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Preservation of Raw *Crassostrea gigas* Oyster Meat: Effects of Weak Organic Acid Marination on Physicochemical, Microbiological, and Sensory Properties

Running head: Marinating Raw *Crassostrea gigas* Oysters with Organic Acids

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SUMMARY

Research background. Oysters have high nutritional value; however, their short shelf life limits their commercialization to areas close to production sites. Affordable and accessible processing techniques that extend shelf life could expand both market reach and consumer access to oysters. This study evaluated the physicochemical, microbiological, and sensory properties of raw *Crassostrea gigas* oyster meat semi-preserved with weak organic acids and saline solutions under refrigerated storage (4 °C).

Experimental approach. Aliquots of (100±2) g of raw oyster meat were placed into plastic containers containing different solutions: W - sterile deionized water only (negative control treatment); NaCl – base solution (NaCl, 5 % *m*/*V*) only; CA – base solution with 2 % citric acid; LA – base solution

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with 2 % lactic acid; AA – base solution with 2 % acetic acid. Sensory, physicochemical and microbiological characteristics of the semi-preserves were monitored for 16 days.

Results and conclusions. Incorporating weak acids into the marination solutions effectively inhibited the growth of mesophilic and psychrotrophic bacteria in semi-preserved oysters during 16 days of refrigerated storage. In contrast, W and NaCl treatments exceeded the recommended limit of 5 log CFU/g for seafood after 3 and 11 days, respectively. By day 16, TVB-N values indicated early spoilage in W (30.03±1.1) mg/100 g, satisfactory freshness in NaCl (24.53±2.6) mg/100 g and CA (18.33±1.1) mg/100 g, and excellent freshness in LA (14.70±0.0) mg/100 g and AA (14.95±1.8) mg/100 g. TBARS values remained below 3 mg MDA/kg in all treatments, indicating good oxidative stability. Among the acids, AA maintained higher pH values (~3.78 at day 16) than CA (~3.26) and LA (~3.14) and showed the lowest microbial loads; however, it received the highest scores for acid odour (median=5.35) and the lowest for characteristic oyster odour. CA and LA produced sensory profiles more similar to fresh oysters, with higher characteristic odour scores and lower acid odour scores, but slightly higher spoiled odour scores (still low in absolute terms). Overall, AA was the most effective for microbiological and physicochemical preservation, while CA and LA offered better sensory acceptance. These results highlight the potential of weak organic acids, particularly AA, as a low-cost method to extend the shelf life of raw oysters to at least 16 days under refrigeration.

Novelty and scientific contribution. This study evaluated the effects of marination with weak acids on the physicochemical, microbiological, and sensory properties of raw oyster meat. The wide range of parameters analysed highlights not only its suitability for consumption but also consumer preferences based on sensory aspects such as colour and odour. The combined findings can assist the industry in selecting the most appropriate acid for developing different oyster-based products.

Keywords: bivalve molluscs; oyster meat; shellfish consumption; shelf life; sensory analysis; semi-preserved products

INTRODUCTION

Oysters are marine bivalves of high economic and nutritional value and the most cultivated shellfish worldwide. The global aquaculture market was valued at USD 9,251.5 million in 2024 and is projected to reach USD 11,770.5 million by 2031, growing at 3.5 % annually (*1*). The Pacific oyster (*Crassostrea gigas*), the most widely consumed species, dominates global production, with China contributing nearly 89 % of the total (*2*). In addition to their market relevance, oysters are a rich source of high-quality protein, essential amino acids, and trace minerals (*3*).

However, oysters are highly perishable due to high water activity, active endogenous enzymes, and susceptibility to microbial contamination (*4*). Maintaining quality and safety during storage and distribution is challenging (*3*), and the raw consumption of live oysters poses potential health risks associated with pathogenic contamination (*5*). Preservation strategies include refrigeration, freezing, high-pressure processing (HPP), modified atmosphere packaging (MAP), and natural preservatives (*3-16*).

Marination is a traditional technique that uses natural products, such as weak organic acids, as a mild preservation method. In addition to enhancing flavour, marination can inhibit microbial growth through the combined effects of organic acids and other natural preservatives (*10,12-14,17*). Marinated seafood products are valued for their convenience, sensory appeal, and extended refrigerated shelf life (*14*). Organic acids such as acetic, citric, and lactic acids exhibit antimicrobial activity by penetrating microbial membranes in undissociated form, acidifying the cytoplasm, and disrupting metabolism. They also destabilise membranes, impair nutrient transport, and slow enzymatic and oxidative reactions, helping preserve colour, texture, and flavour (*13,14,16*).

Demand for ready-to-eat oysters (*4*) underscores the need for preservation strategies that ensure safety and quality while meeting consumer expectations. Semi-preserves are products that are not subjected to pasteurisation and therefore remain essentially in their raw state. As such, they represent an attractive option for consumers seeking minimally processed products. However, few studies have investigated the production of semi-preserves from raw, shucked oysters, highlighting a gap in the development of minimally processed oyster products. The present study evaluates the effect of marination with weak organic acids on the quality and shelf life of refrigerated shucked *C. gigas*, aiming to support the development of safe, nutritious, and convenient oyster products.

MATERIALS AND METHODS

Sample and solution preparation

Approximately 480 Pacific oysters (*Crassostrea gigas*) were harvested in November 2022 from a marine farm located in the southern part of Santa Catarina Island, Brazil (27°49′5.10″S; 48°34′4.84″W), and mechanically washed. The oysters were transported to the Fish Technology Laboratory at the Federal University of Santa Catarina (UFSC), where they were manually shucked and rinsed with deionised water.

For the preparation of marination solutions, food-grade acids were diluted in a base solution consisting of deionised water and NaCl (5 % *m/V*). The tested solutions, their abbreviations, and compositions were as follows: W – sterile deionised water only (negative control); NaCl – base solution only (Diana Salt, Paranaguá, Brazil); CA – base solution with 2 % (*m*/*V*) citric acid (Allimentari,

São Paulo, Brazil); LA – base solution with 2 % (*V/V*) lactic acid (Allimentari, São Paulo, Brazil); AA – base solution with 2 % (*V/V*) acetic acid (Heinig, Brusque, Brazil). The concentrations of the marination solutions were selected according to Tribuzi *et al.* (*18*). All solutions were prepared one day prior to the production of the semi-preserves and stored under refrigeration at 4 °C until use.

Preparation of semi-preserves

Aliquots of (100±2) g of raw oyster meat were placed in plastic containers (300 mL; Altacoppo, Carapicuíba, Brazil), and the containers were organized in five treatment groups (12 containers per group). Each container was filled with 200 g of the corresponding marinade solution (ratio of 1:2 of meat:marinade, *m*/*m*) and hermetically sealed. The semi-preserves were stored at (4±1) °C in a biochemical oxygen demand (BOD) incubator- (TE371/240 L; Tecnal, Piracicaba, Brazil) for 16 days. Microbiological, physicochemical, and sensory analyses were conducted after 2, 7, 11, and 16 days of storage according to Puértolas *et al.* (*9*). At each sampling point, three containers per treatment were withdrawn from the BOD incubator and transferred to the laboratory for analysis.

Characterization of raw oyster meat

Ash content was determined by weighing the residue after incineration at (550±10) °C for 5 h, as described by Instituto Adolfo Lutz (*19*). Protein content was determined using the Kjeldahl method (*20*). Crude fat content was determined by extracting the sample with petroleum ether using a Soxhlet apparatus (*21*). Total carbohydrate content and caloric value (*E*/kJ) were calculated by difference, according to the equations (*22*) :

$$w(\text{carbohydrate})=100-(m(\text{protein})+m(\text{fat})+m(\text{ash})) \quad /1/$$

$$E(\text{KJ})=4\cdot(m(\text{protein})+m(\text{carbohydrate})+9\cdot(m(\text{fat})))\cdot 4.184) \quad /2/$$

Analytical determinations

Samples were removed from the BOD at each experimental time and kept at room temperature for 30 min, then transferred to sieves for 2 min, allowing separation of the liquid from the meat. The oyster meat and the drained liquid were weighed separately, and the mass loss (in %) was calculated according to Liu and Zhang (*23*), using the equation:

$$\text{Mass loss}=((m_t-m_i)/m_i)\cdot 100 \quad /3/$$

where m_i represents the oyster meat initial mass and m_t represents the mass at time *t* during the marinating process.

The amount of undissolved matter (salt, acid, and oyster solids) in the solutions was determined. Approximately 3 g of the liquid drained from the semi-preserved samples was weighed

and placed in an oven at 105 °C for 24 h, following the procedure proposed by Instituto Adolfo Lutz (*19*). The marination liquid was centrifuged (Kasvi, Pinhais, Brazil) for 20 min at 4000 rpm, and the turbidity of the supernatant was measured using a turbidimeter (Digimed, DM-TU, São Paulo, Brazil).

The samples were homogenized, and their pH was measured with a benchtop pH meter (Hanna-HI, 2020-02, Tamboré Barueri, Brazil) by inserting the electrode directly into each sample. Moisture content was determined by the gravimetric method (*19*), by weighing thawed samples (2 to 10 g) of oyster before and after drying in an oven (Biopar, São Paulo, Brazil) at 105 °C until reaching a constant mass.

The TVB-N analysis was performed according to the Brazilian official methods for animal-source foods (*24*), with some modifications. A mass of 5 g of oyster meat was homogenized with 45 mL of 6 % perchloric acid solution (Neon, São Paulo, Brazil) using a Turrax homogenizer (Ultra-Turrax T18, IKA, Staufen, Germany) at 12 000 rpm for 2 min and filtered through filter paper. A 25-mL aliquot of the filtrate was placed in the steam distillation apparatus (Tecnal, Piracicaba, Brazil) along with five drops of phenolphthalein (Synth, Diadema, São Paulo) and 3.25 mL of 20 % sodium hydroxide (Synth, Diadema, Brazil). The distillate was collected in an Erlenmeyer flask with 50 mL of 3 % boric acid (Neon, São Paulo, Brazil) and five drops of Tashiro indicator. Distillation was considered complete when a final volume of 100 mL was obtained (50 mL of distillate and 50 mL of solution), and then titration with 0.1 M hydrochloric acid (Neon, São Paulo, Brazil) was performed. Finally, a blank test was performed, replacing the 25-mL filtrate with 25 mL of 6 % perchloric acid solution. The results were expressed in mg TVB-N per 100 g of oyster meat.

The lipid oxidation was assessed by evaluating TBARS as described by Vyncke (*25*) and adapted by Fogaça (*26*). A mass of 10 g of the oyster sample was homogenized with 7.5 % trichloroacetic acid (TCA) (Dinâmica, Indaiatuba, Brazil) for 5 min. The homogenate was filtered through Whatman n° 1 filter paper. The supernatant (5 mL) was mixed with 5 mL of 0.02 M thiobarbituric acid (TBA) solution (Sigma Aldrich, St. Louis, EUA). The sample was heated at 95 °C for 10 min and cooled on ice or at room temperature for 10 min. The absorbance was determined at 532 nm using a UV-Vis spectrophotometer (Kasvi, Model K37-UVVIS, Brazil). 1,1,3,3-Tetraethoxypropane (TEP) (Sigma-Aldrich, Dublin, Ireland) was used as a standard. The TBARS value was expressed as mg malonaldehyde/kg (mg MDA/kg).

To determine the NaCl concentration, 0.5 g of the sample was homogenized in distilled water using an Ultra-Turrax (Ultra-Turrax T18, IKA, Staufen, Germany) at 12,000 rpm for 2 minutes. The solution was then brought up to 40 mL with distilled water and centrifuged at 4000 rpm for 10 minutes (Kasvi, K14-4000, Pinhais, Brazil). A 500 µL aliquot of the supernatant was analyzed using a chloride

analyzer (Cole Parmer, Chloride Analyzer 926, Cambridge, United Kingdom). All analytical determinations were performed in triplicate.

Evaluation of the mass transfer

The water gain (WG) and salt gain (SG) were determined in g/100 g using equations 4 and 5, respectively, which allowed calculating the mass transfer between the oysters and the tested solutions (*18*):

$$WG=((m_{w(t)}-m_{wo})/m_o)\cdot 100 \quad /4/$$

$$SG=((m_{s(t)}-m_{so})/m_o)\cdot 100 \quad /5/$$

where m_o is the initial mass of the oyster meat, $m_{w(t)}$ is the water content at time t, m_{wo} is the initial water content in oyster meat, $m_{s(t)}$ is the salt content at time t, and m_{so} is the initial salt content in oyster meat.

Microbiological analysis

Sterile bags were filled with 10 g of oyster meat and 90 mL of 0.1 % peptone water with 0.05 % sodium chloride (Merck, Pinhais, Brazil), and the samples were homogenized. The mesophilic bacteria count was performed following the ISO 4833:2015 method (*27*). Serial decimal dilutions were inoculated using the pour plate technique in sterile Petri dishes, followed by the addition of previously melted and cooled plate count agar (PCA; Merck, Pinhais, Brazil). The plates were incubated at (30±1) °C for (48±2) h, and results were expressed as CFU/g. Psychrotrophic bacteria counts were determined according to the American Public Health Association method (*28*). Serial decimal dilutions were inoculated by surface spreading on PCA agar. Plates were incubated at (7±1) °C for 10 days, and results were expressed as CFU/g.

Sensory analysis

Colour parameters

A computer vision system (*29*) was used to determine the colour parameters L^*, a^*, and b^* of the CIELAB scale in the samples, with L^* representing lightness (black to white), a^* representing red/green, and b^* representing yellow/blue. Images of the samples were captured with a camera (Canon EOS1100D, Nikon Corporation, Taiwan, Japan) and processed using the software ImageJ v.1.6.0 (*30*). A plug-in (colour space converter) converted the colour from the red, green and blue (RGB) system to the CIELAB scale, and the total colour difference (ΔE^*) was calculated according to the following equation:

$$\Delta E^* = \sqrt{(\Delta a)^2 + (\Delta b)^2 + (\Delta L)^2} \quad /6/$$

The analyses were performed in triplicate. Colour analysis was not performed on day 11 due to an insufficient amount of oyster meat, which did not meet the minimum requirements established by the analytical protocol.

Odour parameters

The sensory analysis of marinated raw oyster meat (approved by the UFSC ethics committee under Opinion n° 5.405.325 - CAAE 58147722.5.0000.0121) was organised into four stages: (*i*) recruitment, (*ii*) training, (*iii*) selection, and (*iv*) sensory analysis. E-mails were sent to students on food science and aquaculture courses to recruit volunteer evaluators. A Google Forms questionnaire was then used to analyse their eating habits, availability, and health status. Individuals were selected based on being regular consumers of oysters and denying any health problems (allergy, hypertension, diabetes, rhinitis). The methodology proposed by Meilgaard *et al*. (*31*) was used to train the volunteers. Colour and odour scales were employed, adapting the NBR ISO 8586 (*32*) approach. Evaluators were asked to arrange randomly organised samples in ascending order of colour and odour according to NBR ISO 8587 (*33*). They were also asked whether they would or would not consume the evaluated product. For the evaluator selection process, the triangular test, following the NBR ISO 4120 (*34*) standard, along with an unstructured scale, was utilised. Only evaluators who achieved a 75 % accuracy rate in the tests were selected for the study. Sensory evaluation of the oyster samples was performed by a panel of 10 evaluators. The consumer group included 50 % males and 50 % females. The age ranges were: 20–25 years (20 %), 26–35 years (40 %), 36–45 years (30 %), and 46–55 years (10 %). For the actual sensory analysis, unstructured 10 cm scales (*35*) were used. Fresh oyster meat was provided to the evaluators as a reference (methodology proposed by Silva *et al.* (*36*), with adaptations), and they were asked to assess the intensity of the odour (characteristic, acidic, spoiled, and putrid) of the treated oysters. The closer to zero the informed value, the lower the odour intensity perceived by the evaluators, while the closer to ten the value, the higher the intensity, with the extremes being "none" and "extremely strong".

Statistical analysis

The data on pH, total volatile bases, lipid oxidation, colour, and mesophilic bacteria counts, both in the tested solutions and in the meat, met the assumption of normality according to the Shapiro-Wilk test. Therefore, two-way analysis of variance (ANOVA) followed by Tukey's test (95 %) as a post-hoc analysis was used to investigate the effects of treatments and storage time on these parameters.

The data on turbidity, insoluble solids content, psychrotrophic bacteria counts, and sensory evaluation deviated from normality according to the Shapiro-Wilk test; for these, the Kruskal-Wallis test followed by pairwise comparisons (Dunn's test) was used. All statistical analyses were performed using R software v. 4.3.1 (*37*).

RESULTS AND DISCUSSION

Proximate composition of raw oyster meat prior to marination

The moisture, ash, lipid, protein, carbohydrate, and caloric values of fresh oyster meat used in this study are summarized in Table 1. Several factors, such as season environmental conditions and cultivation depth, influence the proximate compositions of *C. gigas* (*38*). In the present study, moisture content of oyster meat was (82.5±0.1) g/100 g, fitting within typical ranges for various oyster species (*39*). Protein content (9.4±0.0) g/100 g aligns with lower ranges often reported for *C. gigas* and related species, commonly between 9 and 14 g/100 g depending on environmental and reproductive parameters (*39*). Lipid content (1.7±0.1) g/100 g is lower than usually observed in *C. gigas* (2.5–4.0 g/100 g), yet within variability influenced by season and gonadal maturation (*40*). Ash (1.2±0.0) g/100 g falls slightly below expected values (2.0–3.5 g/100 g), possibly due to lower mineral accumulation or dilution by high moisture (*39*). Carbohydrates estimated by difference (5.3±0.1) g/100 g reflect typical glycogen reserves outside reproductive periods (*39*). The caloric value (308.7±3.1) kJ/100 g is consistent with expected energy content for fresh oyster meat and highlights its profile as a low-calorie, high-quality protein source (*38*).

Effect of using different weak organic acids and NaCl on mass transfer during the marination process

The choice of a marination solution containing 2 % organic acid and 5 % NaCl is supported by scientific evidence demonstrating its effectiveness in preserving the quality of fishery products (*16*). The positive effects are attributed to the synergistic action between the acid and salt, which together enhance microbiological stability and slow down spoilage processes. This combination has therefore proven to be a promising strategy for the marination of molluscs (*18,41*).

Fig. 1 shows the values of water gain (WG), salt gain (SG), and drip loss for semi-preserved oysters subjected to different treatments during storage at 4 °C. WG was significantly influenced by both treatment and storage time ($p<0.05$), with distinct patterns among the treatments (Fig. 1a). Throughout the 16-day storage period, the solution containing 5 % NaCl resulted in negative WG, indicating water loss. Oysters treated with citric acid (CA) lost water until the seventh day, after which water gain was observed. For lactic acid (LA) and acetic acid (AA) treatments, water content was slightly reduced during the first two days of storage, followed by a subsequent increase.

According to Logrén *et al.* (*16*), the simultaneous presence of salt and acid reduces the pH of minimum water retention (typically corresponding to the isoelectric point) by approximately one unit, reaching around 4.5. Consequently, the dehydrating effect in the presence of NaCl is more pronounced at pH values around 4–5, due to the reduction in positive repulsion forces ($R–NH_3^+$) caused by the strong affinity of Cl^- anions for proteins.

A significantly higher WG was observed for AA compared with CA and LA, which may be related to protein denaturation promoted by the higher pKa value of AA (logarithm of the acid dissociation constant: pKa_AA=4.74; pKa_CA=3.14; pKa_LA=3.86) (*41*). Logrén *et al*. (*16*) reported that AA tends to counterbalance the impact of high NaCl concentration, thus mitigating salt-induced water loss. In contrast, CA and LA, characterised by lower pKa values, exhibit reduced water retention capacity due to degradation of connective tissue proteins, which outweighs the swelling effect of myofibrillar proteins, as reported by Bampi *et al*. (*42*).

Both treatments and storage time significantly influenced ($p<0.05$) SG (Fig. 1b). The NaCl and acid treatments resulted in salt uptake, while the control lost salt. The initial NaCl content in raw oyster meat was (0.46±0.0) g/100 g, and an increase in SG was observed during the first two days of marination. This can be attributed to the high chemical potential gradient between the solution and the oyster meat, with SG tending to stabilise in the following days until equilibrium was reached (*18*).

Oyster meat from the control group gained weight until the seventh day, likely due to water uptake (Fig. 1c). In contrast, oyster meat from the other treatments lost weight until the second day and then tended to stabilise. This behaviour can be ascribed to osmotic equilibrium between the meat and the marinating medium (*18*). The weight loss observed in the NaCl and acid treatments may be linked to myosin denaturation, leading to a reduced capacity for liquid retention (*16*).

Influence of weak organic acids and NaCl on turbidity, insoluble solids content, pH, total volatile basic nitrogen, and lipid oxidation

The insoluble solids content (ISC) was significantly influenced by both storage time and treatment ($p<0.05$). ISC values in the covering liquid (Fig. 2a) increased in all treatments over time compared with the initial values. Despite the different compositions of each treatment, no statistical differences ($p>0.05$) were observed among treatments at day 0. Treatments W and NaCl did not differ statistically ($p>0.05$) from each other throughout the 16 days of storage. The CA treatment exhibited the highest ISC values and differed significantly ($p<0.05$) from the other treatments from day 2 onwards. Treatments LA and AA differed significantly on days 2 and 16, whereas no differences were observed on days 7 and 11.

A significant interaction between storage time and treatment was detected ($p<0.05$) for the turbidity of the solutions. As shown in Fig. 2b, turbidity generally increased over time in all treatments except the control (W). Lower turbidity values were recorded for W and NaCl treatments compared with the acid treatments. After 2 days of refrigerated storage, the NaCl treatment exhibited the lowest turbidity value, which did not differ statistically from CA, LA, and AA but differed from the W. After 7 days, the CA treatment had higher turbidity than the control (W) but did not differ from the other treatments. After 11 and 16 days of storage, the AA treatment showed the highest turbidity values, differing significantly ($p<0.05$) from all other treatments.

Statistical analysis showed that pH, total volatile basic nitrogen (TVB-N), and lipid oxidation (TBARS) parameters were significantly affected by the treatments, either directly or through interaction with storage time ($p<0.05$). The pH of raw oyster meat was (6.29±0.0), a value comparable to that reported by Min *et al*. (*8*) for *Crassostrea gigas* (6.55). After 16 days of storage, the W and NaCl treatments exhibited pH reductions of 6.4 % and 9.9 %, respectively (Fig. 3a). Despite the absence of acids in these treatments, the observed pH decrease may be attributed to the fermentation of oyster glycogen reserves. The breakdown of glycogen through glycolysis into pyruvic acid and lactic acid results in a decrease in pH (*6*). Treatments containing acids showed a marked pH reduction, particularly during the first two days of storage. By the end of the storage period, the CA treatment exhibited a 48.8 % reduction, LA showed 50.9 %, and AA showed a 40.4 % reduction in pH compared with the pH of fresh oyster meat. Throughout storage, the pH of oyster meat remained above pH 3 in all treatments.

The trend observed for the oyster meat pH in the acid treatments was consistent with that of the marination liquid (Fig. 3b), showing a marked increase during the first two days of storage, followed by more stable values thereafter. The initial pH values for the CA, LA, and AA solutions were (1.77±0.1), (1.58±0.0), and (2.40±0.1), respectively, increasing to (3.26±0.1), (3.14±0.0), and (3.78±0.0) by the end of the assay. The W treatment started with a pH of (8.12±0.2) and the NaCl treatment with (5.85±0.0), decreasing to (6.04±0.0) and (5.60±0.0), respectively, by the end of the assay.

The contact between the covering liquid and the oyster meat promotes the diffusion of acid and salt into the meat tissue until concentration equilibrium is reached (*12*). Silva *et al*. (*10*) reported an initial pH of 4.52 and a final pH of 5.17 after 35 days for cooked *Crassostrea gasar* marinated with a 2.5 % AA solution and stored at 4 °C. In a study with sardines, Dericioglu *et al*. (*43*) reported an initial pH of 6.36 and a final pH of 2.86 for samples marinated with 2.5 % AA and stored for three months at 4 °C.

According to Kim *et al.* (*44*), an excellent degree of freshness is associated with TVB-N values ranging from 5 to 15 mg/100 g; satisfactory freshness with values from 16 to 29 mg/100 g; the onset of spoilage with values from 30 to 40 mg/100 g; and values above 50 mg/100 g indicate severely deteriorated products. The TVB-N results obtained in the present study showed an increasing trend over time (Fig. 4a), although different treatments exhibited different TVB-N levels. By the end of the assay (16 days of storage), oyster meat from the W treatment was at the onset of deterioration (30.03±1.1) mg/100 g, NaCl and CA treatments maintained satisfactory freshness (24.53±2.6) mg/100 g and (18.33±1.1) mg/100 g, respectively, while LA and AA treatments still exhibited excellent freshness (14.70±0.0) mg/100 g and (14.95±1.8) mg/100 g, respectively.

Dericioglu *et al.* (*43*) evaluated TVB-N values in sardine marinades and reported that they increased over time. For a 2.5 % acid concentration, the initial TVB-N value was (6.74±0.02) mg/100 g, increasing to (8.10±0.45) mg/100 g after one month and to (15.25±0.28) mg/100 g after three months. Similarly, Silva *et al*. (*10*) reported an increase in TVB-N values for pasteurised canned oysters (*Crassostrea gasar*) during 35 days of storage, from 9.78 mg/100 g on day 0 to 11.98 mg/100 g on day 35.

Products are categorised based on TBARS values, with values below 3 mg MDA/kg indicating excellent quality and those below 5 mg MDA/kg indicating good quality (*43*). As shown in Fig. 4b, TBARS values increased over time; however, all treatments remained below 3 mg MDA/kg. A similar trend has been observed in other studies. For example, in marinated sardines (*43*), the TBARS value at day 0 was (2.13±0.04) μmol MDA/kg, increasing to (4.82±0.57) μmol MDA/kg after three months in the group treated with 2.5 % AA.

Logrén *et al*. (*16*) investigated marination with AA, CA, and LA in Baltic herring fillets and found the lowest TBARS values in fillets marinated with CA and the highest in those marinated with AA. Nevertheless, MDA values increased significantly in all acid treatments when the storage period was extended to four months, reaching approximately 4–8 mg MDA/kg. Min *et al*. (8) studied fresh *Crassostrea gigas* and reported a significant increase in TBARS from 0.24 mg/100 g at day 0 to 0.36 mg/100 g by day 8.

Effect of the use of weak organic acids and NaCl in microbiological analyses

Statistical analysis showed that bacterial levels were significantly influenced by the interaction between storage time and treatment ($p<0.05$). The mesophilic and psychrotrophic counts are presented in Table 2. Considering 5 log CFU/g of mesophiles or psychrotrophs as the rejection limit for seafood (*45*), the W treatment had a shelf life of 3 days, while the NaCl treatment had a shelf life of 11 days.

The antimicrobial action of organic acids is related to their pKa value: the higher the pKa, the stronger the effect (pKa_AA=4.74; pKa_CA=3.14; pKa_LA=3.86) (*16*). Inside the cell cytoplasm, the high pH of the medium facilitates acid dissociation, producing ions that cannot cross the cell membrane (*13*). The accumulation of these ions is toxic, inhibiting metabolic reactions, causing membrane rupture, and disrupting intracellular pH homeostasis (*13*).

The potent antimicrobial activity of organic acids in their dissociated form (*13*) was evident in the acid treatments. Semi-preserved samples treated with CA, LA, and AA showed reduced mesophilic counts and no significant changes in psychrotrophic counts over the 16 days of storage, with none of them reaching the 5-log limit. Therefore, the use of organic acids extended the shelf life of semi-preserved oysters by at least four days compared with the NaCl treatment and by at least 13 days compared with the W treatment.

Sensory evaluation of marinated raw oyster meat

Sensory evaluation is a crucial indicator for assessing freshness changes in seafood during storage (*8*). The mean values and standard deviations for characteristic, spoiled, putrid, and acidic odours are shown in Table 3. The analysis showed that all acid treatments differed significantly from the W treatment in terms of characteristic odour, with the AA treatment obtaining the lowest scores for this parameter.

The spoiled odour intensity, which is associated with lipid oxidation, tended to increase over the storage period. Among the acid treatments, only AA obtained spoiled odour scores similar to W, whereas LA and CA had higher scores. Despite these differences, it is noteworthy that the overall scores remained low, with median values on day 16 of 0.45, 0.30, and 0.00 for LA, CA, and AA, respectively.

Putrid odour scores remained low throughout the storage period, with no significant differences among treatments. Putrid odour is generally associated with high microbial counts and elevated TVB-N values; however, although W and NaCl treatments were unsuitable for human consumption after 16 days of storage, the intensity of putrid odour remained low. This may represent a potential consumer risk, as spoilage may not be readily perceived from the sensory characteristics of the product.

As expected, acid odour scores were higher in the acid treatments than in W and NaCl. However, LA and CA received overall low scores, with median values of 0.15 and 0.20, respectively, whereas AA obtained the highest scores, with a median of 5.35. Among the acid treatments, LA and CA showed overall sensory profiles more closely resembling those of fresh oysters.

Colour is one of the main quality attributes evaluated by consumers prior to purchase (*46*). The means and standard deviations of luminosity (L^*), chromatic coordinates a^* and b^*, and total colour difference (ΔE) obtained from the instrumental colour analysis are presented in Table 4. L^* values decreased significantly over storage time, whereas no significant temporal variation was detected for a^*. For b^* and ΔE, significant interactions between storage time and treatments were observed. The LA treatment showed reduced b^* values only after 16 days of storage. For ΔE, the W treatment exhibited increased values on day 7, while on day 16 the NaCl treatment showed higher values and the AA treatment showed lower values. In *C. gigas*, colour changes are associated with protein denaturation, which may explain the observed temporal variations (*47*).

When using the control (W) as the reference for treatment comparisons, it was found that for a^*, only CA and LA were significantly higher. For b^*, no significant differences were detected until day 7, whereas by day 16, LA showed significantly lower values. For L^*, only AA differed significantly from W. In general, no significant differences among treatments were observed for ΔE, except for NaCl, which differed significantly from W on day 7.

CONCLUSIONS

Marinating raw oysters in weak organic acids proved to be an effective strategy for controlling mesophilic and psychrotrophic bacterial growth, extending the shelf-life to at least 16 days under refrigerated storage at 4 °C. Among the tested acids, acetic acid showed the greatest positive effect on microbiological and physicochemical parameters, maintaining acceptable TVB-N and TBARS levels and comparatively higher pH values than the other acids. However, it also resulted in the highest acid odour scores and the lowest characteristic oyster odour scores, which may limit its sensory acceptance. Lactic and citric acids, on the other hand, produced overall similar results to each other, with sensory attributes more closely resembling those of fresh oysters, higher characteristic oyster odour scores, and lower acid odour scores, although they exhibited slightly higher spoiled odour scores, even if absolute values remained low. Therefore, while acetic acid appears to be the most effective for ensuring microbiological safety and shelf-life extension, lactic and citric acids may be preferable when prioritising sensory quality.

Future research should explore combinations of acids, particularly acetic with lactic or citric, to optimise both safety and sensory attributes. Studies should also investigate lower concentrations of acetic acid to minimise acid odour without compromising antimicrobial efficacy, assess consumer acceptance through sensory panels, and evaluate the impact of marination on volatile compound profiles and bioactive components. Additionally, testing on different oyster species and under varying storage temperatures would further validate and expand the applicability of the findings.

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DECLARATION OF COMPETING INTEREST

The authors report no potential conflicts of interest.

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ETHICS APPROVAL

The project was approved by the ethics committee of the Federal University of Santa Catarina. Opinion n°. 5.405.325 (CAAE 58147722.5.0000.0121).

AUTHOR CONTRIBUTIONS

F. Bernardi contributed to the conceptualisation and design of the work, data collection, data analysis and interpretation, conducting the analysis, writing the article, and critical revision. R.V. de Souza was involved in data analysis and critical revision. L.T.M. Shiose contributed to conducting the analysis. G. Tribuzi and F. Suplicy contributed to the conceptualization, visualization, project administration, and funding acquisition, as well as reviewing and editing the manuscript. M. Miotto was involved in the writing of the original draft, as well as reviewing and editing.

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REFERENCES

1. Deore NO. Oyster farming market report 2024 (Global Edition). 8th ed. Cognitive Market Research; 2024. p. 250. Available from: https://www.cognitivemarketresearch.com/oyster-farming-market-report.

2. Mercer M, Gennari L, Lovatelli A. Pacific oyster farming - A practical manual. FAO Fish Aquac Tech Pap, No. 696. Rome: FAO; 2024.
https://doi.org/10.4060/cc9396en

3. Dou H, Zhu W, Chen S, Zou Y, Xia X. Studies on quality deterioration and metabolomic changes in oysters induced by spoilage bacteria during chilled storage. Foods. 2025;14(2):1-15. https://doi.org/10.3390/foods14020193

4. Su L, Yang W, Liu S, Yuan C, Huang T, Jia R, *et al*. Effect of neutral protease on freshness quality of shucked pacific oysters at different storage conditions. Foods. 2024;13(8):1-15. https://doi.org/10.3390/foods13081273

5. Rusco G, Di Iorio M, Felici A, Galosi L, Iaffaldano N, Roncarati A. Strategies to improve the postharvest management of flat oyster (*Ostrea edulis*) from aquaculture using the short-term storage and package in an innovative closed-circuit system. J Food Sci. 2024;89(1):186-201. https://doi.org/10.1111/1750-3841.16866

6. Chen H, Wang M, Yang C, Wan X, Ding HH, Shi Y, *et al*. Bacterial spoilage profiles in the gills of Pacific oysters (*Crassostrea gigas*) and Eastern oysters (*C. virginica*) during refrigerated storage. Food Microbiol. 2019;82:209-17. https://doi.org/10.1016/j.fm.2019.02.008

7. Lekjing S, Venkatachalam K. Effects of modified atmospheric packaging conditions on the quality changes of pasteurized oyster (*Crassostrea belcheri*) meat during chilled storage. J Aquat Food Prod. 2018;27(10):1106-19. https://doi.org/10.1080/10498850.2018.1534917

8. Min Y, Dong S, Su M, Zhao Y, Zeng M. Physicochemical, microbiological and sensory quality changes of tissues from Pacific oyster (*Crassostrea gigas*) during chilled storage. J Food Sci Technol. 2020;57(7):2452-60. https://doi.org/10.1007/s13197-020-04280-1

9. Puértolas E, García-Muñoz S, Caro M, Alvarez-Sabatel S. Effect of different cold storage temperatures on the evolution of shucking yield and quality properties of offshore cultured japanese oyster (*Magallana gigas*) treated by high pressure processing (HPP). Foods. 2023;12(6):1-20. https://doi.org/10.3390/foods12061156

10. Silva BA, Lourenço LFH, Silva NS, Fernandes GJC, Rocha KS, Joele MRSP, *et al*. The evaluation of oyster marinating (*Crassostrea gasar*) and pasteurization process in vacuum packaging during storage. J Culin Sci Technol. 2021;21(5):759-76.

https://doi.org/10.1080/15428052.2021.2016528

11. Tsai HS, Hsiao YT, Weng YM. Effects of individual and block freezing on the quality of Pacific oyster (*Crassostrea gigas*) during storage under different pretreatment conditions. Sustainability. 2022;14(15):1-12.
https://doi.org/10.3390/su14159404

12. Wang H, Shi B, Wang W, Zhang Y, Cheng KW. Effect of marinating with green tea extract on the safety and sensory profiles of oven-baked oyster. Food Chem. 2024;448(1):1-12.
https://doi.org/10.1016/j.foodchem.2024.139090

13. Baptista RC, Horita CN, Sant'ana AS. Natural products with preservative properties for enhancing the microbiological safety and extending the shelf-life of seafood: A review. Food Res Int. 2020;127:1-23.
https://doi.org/10.1016/j.foodres.2019.108762

14. Mei J, Ma X, Xie J. Review on natural preservatives for extending fish shelf life. Foods. 2019;8(10):1-23.
https://doi.org/10.3390/foods8100490

15. Sun Q, Chen Q, Xia X, Kong B, Diao X. Effects of ultrasound-assisted freezing at different power levels in the structure and thermal stability of common carp (*Cyprinus carpio*) proteins. Ultrason Sonochem. 2019;54:311-20.
https://doi.org/10.1016/j.ultsonch.2019.01.026

16. Logrén N, Hiidenhovi J, Kakko T, Välimaa AL, Mäkinen S, Rintala N, *et al*. Effects of weak acids on the microbiological, nutritional and sensory quality of Baltic herring (*Clupea harengus membras*). Foods. 2022;11(12):1-17.
https://doi.org/10.3390/foods11121717

17. Rahman SM, Islam S, Pan J, Kong D, Xi Q, Du Q, *et al*. Marination ingredients on meat quality and safety - a review. Food Qual Saf. 2023;7:fyad027.
https://doi.org/10.1093/fqsafe/fyad027

18. Tribuzi G, Schmidt FC, Laurindo JB. Operational diagrams for salting-marination processes and quality of cooked mussels. LWT - Food Sci Technol. 2014;59(2):746-53.
https://doi.org/10.1016/j.lwt.2014.06.048

19. Instituto Adolfo Lutz (IAL). Physicochemical methods for food analysis. 4. ed. - São Paulo: Instituto Adolfo Lutz.2008:1-1000. Available from: https://scispace.com/pdf/metodos-fisico-quimicos-para-analise-de-alimentos-4a-edicao-1zvnbdbp13.pdf (in Portuguese).

20. AOAC Official methods 991.20. Determining total nitrogen. Rockville, MD, USA: AOAC International; 2016.

21. ISO 1443:1973. Meat and meat products – Determination of total fat content. First edition. Geneva, Switzerland: International Organization for Standardization (ISO); 1973.

22. Brazil. Resolution No. 360. of December 23, 2003. National Health Surveillance Agency. Establishes the Technical Regulation on Nutritional Labeling of Packaged Foods. Official Gazette of the Union**.** Brasilia. 26 December 2003. Section 1. Available from: https://bvsms.saude.gov.br/bvs/saudelegis/anvisa/2003/rdc0360_23_12_2003.html (in Portuguese).

23. Liu C, Zhang C. Mass transfer kinetics study for improving the uniform quality of lactic and marinated pork (*longissimus dorsi muscle*). IJFST. 2022;57(11):7038-46. https://doi.org/10.1111/ijfs.15980

24. Brazil. Ministry of Agriculture. Livestock and Supply. Manual of Official Methods for the Analysis of Foods of Animal Origin. Ministry of Agriculture. Livestock and supply. Secretariat of Agricultural Defense. – 2. ed. – Brasília: MAPA. 2019. pp 158. Available from: https://www.gov.br/agricultura/pt-br/assuntos/lfda/legislacao-metodos-da-rede-lfda/poa/metodos_oficiais_para_analise_de_produtos_de_origem_animal-_1a_ed-_2022_assinado.pdf (in Portuguese).

25. Vyncke W. Direct determination of the thiobarbituric acid value in trichloroacetic acid extracts of fish as a measure of oxidative rancidity. Fette Sejfen Anstrichmittel.1970; 72(12):1084-87. https://doi.org/10.1002/lipi.19700721218

26. Fogaça FHS, Legat AP, Pereira AML and Legat JFA. Methods for Fish Analysis. Embrapa meio-norte. 2009:40 (Document 189). Available from: https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/663797/1/documento189.pdf (in Portuguese).

27. ISO 4833:2015. Microbiology of the food chain — Horizontal method for the enumeration of microorganisms. Part 1: Colony count at 30 °C by the pour plate technique. Brazil, International Organization for Standardization (ISO); 2015 (in Portuguese).

28. American Public Health Association (APHA). Compendium of methods for the microbiological examination of foods. 5. ed. United States: APHA; 2015.

29. Cárdenas-Pérez S, Chanona-Pérez J, Méndez-Méndez JV, Calderón-Domínguez G, López-Santiago R, Perea-Flores MJ, *et al*. Evaluation of the ripening stages of apple (Golden Delicious) by means of computer vision system. Biosyst Eng. 2017;159:46-58. https://doi.org/10.1016/j.biosystemseng.2017.04.009.

30. ImageJ. v. 1.6.0. Bethesda (MD): National Institutes of Health; [date unknown].

31. Meilgaard M, Civille GV, Carr BT. Sensory Evaluation Techniques. 4th ed. Boca Raton (FL): CRC Press; 2007. p. 464.

32. ISO 8586:2016. Sensory analysis - General guidelines for the selection, training and monitoring of selected assessors and expert sensory assessors. Brazil, International Organization for Standardization (ISO); 2016 (in Portuguese).

33. ISO 8587:2015. Sensory analysis - Methodology - Ranking. Brazil, International Organization for Standardization (ISO); 2015 (in Portuguese).

34. ISO 4120:2013. Sensory analysis - Methodology - Triangle test. Brazil, International Organization for Standardization (ISO); 2013 (in Portuguese).

35. ISO 13299:2021. Sensory analysis — Methodology — General guidance for establishing a sensory profile. Brazil, International Organization for Standardization (ISO); 2021 (in Portuguese).

36. Silva RCSN, Minim VPR, Simiqueli AA, Moraes LES, Gomide AI, Minim LA. Optimized Descriptive Profile: A rapid methodology for sensory description. Food Qual. 2012 24(1):190-200. https://doi.org/10.1016/j.foodqual.2011.10.014

37. R Core Team. R: A language and environment for statistical computing. v. 4.3.1. Vienna, Austria: R Foundation for Statistical Computing; 2023.

38. Minhaz TM, Sarker J, Khan MNA, Khatoon H, Alim MA, Khalequzzaman SM, *et al*. Data on growth performance, proximate composition, and fatty acid content of edible oyster (Crassostrea spp.), farmed on shellstring along Cox's Bazar Coast. Data Brief. 2020;33:1-13. https://doi.org/10.1016/j.dib.2020.106450

39. Chiefa F, Tedeschi P, Cescon M, Costa V, Sarti E, Salgado-Ramos M, *et al*. Nutrients and quality aspects characterizing *ostrea edulis* cultivated in valli di Comacchio (northern Italy) across different seasons. Molecules. 2024;29(23):2-18. https://doi.org/10.3390/molecules29235546

40. Negara BFSP, Mohibbullah S, Sohn JH, Kim JS, Choi JS. Nutritional value and potential bioactivities of Pacific oyster (*Crassostrea gigas*). Int J Food Sci Technol. 2022;57(9):5732-49. https://doi.org/10.1111/ijfs.15939

41. Anagnostopoulos DA, Parlapani FF, Tsara E, Eirinaki MG, Kokioumi D, Ampatzidou E, *et al*. Effect of physicochemical characteristics and storage atmosphere on microbiological stability and shelf-life of minimally processed European sea bass (*Dicentrarchus labrax*) fillets. Foods. 2023;12(6):2-13. https://doi.org/10.3390/foods12061145

42. Bampi M, Domscheke NN, Schmidt FC, Laurindo JB. Influence of vacuum application, acid addition and partial replacement of NaCl by KCl on the mass transfer during salting of beef cuts. LWT - Food Sci Technol. 2016;74:26-33. https://doi.org/10.1016/j.lwt.2016.07.009

43. Dericioglu BN, Alak G, Atamanalp M. Determining protein denaturation of sardine (*Sardina pilchardus)* marinates before and after the maturation. Food Process Preserv. 2019;43(9):1-10. https://doi.org/10.1111/jfpp.14059

44. Kim SS, Yun D-Y, Lee G, Park S-K, Lim J-H, Choi J-H, *et al*. Prediction and visualization of total volatile basic nitrogen in yellow croaker (*Larimichthys polyactis*) using shortwave infrared hyperspectral imaging. Foods. 2024;13(20):1-12. https://doi.org/10.3390/foods13203228

45. Arruda LC, Porto YD, Vieira BS, Fogaça FHS, Castro VS, Figueiredo EES, *et al*. Use of ozone to reduce the proportion of mesophilic and psychrotrophic bacteria among aquatic organisms: A systematic review and meta-analysis. J Food Saf. 2025;45(1):1-15. https://doi.org/10.1111/jfs.70011

46. Vu SV, Knibb W, O'Connor W, Nguyen NTH, In VV, Dove M, *et al.* Genetic parameters for traits affecting consumer preferences for the Portuguese oyster, *Crassostrea angulate.* Aquaculture. 2020; 526:1-6. https://doi.org/10.1016/j.aquaculture.2020.735391

47. Luo Y, Zeng X-B, Hu Y-Y, Li D-Y, Liu X-Y, Liu Y-X, Zhou D-Y. Differences and mechanisms of color deterioration in three types of ready-to-eat shellfishes during storage. Food Chem. 2025;469: 1-11. https://doi.org/10.1016/j.foodchem.2024.142459

Table 1. Proximate composition and caloric value of raw oyster meat used in this study

Parameter	Raw oyster meat
	w/(g/100 g)
Moisture	82.5±0.1
Ash	1.2±0.0
Lipid	1.7±0.1
Protein	9.4±0.0
Carbohydrate	5.3±0.1
E/(kJ/kg)	308.7±3.1

Table 2. The mesophilic and psychrotrophic counts of processed oysters during shelf-life study

t(storage)/day	Mesophilic bacteria					Psychrotrophic bacteria				
	Treatment					Treatment				
	W	NaCl	CA	LA	AA	W	NaCl	CA	LA	AA
0	3.4 ± 3.3^{A}	3.4 ± 3.3^{A}	3.4 ± 3.3^{A}	3.4 ± 3.3^{A}	3.4 ± 3.3^{A}	2.8 ± 3.0^{A}	2.9 ± 3.0^{AB}	2.9±3.0	2.9±3.0	2.9±3.0
2	3.9 ± 2.2^{aA}	3.5 ± 2.8^{ab}	3.4 ± 3.0^{abcA}	3.1 ± 2.6^{bcA}	2.8 ± 2.2^{cA}	1.8 ± 1.8^{A}	3.0 ± 2.7^{A}	<2	<2	<2
7	5.3 ± 5.2^{aB}	4.1 ± 3.9^{b}	1.8 ± 1.8^{cdB}	2.0 ± 1.6^{cdBC}	1.1 ± 1.4^{dB}	4.5 ± 3.9^{AB}	4.6 ± 4.4^{A}	<2	<2	<2
11	6.4 ± 5.6^{aC}	3.5 ± 2.3^{b}	$<1^{cB}$	1.7 ± 1.6^{cB}	1.43 ± 0.8^{cB}	6.3 ± 6.2^{aAB}	4.5 ± 4.0^{aA}	2.8 ± 2.7^{b}	3.0 ± 2.7^{ab}	3.0 ± 2.1^{ab}
16	7.8 ± 7.3^{aD}	3.8 ± 3.6^{b}	2.0 ± 2.0^{cdB}	2.4 ± 2.2^{cC}	1.2 ± 1.5^{dB}	6.4 ± 5.7^{B}	5.3 ± 4.7^{AC}	<2	<2	<2

Superscript letters indicate homogeneous groups according to Tukey's test at 5 % significance. The lowercase letters in the same row indicate homogeneous groups of treatments for each storage time, while superscript uppercase letters in each column indicate homogeneous groups of storage time for each treatment. Rows or columns without uppercase and/or lowercase letters indicate no significant differences ($p>0.05$. Note that the analysis was conducted separately for mesophilic and psychrotrophic bacteria. W=distilled water, NaCl=5 % sodium chloride, CA=2 % citric acid+5 % NaCl, LA=2 % lactic acid 5 % NaCl, and AA=2 % acetic acid+5 % NaCl

Table 3. Sensory parameters of oysters semi-preserved using different solutions and the evolution along storage time at 4 °C for 16 days

t(storage/ day	Treatment				
	Sterile distilled water	Sodium chloride (5 % *m*/*V*	Citric acid (2 % *m*/*V* + sodium chloride (5 % *m*/*V*	Lactic acid (2 % *m*/*V* + sodium chloride (5 % *m*/*V*	Acetic acid (2 % *m*/*V* + sodium chloride (5 % *m*/*V*
Characteristic odor					
2	5.4 ± 2.0^{aA}	6.9 ± 2.1^{aA}	5.1 ± 1.9^{bA}	2.5 ± 1.5^{bA}	1.0 ± 0.8^{cA}
7	6.8 ± 1.8^{a}	6.4 ± 1.8^{a}	4.5 ± 2.0^{b}	4.6 ± 1.9^{b}	3.3 ± 1.5^{c}
11	7.2 ± 2.1^{a}	5.6 ± 2.0^{a}	2.0 ± 1.7^{b}	1.9 ± 1.8^{b}	1.5 ± 1.5^{c}
16	6.3 ± 2.1^{aB}	2.5 ± 2.3^{aB}	3.6 ± 1.1^{bB}	3.1 ± 1.5^{bB}	0.8 ± 0.6^{cB}
Spoiled					
2	0.0 ± 0.0^{bA}	0.0 ± 0.0^{abA}	0.1 ± 0.2^{aA}	0.1 ± 0.2^{aA}	0.0 ± 0.0^{bA}
7	0.0 ± 0.0^{bC}	0.0 ± 0.0^{abC}	0.3 ± 0.4^{aC}	0.1 ± 0.4^{aC}	0.0 ± 0.0^{bC}
11	0.1 ± 0.3^{bB}	0.2 ± 0.3^{abB}	0.5 ± 0.6^{aB}	1.1 ± 1.3^{aB}	0.2 ± 0.4^{bB}
16	0.2 ± 0.3^{bD}	1.3 ± 1.3^{abD}	0.5 ± 0.5^{aD}	1.0 ± 1.4^{aD}	0.3 ± 0.7^{bD}
Putrid					
2	0.0 ± 0.0^{A}	0.0 ± 0.0^{A}	0.1 ± 0.2^{A}	0.0 ± 0.1^{A}	0.0 ± 0.0^{A}
7	0.0±0.0	0.0±0.0	0.0±0.1	0.2±0.4	0.0±0.0
11	0.1±0.2	0.1±0.2	0.1±0.2	0.3±0.4	0.1±0.3
16	0.1 ± 0.1^{B}	0.2 ± 0.3^{B}	0.0 ± 0.1^{B}	0.2 ± 0.3^{B}	0.0 ± 0.1^{B}
Acid					
2	0.0 ± 0.5^{c}	0.3 ± 0.2^{c}	0.4 ± 0.4^{b}	1.0 ± 0.4^{b}	$6.6\pm1.5_{a}$
7	0.3 ± 0.5^{c}	0.1 ± 0.2^{c}	0.3 ± 0.4^{b}	0.2 ± 0.4^{b}	6.0 ± 1.5^{a}
11	0.2 ± 0.4^{c}	0.6 ± 1.0^{c}	0.2 ± 0.3^{b}	$0.6\pm0.6_{b}$	4.4 ± 1.7^{a}
16	0.1 ± 0.1^{c}	0.0 ± 0.0^{c}	1.7 ± 0.8^{b}	$0.6\pm1.0_{b}$	4.6 ± 1.4^{a}

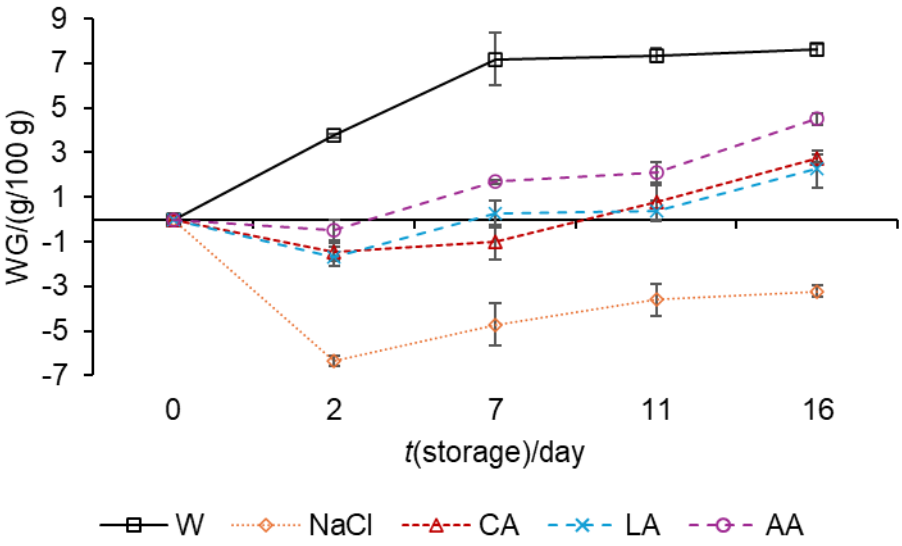
Superscript letters indicate homogeneous groups according to Dunn's test at 5 % significance. The lowercase letters in the same row indicate homogeneous groups of treatments for each storage time, while superscript uppercase letters in each column indicate homogeneous groups of storage time for each treatment. Rows or columns without uppercase and/or lowercase letters indicate no significant differences $p>0.05$

Table 4. Colour parameters *L**, *a**, *b** - means±standard deviation and total colour difference value Δ*E* in semi-preserved oysters with different treatments and stored at 4 °C for 16 days

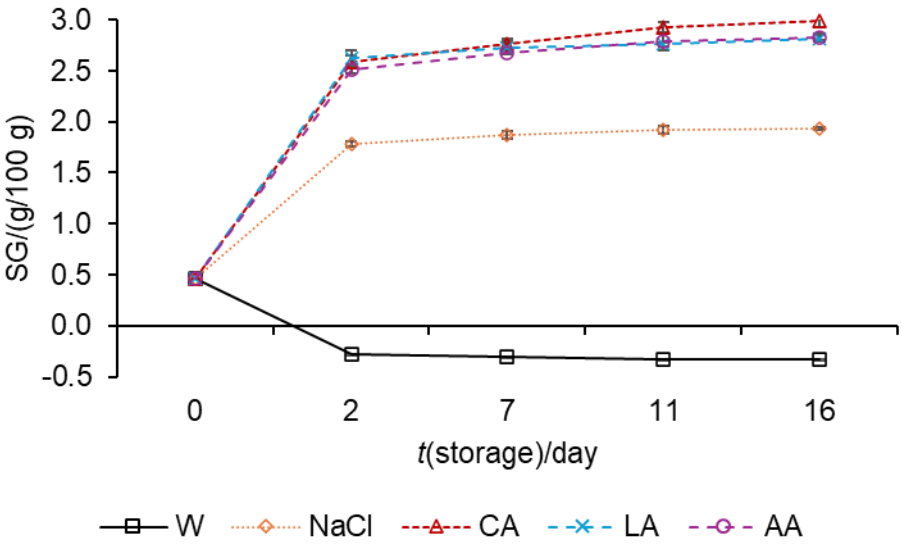
t(storage)/ day	Treatment				
	Sterile distilled water	Sodium chloride 5 % *m*/*V*	Citric acid 2 % *m*/*V* + sodium chloride 5 % *m*/*V*	Lactic acid 2 % *m*/*V* + sodium chloride 5 % *m*/*V*	Acetic acid 2 % *m*/*V* + sodium chloride 5 % *m*/*V*
			*a**		
0	4.79	4.79	4.79	4.79	4.79
2	3.3±0.6^{a}	4.3±0.8^{a}	6.3±2.0^{b}	6.1±1.8^{b}	4.1±0.5^{a}
7	3.9±1.2^{a}	3.8±0.7^{a}	6.3±0.3^{b}	6.7±1.2^{b}	4.6±1.4^{a}
16	1.7±0.5^{a}	3.3±0.1^{a}	6.4±1.2^{b}	6.3±1.8^{b}	4.3±1.1^{a}
			*b**		
0	-14.99	-14.99	-14.99	-14.99^{A}	-14.99
2	-14.5±1.8	-16.5±1.0	-13.6±2.1	-17.6±1.4^{A}	-14.7±1.2
7	-12.2±1.7	-15.3±0.7	-12.4±0.7	-15.0±2.4^{A}	-14.7±1.0
16	-13.7±1.5^{b}	-9.5±0.3^{b}	-12.3±1.8^{ab}	-10.6±0.5^{aB}	-15.4±0.7^{b}
			*L**		
0	65.19^{C}	65.19^{C}	65.19^{C}	65.19^{C}	65.19^{C}
2	68.6±4.7^{abA}	64.9±2.0^{aA}	71.2±1.6^{abA}	68.0±0.4^{abA}	72.3±2.5^{bA}
7	76.1±1.7^{abB}	66.5±4.1^{aB}	72.9±1.7^{abB}	70.5±5.3^{abB}	77.1±5.3^{bB}
16	61.8±1.5^{abC}	65.±4.8^{aC}	67.4±5.5^{abC}	64.3±0.6^{abC}	65.8±3.2^{bC}
			Δ*E*		
0	-	-	-	-	-
2	5.2±2.6^{abB}	2.5±0.8^{bB}	6.8±1.6^{a}	4.3±1.0^{ab}	7.3±2.6^{aA}
7	11.4±1.5^{aA}	3.4±2.0^{bAB}	8.4±1.3^{ab}	7.4±3.5^{ab}	12.0±5.3^{aA}
16	5.1±0.7^{B}	6.9±0.8^{A}	6.1±0.7	5.0±0.4	2.9±0.6^{B}

Superscript letters indicate homogeneous groups according to Tukey's test at 5 % significance. The lowercase letters in the same row indicate homogeneous groups of treatments for each storage time, while superscript uppercase letters in each column indicate homogeneous groups of storage time for each treatment. Rows or columns without uppercase and/or lowercase letters indicate no significant differences $p>0.05$. Note that the analysis was conducted separately for each colour parameter

a)


9
7
5
3
1
-1
-3
-5
-7
WG/(g/100 g)
0
2
7
11
16
t(storage)/day
W
NaCl
CA
LA
AA

b)


3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
SG/(g/100 g)
0
2
7
11
16
t(storage)/day
W
NaCl
CA
LA
AA

c)

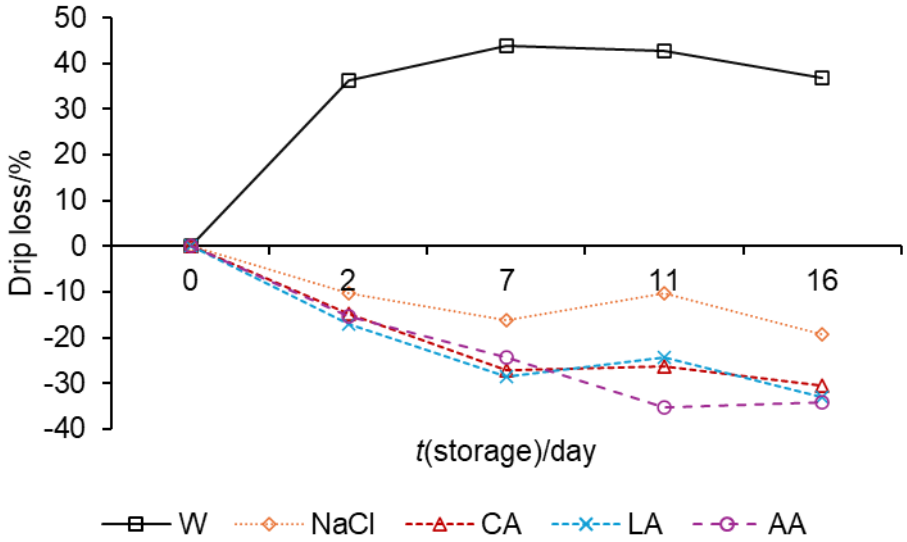
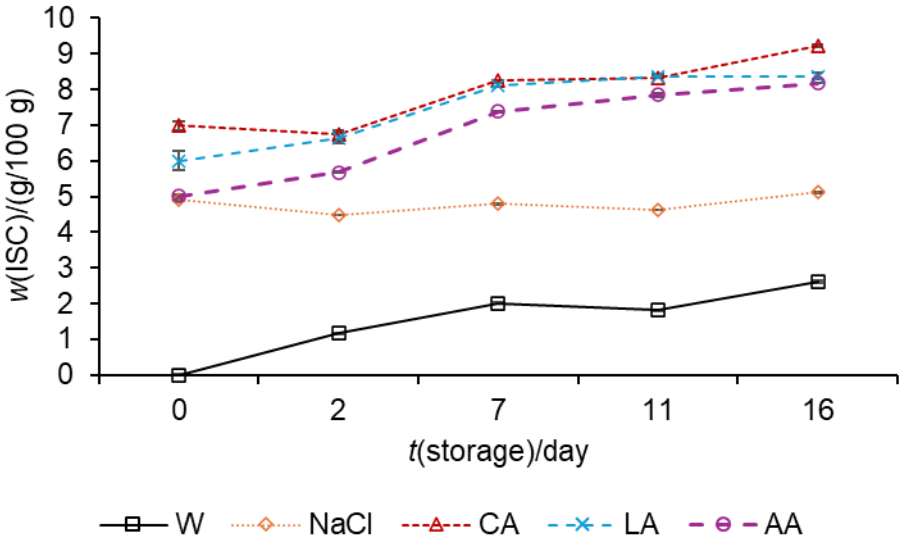


Fig. 1. Values of: a) water gain (WG), b) salt gain (SG), and c) drip loss of the semi-preserved oyster meat during storage at 4 °C for 16 days. W=distilled water, NaCl=5 % sodium chloride, CA=2 % citric acid+5 % NaCl, LA=2 % lactic acid 5 % NaCl, and AA=2 % acetic acid+5 % NaCl

a)



b)

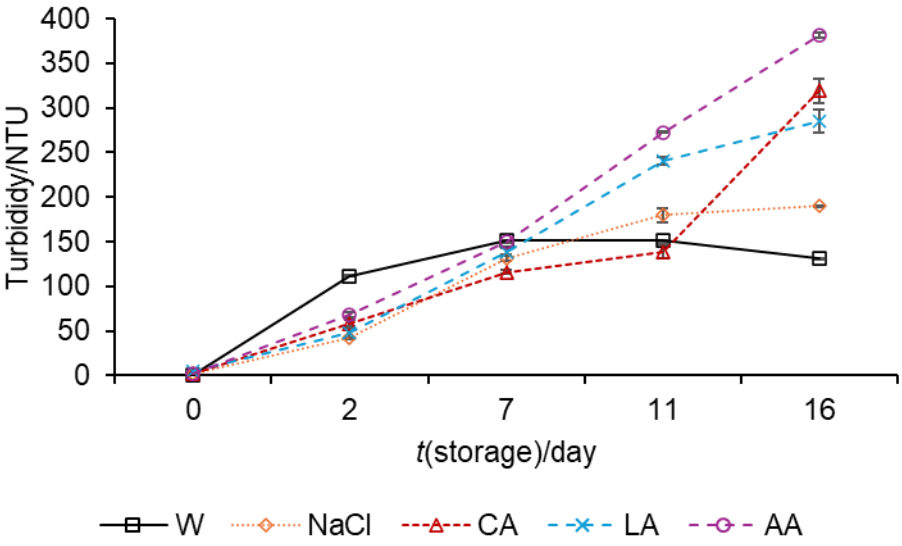
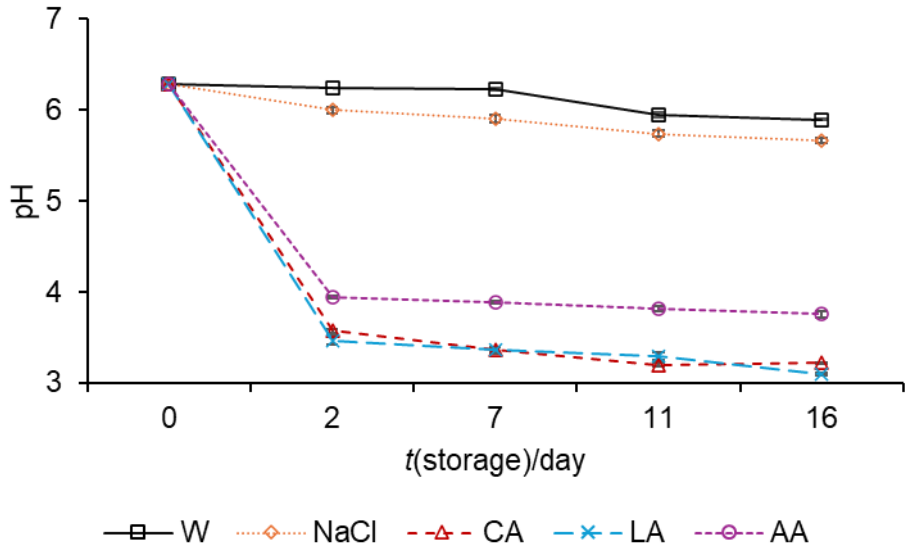


Fig. 2. Values of: a) insoluble solid content (ISC), and b) turbidity of the solution drained from the semi-preserved oysters during storage at 4 °C for 16 days. W=distilled water, NaCl=5 % sodium chloride, CA=2 % citric acid+5 % NaCl, LA=2 % lactic acid 5 % NaCl, and AA=2 % acetic acid+5 % NaCl

a)



b)

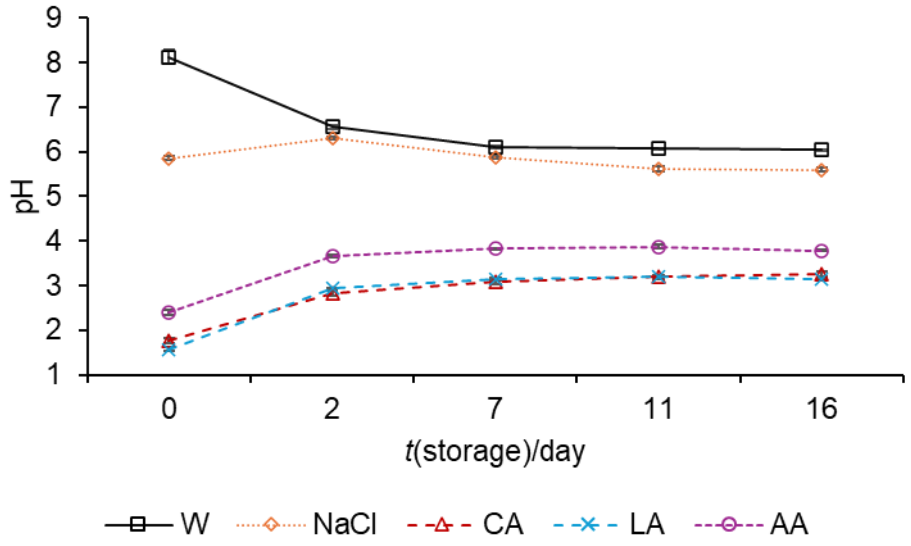
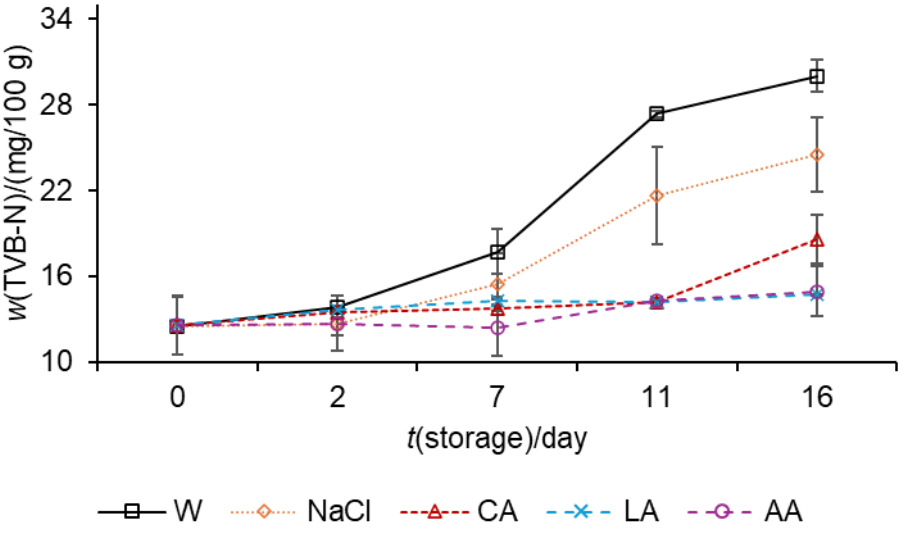


Fig. 3. Values of: a) pH of oyster meat, and b) pH of the covering liquid of the semi-preserved oysters during storage at 4 °C for 16 days. W=distilled water, NaCl=5 % sodium chloride, CA=2 % citric acid+5 % NaCl, LA=2 % lactic acid 5 % NaCl, and AA=2 % acetic acid+5 % NaCl

a)



b)

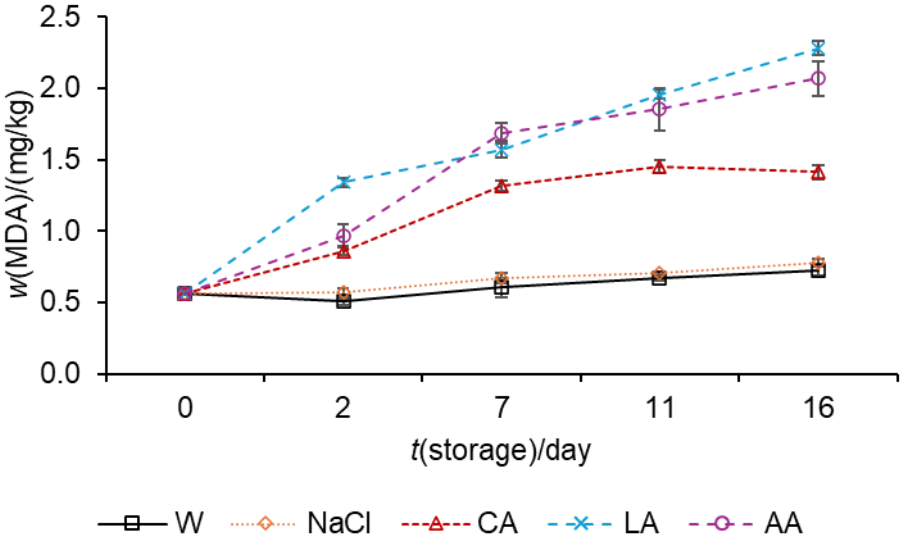


Fig. 4. Values of: a) total volatile basic nitrogen (TVB-N), and b) lipid oxidation (TBARS as *w*(MDA)) of the semi-preserved oyster meat during storage at 4 °C for 16 days. W=distilled water, NaCl=5 % sodium chloride, CA=2 % citric acid+5 % NaCl, LA=2 % lactic acid 5 % NaCl, and AA=2 % acetic acid+5 % NaCl