & Matsuyoshi, 1959), total volatile base nitrogen (TVB-N) and trimethylamine (TMA) content (Malle & Poumeyrol, 1989; Özogul, Polat, & Özogul, 2004), as well as changes in sensory attributes (Dalgaard, 2000).

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Because of consumer demand for fresh refrigerated foods with extended shelf life, considerable research have been directed toward using various preservation technologies to preserve or prolong the shelf life, while ensuring the safety, of fresh foods, including fishery products.

Sodium salts of the low molecular weight organic acids, such as acetic, lactic and citric, have been used to control microbial growth, improve sensory attributes and extend the shelf life of various food systems (Maca, Miller, & Acuff, 1997; Sallam & Samejima, 2004; Zhuang, Huang, & Beuchat, 1996). In addition to their suppressing effect on the growth of food spoilage bacteria, organic salts of sodium acetate, lactate, and citrate were shown to possess antibacterial activities against various food-borne pathogens (Lee, Cesario, Owens, Shanbrom, & Thrupp, 2002; Mbandi & Shelef, 2001; McWilliam Leitch & Stewart, 2002). Furthermore, these salts are widely available, economical, and generally “recognized-as-safe”.

The main objective of this study was to investigate the effects of sodium acetate (NaA), sodium lactate (NaL), and sodium citrate (NaC) treatment on the shelf life, chemical quality and sensory attributes of tray-packaged fresh sliced salmon during refrigerated storage at 1 °C.

2. Materials and methods

2.1. Preparation and treatment of fish samples

Fresh ice-chilled Pacific salmon (*Onchorhynchus nerka*) were purchased, within 24 h post-harvesting, from a local seafood market in Sapporo, Hokkaido, Japan. Salmon samples were headed, gutted, filleted, and cut into skin-on slices (110 g average weight/slice), using the market facilities. Salmon slices were then transported to the laboratory in polystyrene boxes with an appropriate quantity of flaked ice. Within 1 h of arrival, fish slices were divided into four batches (12 kg each); three batches were treated by dipping for 10 min in pre-chilled (4 °C) aqueous solutions (2.5%) of NaA, NaL, or NaC (Wako Pure Chemical Industries Ltd., Osaka, Japan), while the fourth batch was dipped in pre-chilled distilled water as a control sample. Fish to dipping solution ratio was 1:2.5. After dipping, fish slices were allowed to drain for 5 min on a sterile stainless wire mesh screen at the ambient temperature (18 °C). Five slices from each dipping treatment were placed in a Styrofoam tray and packaged by overwrapping with polyvinylidene film. This packaging permits an aerobic condition during storage. Packaged slices were subsequently labelled and stored at 1 °C. The sliced salmon were sampled for examination at storage days 0, 3, 6, 9, 12, and 15. On each sampling occasion, fish slices from every batch were subjected to chemical and sensory analyses.

2.2. Chemical analyses

2.2.1. pH measurement—Ten grammes of each sample were blended with 20 ml distilled water in a blender for 30 s and pH value of fish homogenate was measured by a digital pH-meter (HM-5 S; TOA Electric Industrial Co. Ltd., Tokyo, Japan) standardized at pH 4 and 7.

2.2.2. ATP breakdown products—ATP-related compounds were determined according to the method of Ryder (1985). Fish extract used for the analysis was prepared by homogenization of 5 g of fish muscle (without skin) with 25 ml chilled 0.6 M perchloric acid in a laboratory homogenizer (AM-5 Ace homogenizer, Nihonseiki., Japan) at 0 °C for 1 min. The homogenate was centrifuged at 6000 rpm for 10 min; the supernatant was then decanted and immediately neutralized to pH 6.5–6.8 with 1 M potassium hydroxide solution. After standing at 2 °C for 30 min, the precipitated potassium perchlorate was removed by filtration through Whatman No. 1 filter paper. The filtrate was diluted to 20 ml prior to storage at –80 °C until analyzed. High performance liquid chromatography (D-2000 Elite type HPLC System; HITACHI High-Technologies Corporation, Tokyo, Japan) with an L-2200 auto-sampler, two L-2130 pumps, an organizer, L-2300 column oven, and L-2420 UV–Vis detector, was used

for quantitative analysis of ATP breakdown compounds of the prepared samples. Twenty microliter aliquots of the sample extracts were injected in duplicate into the HPLC. The UV detector was set at 254 nm, and the separation of the nucleotide products was achieved by a 5 µm-column (250 mm × 4.6 mm ID; HITACHI, Tokyo, Japan) equilibrated at 30 °C. Integration was carried out using a D-2000 Elite Software programme installed in a Windows XP Professional computer system (HITACHI, Tokyo, Japan). The mobile phase of 0.04 M potassium dihydrogen orthophosphate and 0.06 M dipotassium hydrogen orthophosphate dissolved in Milli Q-purified (0.22 µm Millipore) distilled water was used at a flow rate of 2 ml/min. The peaks obtained from fish muscle extracts were identified by comparing against the standard solutions. All chemicals, solvents, and nucleotide standards were of HPLC grade (Wako Pure Chemical Industries Ltd., Osaka, Japan) and all the solutions were filtered through a 0.45 µm filter prior to injection into the HPLC. ATP breakdown products, comprising adenosine diphosphate (ADP), adenosine monophosphate (AMP), inosine monophosphate (IMP), inosine (Ino), and hypoxanthine (Hx), were measured and the *K* value was calculated using the formula described by Saito et al. (1959):

$$K \% = \frac{(\text{Ino} + \text{Hx})}{(\text{ATP} + \text{ADP} + \text{AMP} + \text{IMP} + \text{Ino} + \text{Hx})} \times 100$$

2.2.3. Total volatile base nitrogen (TVB-N) and trimethylamine (TMA)—Fish extracts for determination of total volatile base nitrogen (TVB-N) and trimethylamine (TMA) were prepared by homogenizing 100 g of fish sample with 200 ml of 7.5% (v/v) aqueous trichloroacetic acid (TCA) solution in a laboratory homogenizer for 1 min at high speed. The homogenate was centrifuged at 3000 rpm for 5 min and the supernatant liquid was then filtered through Whatman No. 1 filter paper. TVB-N was measured by steam-distillation of the TCA-fish extract, using the modified method of Malle and Tao (1987). Twenty-five milliliter of the filtrate were loaded into a Kjeldahl-type distillation tube, followed by 5 ml of 10% (w/v) aqueous NaOH solution. Steam-distillation was performed using a vertical steam-distillation unit, and the distillate was received into a beaker containing 15 ml of 4% (v/v) aqueous boric acid solution up to a final volume of 50 ml. The titration was allowed to run against aqueous 0.05 M sulphuric acid solution using an automatic titrator (DL 25 Titrator, Mettler-Toledo AG, Greifensee, Switzerland) equipped with stirrer and pH electrode.

The same experimental procedure of TVB-N was used for the TMA measurement (Malle & Poumeyrol, 1989). The only difference was the addition of 20 ml of 35% (v/v) formaldehyde to the distillation tube to block the primary and secondary amines, whilst leaving only the tertiary amines to react. The amount of TVB-N and TMA were calculated from the volume of 0.05 M sulphuric acid used for titration and the results were expressed in mg nitrogen/100 g of sample.

2.3. Sensory analysis of cooked fish

The sensory attributes of cooked fish were evaluated by a panel of 15 semi-trained panellists on each day of sampling. Salmon slices were cooked for 15 min to an internal temperature of 75 °C in a preheated conventional microwave oven (Sharp Electronics, Japan) adjusted to 180 °C. Four representative fish samples of the different treatments were individually presented in covered small porcelain dishes to each panellist. The judges were not informed about the experimental approach and the samples were blind-coded with 3-digit random numbers. Panellists were instructed to eat crackers and drink water, as palate cleansers, and pause for 30 s between samples. Panellists were asked to evaluate the overall acceptability with regard to appearance, odour intensity, salmon flavour and aftertaste, tenderness, juiciness, off-odour, and off-flavour. An eight-point hedonic scoring scale, with 8 = extremely intense/juicy/tender, 7 = very intense/juicy/tender, 6 = moderately intense/juicy/tender, 5 = slightly intense/juicy/tender, 4 = slightly bland/dry/tough, 3 = moderately bland/dry/tough, 2 = very bland/dry/tough,

1 = extremely bland/dry/tough, was employed for odour and flavour intensity, juiciness, and tenderness, respectively, while a nine-point hedonic scale, ranging from extremely acceptable (9) to extremely unacceptable (1) was utilized for evaluation of the appearance. Moreover, a six-point scoring scale, with 6 = no-detected off-odour/off-flavour, 5 = barely detected off-odour/off-flavour, 4 = slight off-odour/off-flavour, 3 = moderate off-odour/off-flavour, 2 = strong off-odour/off-flavour, 1 = extreme off-odour/off-flavour was used for the assessment of the off-odour and off-flavour, respectively. Salmon samples receiving overall scores of more than 4 were considered acceptable, while a score between 3 and 4 was considered the borderline of acceptability.

2.4. Statistical analysis

All measurements were carried out in triplicate. Data were subjected to analysis of variance (ANOVA) using the general linear models procedure of the statistical analysis system software of SAS Institute (SAS Institute, Inc., 1990). Differences among the mean values of the various treatments and storage periods were determined by the least significant difference (LSD) test, and the significance was defined at $P < 0.05$.

3. Results and discussion

3.1. Chemical quality

3.1.1. Changes in pH value—The effect of organic acid salts and storage time on the pH of salmon slices during storage at 1 °C is shown in Table 1. The initial pH value of the control slices (6.45) was significantly ($P < 0.05$) higher than that of samples treated with NaA (6.32) or NaL (6.36), but not NaC (6.41). These findings are consistent with those of Kim, Hearnberger, Vickery, White, and Marshall (1995), who reported an initial decrease in pH value of catfish fillets treated by tumbling with 0.5% sodium acetate when compared with untreated control fillets, and also with Williams, Rodrick, and West (1995), who reported a decrease in the initial pH of NaL-treated catfish fillets (6.32 versus 6.5 for the control). On the other hand, Zhuang et al. (1996) found no differences ($P > 0.05$) in the initial pH values between control catfish fillets and those treated with 2% NaA or NaL.

Storage time had a significant ($P < 0.05$) effect on the pH values, which tends to increase for each of the control as well as NaA- and NaC-treated salmon slices and, by the end of the storage period (day 15), significant difference was observed in the pH values between control (7.1) and all of the other treated samples, which were 0.50–0.63 U lower than the control. On the other hand, González-Fandos, Villarino-Rodríguez, García-Linares, García-Arias, and García-Fernández (2005) found no significant change in the pH of salmon slices throughout a storage period of 45 days at 2 and 10 °C.

NaL has been revealed to stabilize the pH during storage of meat products (Maca et al., 1997; Sallam & Samejima, 2004). Our results also verified an almost constant pH (6.34–6.37) for NaL-treated salmon slices throughout the storage time, while the pH of control or NaA- and NaC- treated samples were significantly increased.

3.1.2. ATP breakdown products—The initial quality loss in fish is primarily caused by post-mortem autolytic changes and is unrelated to the microbiological activities. Of particular importance in this respect is the degradation of adenosine nucleotides (ATP-related compounds) (Gram & Huss, 2000). The rate and pattern of nucleotide degradation in fish varies with species, body location (dark or white muscle), fish maturity, stress during capture, handling, season and storage conditions (Erikson, Beyer, & Sigholt, 1997; Huss, 1995; Luong, Male, Masson, & Nguyen, 1992). Degradation of ATP goes through the intermediate products ADP, AMP, IMP, Ino and Hx. Most of the adenosine nucleotides disappeared quickly since

they degraded to IMP within 1–3 days after fish capture, and as the degradation continues, Ino and then Hx will be produced. The autolytic changes contribute to spoilage, mainly by making catabolites available for bacterial growth (Huss, 1995). Traditionally, the degradation of ATP to IMP has been attributed to muscle endogenous autolytic enzymes (Gram & Huss, 1996), meanwhile the degradation of IMP to Ino and Hx has also been connected with the growth of bacteria. Hx has a slight bitter taste and is regarded as a contributor to off-flavours (Dalgaard, 2000; Gram & Huss, 2000), whereas IMP is desirable as a flavour component enhancer and is strongly associated with acceptability in fresh fish (Fletcher & Statham, 1988).

Hypoxanthine (Hx) accumulation in fish muscle is shown in Fig. 1. The levels of Hx were significantly ($P < 0.05$) increased from initial values of 0.62–0.68 $\mu\text{mol/g}$ of salmon to final values of 3.58, 2.13, 2.43, and 2.7 $\mu\text{mol/g}$ for control, NaA-, NaL- and NaC- dipped samples, respectively, by the end of the storage period. Significant increase in Hx concentration with the increase of storage time has also been reported in various studies for many seafoods (Alasalvar et al., 2001; Greene, Babbitt, & Reppond, 1990; Özogul, Özogul, & Gökbulut, 2006).

It has been reported that bacterial growth has a direct correlation with Hx production, and the rate of bacterial production of Hx is higher than the production rate by the autolytic activities (Gram & Huss, 1996). Treatment of salmon slices with the sodium salts of organic acids induced significant ($P < 0.05$) reduction in Hx values when compared with the non-treated control slices. This might be related to the inhibitory effect of these salts on the growth of the various bacterial groups (Maca et al., 1997; Sallam & Samejima, 2004; Zhuang et al., 1996) with consequent reduction in Hx formation.

Both rates of Hx production and Hx concentration vary substantially between fish species. Nevertheless, Hx concentration has been useful for shelf life determination in specific seafoods (Dalgaard, 2000). Our result also revealed that hypoxanthine (Hx) concentrations can be a useful index for freshness of sliced salmon during refrigerated storage.

The K value index, calculated from ATP degradation products, is the percent of the sum of Ino and Hx divided by the sum of ATP, ADP, AMP, IMP, Ino, and Hx. The K value has been reported as a good indicator of fish freshness in various species of fish (Ehira & Uchiyama, 1987; Özogul et al., 2006). Many factors affect the K value of fish, including fish species (Hattula & Kiesvaara, 1992), type of muscle (Murata & Sakaguchi, 1986), stress of fish during capture (Erikson et al., 1997), and storage temperature (Guizani, Al-Busaidy, Al-Belushi, Mothershaw, & Rahman, 2005).

Fig. 2 summarizes the mean K values obtained for salmon slices analyzed during refrigerated storage at 1 °C. At the beginning of the storage, the K value ranged from 13.8% to 14.4%, and then increased to a high level of 72.3% in the control samples at day 15 of the storage. On the other hand, significantly ($P < 0.05$) lower K values of 41.1%, 47.5%, and 51.2% were detected, in comparison with the control, by the end of the storage period for NaA-, NaL-, and NaC-treated samples, respectively. K value development during cold storage of salmon has also been reported in various studies (Einen & Thomassen, 1998; Erikson et al., 1997).

In this study, the pattern of increase of K value for control samples occurred linearly at a relatively high rate of 6% per day during the first 6 days, and then increased with a slow rate of 2.44% per day during the following 9 days, indicating that the K value is considerably affected by the early autolytic activity. In treated samples, however, the K value increased at moderate rates of 2.81%, 3.27%, and 3.84% per day for samples dipped in NaA, NaL, and NaC, respectively during the first 6 days of storage, and then it increased with much slower rates of 1.41%, 1.57%, and 1.53% in the same samples, respectively, during the next nine days. The increase of the K value primarily resulted from the sharp decline of IMP in the fish flesh

during the first week of storage (data not shown). This finding is in agreement with those of Özogul et al. (2004) and Guizani et al. (2005), who showed that the K value was strongly affected by the fast depletion of IMP.

For both the control and treated samples, the K value significantly ($P < 0.05$) increased with the storage time. In addition, it was found that, as the K value increased, the sensory quality of sliced salmon decreased, and when the sliced salmon of control was considered unacceptable (days 7–8), based on the sensory evaluation, a K value of about 55% was estimated; nevertheless the K value for all of the treated samples did not reach such a value even by day 15 at the end of the storage period. Wide variations in the K value have been reported among the different species on the day of fish rejection. Özogul et al. (2004) detected a K value of 80% for vacuum-packed sardine stored at 4 °C on the rejection day (day 9), while a lower K value of 39% was determined on the day of rejection (day 17) for sea bream stored at 2 ± 2 °C (Alasalvar et al., 2001).

In some species, the K value increases faster than the observed sensory changes. Greene et al. (1990) found that the K value of flattened sole was 80% after only 1 day of storage in ice. Likewise, Luong et al. (1992) revealed that the K value of Pacific cod, stored on ice (0–4 °C), approached 100% after 2 days; yet the fish were judged suitable for consumption up to 10 days later.

The K value and Hx concentration determined in this study were found to be almost associated with the freshness quality in both the control and treated sliced salmon during the refrigerated storage. Generally, the determination of ATP breakdown products is most reliable and suitable for the evaluation of fish freshness, when a high demand of freshness, as in Japan, is proposed for sashimigrade seafood (Ehira & Uchiyama, 1987). Sashimi is raw fish or shellfish served sliced, “Sashimi”, or as a finger-size piece of raw fish on a bed of a small rice ball “Sushi”. A maximum K value of 20% has been set for sashimi (Saito et al., 1959). It is not, however, relevant to establish any concentration limit of ATP breakdown products as a limit acceptable for fish, because there are variations in breakdown products between fish species and even between the individuals within the same fish species.

3.1.3. Total volatile base nitrogen—TVB-N and TMA are most useful indices for spoilage in fresh and lightly preserved seafood (Dalgaard, 2000). In the current study, the initial TVB-N values (mg N/100 g muscle) in sliced salmon analyzed ranged from 8.69 in NaC-treated samples to 9.32 in NaL-treated samples (Fig. 3). Slight increase in the TVB-N value was then observed throughout the first days of storage, reaching a value of 13.6, 11.3, 12.8, and 12.8 mg N/100 g by day 6 in each of the control, NaA-, NaL- and NaC- treated samples, respectively. By day 9 and afterwards, however, a sharp rise of TVB-N value was noticed in the control, which reached a value of 22.7 mg N/100 g muscle on day 9, while the sliced salmon dipped in NaA, NaL, or NaC showed lower values of 14.6, 15.8, and 17.8 mg N/100 g muscle, respectively, on the corresponding day of storage. A similar pattern of the increase in TVB-N values for the control has been reported by Hozbor et al. (2006) during cold storage of sea salmon.

At the time of fish rejection (days 8, 12, 12, and 15 for control, NaC-, NaL-, and NaA-treated samples, respectively), a TVB-N value of about 20 mg N/100 g muscle was detected. Similarly, Özogul, Özyurt, Özogul, Kuley, and Polat (2005) reported a TVB-N value of 22.6 mg/100 g at time of spoilage in European eel stored in boxes at 3 ± 1 °C, although they recorded a higher value of 103 mg TVB-N per 100 g flesh by the end of the storage period (12 days). It has been suggested that the TVB-N value is affected by species, season, harvesting area, age and sex of fish (Kilinc & Cakli, 2005).

As for many fish species, the formation of TVB-N increased with the time of storage, and by the end of the storage period (day 15), a significantly ($P < 0.05$) higher value of 34.5 mg/100 g was detected for TVB-N in control when compared with those in the different treated samples, which attained much lower values of 19.3, 22.6, and 24.4 mg N/100 g muscle for samples dipped in NaA, NaL, and NaC, respectively. Nevertheless, the TVB-N values in the different samples analyzed, throughout the entire storage period, were all below the maximum value of 35 mg N/100 g flesh specified by the EC guidelines (Commission Decision 95/149/EC, 1995) for different species of raw fish. Based on the results obtained from this study, TVB-N value could be useful in assessing the degree of salmon deterioration more than in evaluating the changes occurring during the first stages of storage.

3.1.4. Trimethylamine—The changes in TMA content in fresh sliced salmon stored under refrigeration at 1 °C are shown in Fig. 4. The initial TMA value ranged from 0.65 to 0.73 mg/100 g muscle, which then increased very slowly during the first 6 days of storage, reaching low values of 1.63, 1.08, 1.18, and 1.36 mg/100 g for each of the control, NaA-, NaL-, and NaC-dipped samples, respectively. By the day 9 of storage and thereafter, however, the TMA value of control samples increased steadily, attaining a final value of 6.57 mg/100 g flesh by the end of the storage period (day 15), whereas significantly ($P < 0.05$) lower values of 3.41, 4.37, and 4.58 mg/100 g flesh were detected for sliced salmon dipped in NaA, NaL, and NaC, respectively.

The values and pattern of increase in the TMA for control samples are comparable to those reported in salmon portions kept in plastic bags and stored in ice at 0 °C (Béné, Hayman, Reynard, Luisier, & Villettaz, 2001). Nonetheless, much higher production of TMA-N was observed in other different species of fish by the end of the storage period at refrigerated temperature (Magnússon & Martinsdóttir, 1995; Özogul et al., 2004). In contrast, Einen and Thomassen (1998) claimed that two sides filleted Atlantic salmon can be stored on ice for at least 12 days without any detectable formation of TMA.

The relatively small increase in TMA over the storage period in this study reflects the low level of trimethylamine oxide (TMAO) in the flesh of sliced salmon. Salmon has been reported to have a low level of TMAO, ranging from 11 to 14 mg/100 g flesh (Emborg, Laursen, Rathjen, & Dalgaard, 2002). In addition, it has been indicated that the concentrations of TMA-N in numerous fatty fish never reached the limit of 5 mg TMA-N/100 g (Özogul et al., 2004), although the rejection limit in fish flesh is usually more than this limit.

The level of TMA found in fresh fish rejected by sensory panels varies between species, but is typically around 10–15 mg TMA-N/100 g in aerobically-stored fish (Dalgaard, Gram, & Huss, 1993). In the present study, the TMA value detected at the time of fish rejection, as estimated by the sensory attributes, was <4 mg TMA-N/100 g for both control and treated salmon samples. Such a value is about 3-fold lower than the proposed value for spoiled fish. However, Hozbor et al. (2006), determined a higher concentration of 15.8 mg nitrogen/100 g for TMA at the point of spoilage (day 10) in sea salmon during aerobic storage in ice at 0 °C.

TVB-N and TMA are directly related to the microbial spoilage in various species of fish during their storage under refrigerated conditions (Dalgaard, 2000). The amount of TVB-N and TMA were low during the edible storage period and increased only rapidly when the fish was near to rejection. Therefore, TVB-N and TMA are considered unreliable to estimate the degree of freshness in the early stages of storage of sliced salmon; they only reflect the degree of spoilage in the later stages.

3.2. Sensory attributes

Sensory attributes of cooked salmon (pooled data over the storage period) treated by the sodium salts of the three different organic acids used are presented in Table 2. Owing to development of off-odour, resulting from the microbial and chemical changes, the control and NaL- and NaC-treated samples were not evaluated for the sensory attributes by day 9, and after 12 days of storage, respectively. NaA-treated samples, however, were evaluated until the end of the storage period (day 15). No significant differences in the acceptability scores were detected between control and treated samples before storage. Storage time had no effect ($P > 0.05$) on the appearance, juiciness, or tenderness of cooked salmon slices, whereas salmon odour, flavour and aftertaste, and the overall acceptability scores were significantly decreased ($P < 0.05$) as the storage time increased (data not shown). Salmon slices exhibited shelf lives of 8, 12, 12 and 15 days of storage for the control, NaL-, NaC-, and NaA-treated samples, respectively.

Sensory scores of sliced salmon treated with the sodium salts of organic acids were in the typical category for appearance, juiciness, and tenderness compared to control fish. No difference ($P > 0.05$) was detected in the appearance, juiciness, or tenderness either between the control and treated samples, or among the three different treatments.

Comparable scores for both odour and flavour were obtained for the analyzed samples. The intensity of salmon odour was higher ($P < 0.05$) in the control than in NaA-treated samples, whereas no significant difference were detected for salmon odour between the different treatments. Salmon flavour and aftertaste were significantly ($P < 0.05$) higher in the control than in treated samples, but these were not significantly differ from each other. However, Williams et al. (1995) revealed that no colour, texture, odour or flavour differences ($P > 0.05$) were detected between controls and catfish fillets treated with 1 and 2% NaL through 4 days of storage at 1.11 °C, as they verified that fillets treated with 2% NaL were rated acceptable in colour, texture, odour, and flavour through 7 days of storage at the same temperature.

Comparable results were also demonstrated in the present study for both off-odour and off-flavour scores in the different treatments and the control. Significant differences ($P < 0.05$) were identified for the intensity of the off-odour and off-flavour scores between the control and all of the different treatments; however, all of the analyzed samples from the different treatments were judged by the sensory panels as organoleptically acceptable. No off-odour or off-flavour could be detected, by any of the 15 panellists, for the NaC-treated salmon. However, a slight acetic acid (vinegar) odour was distinguished in NaA-treated samples by three (20%) of the panellists, while two (13.3%) of the panellists could recognize a slight off-flavour described as “metallic” or “chemical” for NaL-treated samples. Likewise, an objectionable off-flavour and aftertaste, described as “sodium” or “metallic” has also been reported by approximately 10% of panellists for catfish fillets treated with 2% NaL (Williams et al., 1995).

Significant difference ($P < 0.05$) has been detected for the overall acceptability between the control and treated samples, while no differences were detected among the different treatments. Control salmon slices showed the highest score (6.58) of overall acceptability, followed by NaC- and NaL-treated samples (5.94 and 5.87, respectively), while samples treated with NaA exhibited the least acceptable scores (5.59). Nonetheless, all of the analyzed samples were considered as acceptable (achieved overall scores of more than 4) during all the occasions of the sensory analysis.

4. Conclusion

This study concluded that dipping of fresh salmon slices in aqueous solutions (2.5%) of the sodium salts of organic acids can maintain the chemical quality, and extend the shelf life of the product with only minor sensory changes during the refrigerated storage; therefore, sodium acetate, sodium lactate, and sodium citrate can be utilized as safe organic preservatives for fish under refrigerated storage.

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Fig. 1. Changes in hypoxanthine (Hx) concentrations of sliced salmon treated by dipping in sodium acetate (NaA), sodium lactate (NaL) and sodium citrate (NaC) solutions during storage at 1 °C. Values represent means $\pm$ SE of three replicates; LSD is defined at $P < 0.05$.

Fig. 2. Changes in *K* value of sliced salmon treated by dipping in sodium acetate (NaA), sodium lactate (NaL) and sodium citrate (NaC) solutions during storage at 1 °C. Values represent means $\pm$ SE of three replicates; LSD is defined at $P < 0.05$.

Fig. 3. Effects of sodium acetate (NaA), sodium lactate (NaL) and sodium citrate (NaC) treatments on total volatile base nitrogen (TVB-N) content in sliced salmon during storage at 1 °C. Values represent means $\pm$ SE of three replicates; LSD is defined at $P < 0.05$.

Fig. 4.

Effects of sodium acetate (NaA), sodium lactate (NaL) and sodium citrate (NaC) treatments on trimethylamine (TMA) concentration in sliced salmon during storage at 1 °C. Values represent means $\pm$ SE of three replicates; LSD is defined at $P < 0.05$.

Table 1

Effects of organic acid salt treatments and storage time on the pH of sliced salmon during refrigerated storage (1 °C)

Storage time (day)	Control	2.5% NaA	2.5% NaL	2.5% NaC
0	6.45 ± 0.02; ^{az}	6.32 ± 0.01; ^{ax}	6.36 ± 0.03; ^{axy}	6.41 ± 0.01; ^{ayz}
3	6.52 ± 0.01; ^{aby}	6.37 ± 0.02; ^{abx}	6.33 ± 0.01; ^{ax}	6.46 ± 0.01; ^{ay}
6	6.64 ± 0.02; ^{bcz}	6.36 ± 0.03; ^{abx}	6.34 ± 0.02; ^{ax}	6.49 ± 0.03; ^{aby}
9	6.61 ± 0.02; ^{bcy}	6.38 ± 0.01; ^{abx}	6.36 ± 0.01; ^{ax}	6.54 ± 0.03; ^{bcy}
12	6.72 ± 0.02; ^{cz}	6.43 ± 0.03; ^{bx}	6.37 ± 0.02; ^{ax}	6.55 ± 0.02; ^{bcy}
15	7.10 ± 0.01; ^{dz}	6.42 ± 0.02; ^{bx}	6.37 ± 0.01; ^{ax}	6.61 ± 0.03; ^{cy}

^{a-d} Means ± SE, in the same column, followed by different superscripts, are significantly different ($P < 0.05$).

^{x-z} Means ± SE, in the same row, followed by different superscripts, are significantly different ($P < 0.05$).

Table 2

Mean sensory attribute scores of the cooked sliced salmon treated with sodium acetate, sodium citrate and sodium lactate during refrigerated storage at 1 °C^A

Sensory attributes	Control	2.5% NaA	2.5% NaL	2.5% NaC	Overall SEM
Appearance ^a	7.56 ^x	7.34 ^x	7.52 ^x	7.55 ^x	0.12
Salmon odour ^b	5.89 ^x	5.08 ^y	5.41 ^{x, y}	5.54 ^{x, y}	0.13
Flavour and aftertaste ^b	6.37 ^x	5.38 ^y	5.49 ^y	5.53 ^y	0.14
Juiciness ^b	6.61 ^x	6.35 ^x	6.53 ^x	6.57 ^x	0.12
Tenderness ^b	6.89 ^x	6.52 ^x	6.71 ^x	6.68 ^x	0.09
Off-odour ^c	5.43 ^x	4.52 ^y	4.75 ^y	4.82 ^y	0.11
Off-flavour ^c	5.45 ^x	4.61 ^y	4.80 ^y	4.91 ^y	0.09
Overall acceptability	6.58 ^x	5.59 ^y	5.87 ^y	5.94 ^y	0.08

^A Pooled data over the storage time.

^a Nine-point hedonic scale; from 9 (extremely acceptable) to 1 (extremely unacceptable).

^b Eight-point hedonic scale; from 8 = extremely intense/juicy/tender to 1 = extremely bland/dry/tough for odour and flavour intensity, juiciness, and tenderness, respectively.

^c Six-point scoring scale; from 6 (none-detected) to 1 (extreme off-odour/off-flavour).

^{x-z} Scores in the same row, followed by different superscripts, are significantly different ($P < 0.05$).