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The influence of lipid composition, storage temperature, and modified atmospheric gas combinations on the solubility of CO_2 in a seafood model product

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ABSTRACT

The demand for tasty, convenient, fresh seafood products is continually increasing. This stresses the need for processing methods that can prolong the otherwise short shelf life of seafood. A well-studied method is the use of modified atmosphere packing. However, research into the use of modified atmosphere packaging for seafood with varying lipid composition is limited. Thus, in this experiment the effect of lipid profile, storage temperature, and the gas composition of the modified atmosphere on the solubility of CO_2 in a seafood model product was investigated. The temperature dependent Henry's constants for the various compositions showed that the physical state of the lipids clearly influenced the solubility of CO_2 in the model products, with liquid fat leading to a similar solubility of CO_2 as water, while CO_2 only being minimally dissolved in solid fats.

1. Introduction

Recent socio-economic development has led to an increase in time pressure brought about by work and pastime activities as well as increasing amounts of single person and/or small households (Speranza et al., 2009). Extensive campaigning has increased consumers awareness of the benefits of fish and seafood, however many feel a lack of abilities and experience with preparing seafood. This has tremendously increased the demand for convenient, tasty meal products based on fresh fish (Hansen et al., 2015; Mendes and Gonçalves, 2008). Fresh seafood has a limited shelf life as a result of multiple factors often specific to these particular foods, including high post mortem pH, presence of large amounts of unsaturated fatty acids (affected by fish species), and presence of autolytic enzymes (Gram and Huss, 1996; Sivertsvik et al., 2002). The nature of seafood stresses the need for improved preservation methods that allow extension of shelf life. Multiple technologies are being used for this purpose, and modified atmosphere packaging (MAP) in combination with refrigeration has become one well-established method (Lambert et al., 1991). Several studies have found MAP to extend shelf life for several days compared to air storage depending on species and temperature (Powell and Tamplin, 2012; Sivertsvik et al., 2003; Speranza et al., 2009; Torrieri et al., 2006; Tsironi and Taukis, 2010; Özogul et al., 2004). The spoilage of fish begins as soon as the fish dies and is ascribed to a series of reactions where degradation is caused by bacteria (Speranza et al., 2009).

MAP often uses a mixture of oxygen (O_2), nitrogen (N_2), and carbon dioxide (CO_2), and the prolongation of shelf life is often ascribed to the bacteriostatic effect of CO_2 (Genigeorgis, 1985). A certain amount of CO_2 has to be dissolved into the food in order to inhibit bacterial growth (Gill and Penney, 1988), and it has been found that the inhibition obtained is proportional to the concentration of dissolved CO_2 (Devlieghere et al., 1998a,b). CO_2 is generally highly soluble in both muscle and fatty tissues and even more so in pure water (Gill, 1988). Several factors will however influence the uptake; including pH, lipid content, lipid type (Gill, 1988; Jakobsen and Bertelsen, 2004), salt content (Rumpf et al., 1994), amount of initial CO_2 in the gas mixture (Devlieghere et al., 1998a), and water content (Sivertsvik et al., 2004). Several studies have found that solubility of CO_2 in muscle food could be estimated based on the water content alone, for instance in raw fish (Sivertsvik et al., 2004), chicken (Rotabakk et al., 2010), and meat (Gill, 1988). However disagreements exists as Fava and Piergiovanni

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(1992) concluded the solubility of CO_2 in fresh meat and meat products estimated based on water content alone was misleading. Probably the most important factor influencing the solubility of CO_2, is temperature. This effect has been extensively studied, amongst other by Gill (1988), Mendes et al. (2011), and Rotabakk (2013). Previous results generally agree that increasing temperatures will decrease the solubility of CO_2 in muscle tissues, just as it is known from water (Caroll et al., 1991). The relationship between temperature and solubility of CO_2 in fatty samples is not as simple. Rotabakk (2013) found the solubility of CO_2 in liquid salmon oil to be similar to that in water. However, when Gill (1988) examined the solubility of CO_2 in fat from lamb, beef, and pork, he found the solubility to increase with increasing temperatures, to a certain point, unlike that seen in water or muscle tissue. The point at which increasing temperatures led to a decrease in solubility of CO_2 was different for the different fat sources. These results shows that the effect of temperature on the solubility of CO_2 in fatty tissue is more complex than other samples and the mechanism is not well understood (Gill, 1988; Jakobsen and Bertelsen, 2006). Besides shelf life, solubility of CO_2 also influences the risk of packages collapsing (Rotabakk and Sivertsvik, 2012). Thus, understanding and manipulating the solubility of CO_2 in various products is important from both a packaging and shelf life point of view. This underlines the fact that different foods, with different compositions have to be treated differently. Thus, in order to optimize the industrial use of MAP it is essential to obtain knowledge regarding the specific product and processing of interest in relation to the solubility of CO_2.

Even though solubility of CO_2 in various products is well studied, comparison between studies are often difficult. Furthermore, investigation of the solubility of CO_2 in seafood products with varying lipid composition is limited. The aim of this study is thus to expand the knowledge of the solubility of CO_2 in seafood by studying the effect of lipid phase composition of a fish mince model product, temperature, and initial gas mix.

2. Materials and methods

A three-factor storage experiment was conducted, the factors being lipid composition (mix of stearic acid, oleic acid and an eicosapentaenoic acid (EPA)/docosahexaenoic acid (DHA) mix), storage temperature (0°, 8°, and 20 °C), and packaging gas CO_2 concentration (35, 50, and 70%, balanced with N_2).

2.1. Production of fish model product

Frozen mince of silver smelt (*Argentina silus*) were purchased from Norwegian Seafood Company. The fish mince had a water content of 69.8 ± 0.5% and lipid content of 1.2 ± 0.1%. The lipid phase was primarily made up of saturated- and monounsaturated fatty acids (6% C14:0, 37% C16:0, 6% C18:0, 20% C18:1, 12% C20:1, 15% C22:1). The fish mince was thawed at 4 °C for 24 h prior to being mixed in a bowl chopper (Blixer 6, Robot Coupe, France) at 20 000 rpm. Salt (0.5%) was added prior to the addition of 6.5% of potato starch, 20% of skimmed milk (0.1% lipid), and 18% of the lipid mixtures. The composition of the model product was calculated in order to keep the total amount of added liquid and lipids constant. The lipids were stearic acid as free fatty acid (Stearic Acid ≥95%, Sigma-Aldrich, St. Louis, Missouri, USA), oleic acid as free fatty acid (Oleic Acid 90%, Sigma-Aldrich, St. Louis, Missouri, USA) and an EPA/DHA oil mix as triglycerides (EPAX 4535 TG/N, Epax Norway, Ålesund, Norway). Stearic- and oleic acid had high purity (97% C18:0 and 93% C18:1 combined with 6% C18:2, respectively) whereas the marine oil had a more diverse fatty acid profile with two major constituents and multiple minors (51% C20:5, 37% C22:6, 1–5% C18:4, C20:4, C22:1, C22:5). The lipids were mixed according to Fig. 1, and will hereafter be denoted as “recipe 1”, “recipe 2”, etc. The lipids were chosen based on melting points, in order to investigate the influence of the different phases of lipids on the solubility of CO_2.

A total mixing time of 150s was applied. A control sample, recipe 8, was produced with extra milk, but without the addition of lipids. Each recipe of mince was produced in two batches and mixed by hand for 30s. The mince was stuffed in plastic casing (Ø = 60 mm, L = 30–40 cm), closed with metal clips and heat-treated at 100 °C for 1 h. After the heat treatment, the mince product was cooled in the fridge at +4 ± 1 °C for 2–4 h, prior to being frozen at −23 ± 1 °C until packaging.

2.2. Packaging

The mince product was thawed for 48 h at 4 °C prior to being sliced in portions. The samples were packaged (101.3 g ± 4.1 g) in 300 ml semi rigid crystalline polyethylene terephthalate (CPET) trays (C2125-1B, Færch Plast, Holstebro, Denmark) using an automatic packaging machine (TL250, Webomatic, Bochum, Germany). This gave a degree of filling of approximately $^1/_3$. The atmosphere was evacuated (final vacuum pressure of 18 mbar) and subsequently flushed with the gas mixture prior to adhering the top film of a 40 μm combination of polyethylene (PE), ethylene vinyl alcohol (EVOH), polyamide (PA), and polyethylene terephthalate (Topaz B-440 AF, Plastopil, Almere, The Netherlands). Food grade CO_2 and N_2 was mixed using a gas mixer (MAP Mix 9000, Dansensor, Ringsted, Denmark) to obtain pre-set packaging gas mixtures of 35% CO_2, 50% CO_2, or 70% CO_2 all balanced with N_2. Hereafter referred to as 35/65, 50/50, and 70/30. Oxygen transmission rate (OTR) was 66–78 $cm^3 \times 25\ \mu m/m^2$ x 24 h^1 x bar^1 at 23 °C for the tray and 2.5 $cm^3 \times 40\ \mu m/m^2 \times 24\ h^1 \times atm^1$ at 23 °C for the cover film.

After packaging, the trays were stored at 0 °C (0.6 ± 0.7 °C), 8 °C (7.8 ± 0.5 °C), or 20 °C (20.0 ± 0.3 °C) respectively, for 7 days.

2.3. Water content, lipid content, and fatty acid composition

The water content of all the groups was determined gravimetrically by drying the samples for 24 h at 105 °C (ISO.6496, 1983).

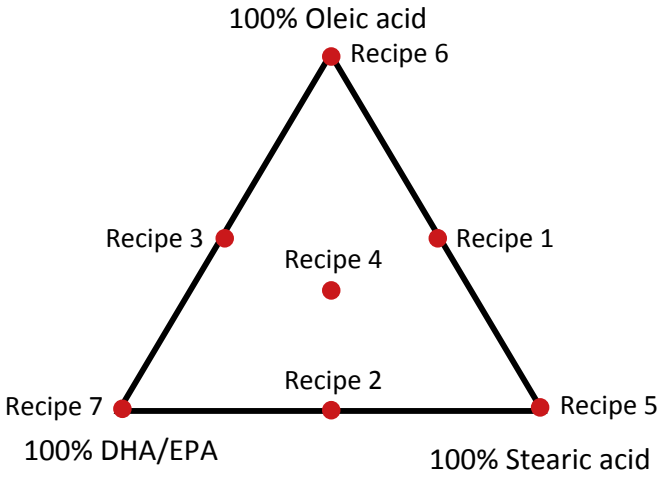

Fig. 1. Composition of lipid mixtures added to the fish model product recipe 1 through 7. All mixtures were added to a total of 18% added lipid in the final product. A control, recipe 8, without addition of external lipids was included in the experiment. Recipe 1: 50/50 oleic/stearic acid, recipe 2: 50/50 Stearic/DHA and EPA mix, recipe 3: 50/50 Oleic/DHA and EPA mix, recipe 4: 33/33/33 Oleic/Stearic/DHA and EPA mix, recipe 5: 100% stearic acid, recipe 6: 100% oleic acid, recipe 7: 100% DHA and EPA mix, and recipe 8: control.