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Modeling the effect of pre-treatment with nisin enriched osmotic solution on the shelf life of chilled vacuum packed tuna

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ABSTRACT

The objective of this study was the kinetic modeling of the effect of storage temperature on the quality and shelf life of chilled tuna, vacuum packed and osmotically pre-treated with the addition of nisin as antimicrobial agent. Tuna fillets were treated at 15 °C in osmotic solution with 50% high dextrose equivalent maltodextrin (DE 47) plus 5% NaCl, for 0–360 min. Untreated and 30 min osmotically pre-treated fish slices with and without nisin ($2 \cdot 10^4$ IU/100 g osmotic solution), vacuum packed and stored at controlled isothermal conditions (0–15 °C) were studied. Quality assessment and modeling was based on microbial growth, total volatile basic nitrogen (TVB-N), trimethylamine nitrogen (TMA-N), lipid oxidation (TBARS) and sensory scoring.

The water activity decreased to 0.96 at 30 min of pre-treatment. Osmotic pre-treatment led to significant shelf life extension of fish, in terms of microbial growth and sensory quality. The addition of nisin in the osmotic solution further increased the shelf life of tuna. Based on LAB growth, the shelf life was 10 days for untreated and 27 days for osmotically treated vacuum packed fish at 5 °C. The addition of nisin increased shelf life to 51 days at 5 °C.

1. Introduction

Chilled fresh and minimally processed fish are very perishable food products and their quality deterioration during storage is attributed mainly to microbial growth (Gram and Huss, 1996). During the last decades, considerable research focuses on the control of microbial growth and physicochemical reactions to improve fish quality and extend its shelf life. Yellowfin tuna (*Thunnus albacares*) are large pelagic fish, commercially important in the international market. Research on fresh tuna meat has focused on the risk of poisoning due to histamine formation by several mesophilic as well as psychrotolerant bacteria including *Morganella* spp. and *Photobacterium* spp. (Economou et al., 2007; Emborg et al., 2005). Tuna stored at high or fluctuating temperatures poses a histamine fish poisoning (HFP) risk while potential for histamine formation was observed in vacuum packed tuna slices stored as low as 2 °C (Emborg et al., 2005). However, there is a lack of kinetic data on the growth of bacteria contributing to spoilage and shelf life limitation of fresh tuna and the potential of minimal processing methods to extend shelf life of tuna fillets (Economou et al., 2007; Tsironi et al., 2008). Al-Bandak et al. (2009) investigated the efficacy of *Majorana syriaca* extract to control the lipid oxidation and microbial spoilage of minced chilled Yellowfin tuna flesh.

The decrease in water activity as a result of an osmotic pre-treament, has received significant attention by researchers in order to improve food stability as well as nutritional and sensorial properties of foods (Cath et al., 2006; Collignan et al., 2001; Rastogi et al., 2002; Torreggiani, 1993). During the osmotic dehydration, water flows from the product into the osmotic solution, while osmotic solutes are transferred from the solution into the product (Raoult-Wack, 1994). Water activity reduction caused by osmotic pre-treatment can inhibit microbial growth in the food matrix (Rastogi et al., 2002). Studies for osmotic pre-treatment of fish products investigate the influence of different solutes (sucrose, corn starch syrup, salt) on mass transfer phenomena (Collignan and Raoult-Wack, 1994; Corzo and Bracho, 2005, 2007; Corzo et al., 2006; Gallart-Jornet et al., 2007; Medina-Vivanco et al., 2002; Mujaffar and Sankat, 2006; Tsironi et al., 2009). Tsironi and Taoukis (2014) developed a mathematical model that predicts the growth of *Pseudomonas* spp. in gilthead seabream slices, as a function of processing conditions (osmotic solution concentration,

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temperature and time).

Nisin is a low-molecular-weight polypeptide produced by the bacterial dairy starter culture *Lactococcus lactis*. It is a broad spectrum bacteriocin, being active against a wide range of Gram-positive bacteria (Thomas and Delves-Broughton, 2005). Nisin has been approved for use as an antimicrobial in food by the FAO/WHO Committee on Food Additives and in 1988 obtained a generally recognized as safe (GRAS) status in the United States (FDA, 1988). Nisin has been reported as an effective antilisterial agent for modified atmosphere packed smoked salmon (Nilsson et al., 1997; Szabo and Cahill, 1999). According to Nykanen et al. (2000), nisin and sodium lactate synergistically inhibited listeria when injected into rainbow trout before cold smoking. The antimicrobial pre-treatment did not adversely affect the sensory quality of fish that remained acceptable to the sensory panel for 1 week more than untreated samples. Tsironi and Taoukis (2010) investigated the effect of modified atmosphere packaging and osmotic pre-treatment with the addition of nisin on the shelf life of gilthead seabream. The combined effect of chitosan, nisin and sodium lactate in modified atmosphere packed chilled hake burgers was evaluated by Schelegueda et al. (2016). According to Kakatkar et al. (2017), the combination of nisin and irradiation can extend the shelf life of chilled seer fish sticks from 34 to 42 days.

The objective of this study was to evaluate and model the combined effect of osmotic pre-treatment and added nisin on the shelf life of vacuum packed, tuna (*Thunnus albacares*) during refrigerated storage.

2. Materials and methods

2.1. Raw material

Yellowfin tuna (*Thunnus albacares*) slices (weight: 100 ± 10 g) were ice packed and air shipped to the laboratory directly after slicing at the fish processing location (CEFRICO, Vigo, Spain). Upon receipt, slices were cut into cubic slices ($2 \times 2 \times 2cm^3$, 10±1 g) in a laminar flow hood. Osmotic solution was prepared by dissolving high dextrose equivalent maltodextrin (HDM) (GLUCIDEX® 47 Roquette, France) and distilled water at a concentration of 50%, with or without nisin (Nisin from *Lactococcus lactis*, Sigma-Aldrich, USA; 1000 IU/g fish in the osmotic solution). The osmotic treatment conditions were chosen based on previous studies on fish fillets (Tsironi et al., 2009; Tsironi and Taoukis, 2010, 2014).

2.2. Osmotic pre-treatment

Sliced samples were osmotically treated in 50% solution of HDM plus 5% NaCl with or without nisin at 15 °C for 0, 20, 40, 60, 90, 120, 180, 240, 300 and 360 min. The solution to sample ratio was 5:1 (w/w) to avoid significant dilution of the medium by water removal (Medina-Vivanco et al., 2002). Nine beakers filled with pre-weighed osmotic solutions were kept at 15 °C in a high-precision (±0.2 °C) low-temperature incubator (Sanyo MIR 153, Sanyo Electric, Ora-Gun, Gunma, Japan), as described by Tsironi and Taoukis (2010). Three replicate samples were removed and measured each time and the average values were taken.

Water loss, solid gain, salt content and water activity were investigated during pre-treatment. Triplicate samples were taken each time. Moisture content was determined by drying at 110 °C (WTB BINDER 7200, Type E53, Tuttlingen, Germany) for 24 h. Salt content of fish was determined titrimetrically using silver nitrate solution by the Mohr method (AOAC, 1990). Water activity was determined using an a_w-meter (Rotronic AG, AM3+Aw VD, Bassersdorf, Switzerland). Water loss (WL) and solid gain (SG) were calculated according to Tsironi et al. (2009).

2.3. Shelf life kinetic study

The optimal OD conditions were selected based on the mass transfer kinetics and the shelf life of the shelf life extension of chilled tuna slices by OD treatment was evaluated. Untreated (Control) and osmotically pre-treated fish slices without (coded as OD) and with nisin (coded as ODn) were vacuum packed (Boss NT42N, Bad Homburg, Germany). Two replicated storage experiments were carried out. All packages were stored at controlled isothermal conditions of 0, 5, 10 and 15 °C in high-precision (±0.2 °C) low-temperature incubators (Sanyo MIR 153, Sanyo Electric, Ora-Gun, Gunma, Japan). Temperature in the incubators was constantly monitored with electronic, programmable miniature dataloggers (COX TRACER®, Belmont, NC). Samples were taken in appropriate time intervals to allow for efficient kinetic analysis of quality deterioration.

2.3.1. Microbiological analysis

For microbiological enumeration, a 10 g of sample were transferred to a sterile stomacher bag with 90 mL sterilized Ringer solution (Merck, Darmstadt, Germany) and was homogenized for 60 s with a Stomacher (BagMixer® interscience, France). Total aerobic viable count was enumerated on Plate Count Agar (PCA, Merck, Darmstadt, Germany) after incubation at 25 °C for 72 h. *Pseudomonas* spp. were enumerated on Cetrimide Agar (CFC, Merck, Darmstadt, Germany) after incubation at 25 °C for 48 h. For *Lactobacilli* enumeration the pour-plate method was used on De Man-Rogosa-Sharpe Agar (MRS, Merck, Darmstadt, Germany) followed by incubation at 25 °C for 96 h.

Two replicates of at least three appropriate dilutions were enumerated. The microbial growth was modeled using the Baranyi Growth Model (Baranyi and Roberts, 1995). For curve fitting the program DMFit was used (available at http://www.combase.cc/index.php/en/). Kinetic parameters such as the rate (k) of the microbial growth were estimated.

2.3.2. Measurements of chemical indices

2-Thiobarbituric acid reactive substances (TBARS) assay, to evaluate lipid oxidation, was performed according to the method of Loovas (1992). The absorbance was measured at 532 nm with a digital spectrophotometer (Unicam Helios, Spectronic Unicam EMEA, Cambridge, United Kingdom). The concentration of TBARS was calculated from a standard curve prepared by 1,1,3,3-tetraethoxypropane and expressed as mg malonaldehyde/kg muscle.

Total volatile basic nitrogen (TVB-N) and trimethylamine nitrogen (TMA-N) analyses were conducted on a single TCA extraction by distillation in a Kjeldhal rapid distillation unit (Büchi 321 Distillation unit, Flawwil, Switzerland) and titration with sulphuric acid (Pivarnik et al., 2001).

2.3.3. Sensory analysis

The sensory attributes of raw and cooked fish were evaluated by a trained sensory panel of 8. Tuna slices were cooked individually wrapped in aluminum foil, at 180 °C for 20 min, in preheated oven, as described by Tsironi and Taoukis (2010). Rating was assigned separately for each parameter (color and odor of raw fish and appearance, odor, texture and taste of cooked samples) on a 1 to 9 scale (9 being the highest quality score and 1 the lowest). A sensory score of 5 was taken as the average score for minimum acceptability (Tsironi and Taoukis, 2010).

2.4. Data analysis

Values of the different measured indices were plotted vs time for all temperatures studied and the apparent order of quality loss