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# EFFECT OF PACKAGING METHODS ON THE STORAGE STABILITY OF DRIED CAPELIN IN TEMPERATURE AND HUMIDITY CONDITIONS OF UGANDA

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## ABSTRACT

Commercially dried capelin (*Mallotus villosus*) was packaged using conventional air packaging (AP), vacuum packaging (VP), modified atmosphere packaging (MAP, 99.9% $N_2$) and hessian bags (HB) before storage in simulated temperature and humidity conditions of Uganda (Relative Humidity ≈ 54% and 83%; Temperature ≈ 30 °C and 17 °C respectively) for 8 weeks. Physicochemical, lipid and microbiological stability of the dried capelin was assessed during this period and varied with packaging method. Water content and water activity increased significantly for HB packed capelin (12.7 – 17.6% and 0.62 - 0.74 respectively). pH and colour were generally stable for all methods within a narrow range. Lipid content decreased significantly towards the end of storage in HB packed dried capelin. Primary lipid oxidation as measured by peroxide value (PV) was lowest in vacuum packed dried capelin (31.46 – 53.49 µmol/kg) over the 8 weeks. Secondary lipid oxidation indicated by thiobarbituric reactive substances (TBARS) content decreased significantly with storage time in modified atmosphere packed dried capelin (250.33 – 152.85 µmol MDA/kg). Free fatty acid (FFA) content of dried capelin increased throughout storage irrespective of packaging method. Total microbial count (TC) decreased significantly in vacuum packed dried capelin (4.81 – 3.55 Log cfu/g) while mould counts increased significantly in HB packed dried capelin (1 – 2.97 Log cfu/g). Yeasts initially proliferated in the air packed dried capelin however, the counts were generally low over the 8 weeks. Preliminary high coefficients of determination for independent validation ($R^2_{cv}$) values (0.92 - 0.96) indicate that near infrared spectroscopy (NIR) can potentially be used to estimate changes in water content, water activity and pH of dried capelin with a good degree of accuracy. Overall, the present study showed that storage stability of dried capelin was dependent on packaging method. Nevertheless, the good quality of dried capelin raw material ensured that most quality indicators remained within acceptable specification limits for human consumption by the end of the storage period.

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## 1. INTRODUCTION

Small pelagic fishes are utilised largely for production of fish meal, oil and animal feeds. However, they have grown in importance for the food and nutrition security of people in developing countries especially in Africa and Asia (Tacon and Metian, 2009). They are an affordable source of protein, omega-3 fatty acids and micronutrients (Andrew, 2001; Tacon and Metian, 2013). More than half of the population in Sub-Saharan Africa obtains at least 25% of its protein requirements from small pelagic fishes (Tacon and Metian, 2009). In Uganda, the importance of small pelagic fishes cannot be understated. According to the Ministry of Agriculture Animal Industry and Fisheries in Uganda (MAAIF, 2011), small pelagic fishes contributed 210,000 metric tons of the 460,000 metric tons total fish production in Uganda. However, based on extrapolated average retail prices, this was equivalent to approximately 20% of the estimated total production value of 1.2 billion USD. The main species based on catch and market value are *Rastrineobola argentea* (Mukene), *Brycinus nurse* (Ragogi) and *Neobola bredoi* (Muziri). The small pelagic fishes are vital for the domestic as well as regional markets mainly due to a decline in large pelagic fish catches.

Post-harvest losses of small pelagic fishes (40 - 90%) continue to persist due to poor processing and limited handling capacity of large quantities landed as well as poor packaging and storage practices (Masette, 2012). Small pelagic fishes are traditionally preserved by open sun-drying which is subject to prevailing weather conditions (Masette, 2011). Dried foods have a long shelf life and are generally regarded among the safest for human consumption (Calicioglu *et al.*, 2002; Dewi *et al.*, 2011). However, final product moisture content varies considerably with the traditional method of drying (Ofulla *et al.*, 2011). This makes the products susceptible to mould growth and mycotoxin contamination (Kilic, 2009). Many of these are air borne moulds that infest dried fish which is often left unpackaged after processing in developing countries (Park, 2014; Odoli, 2015).

Small pelagic fishes in Uganda have high fat content in the range of 9 - 14% (Masette, 2014). Fish oils contain high content of long-chain unsaturated fatty acids. This predisposes them to oxidative and hydrolytic degradation (Bragadóttir *et al.*, 2002). More so, packaging of dried fish remains largely rudimentary in many developing countries particularly in Africa. In use are mainly; sacks, paper cartons, wooden and bamboo baskets (Abolagba and Nuntah, 2011). In addition, the tropics generally have high ambient temperature and relative humidity (Kottek. *et al.*, 2006). Such conditions, in the absence of proper packaging provide a conducive environment for deteriorative effects of microorganisms, oxidative and enzymatic reactions (Petersen *et al.*, 1999). Consequently, it is necessary to apply proper packaging solutions in order to ensure the shelf stability of dried small pelagic fishes.

Approximately 20% of Uganda's total surface area is covered by water of which L. Albert is one of five major lakes. Lake Albert is located in the western rift valley in Uganda and is the natural habitat for *B. nurse* and *N. bredoi* which constitute 80% of its total catch (MAAIF, 2011). This region is characterised by an equatorial climate (Kottek *et al.*, 2006). The temperature and relative humidity conditions of this region were simulated in the present study based on data from the regional weather station as reported by the Uganda Bureau of Statistics (UBOS, 2015) and used for the study.

Capelin (*Mallotus villosus*) is an important small pelagic fish in the northern hemisphere (ICES, 2013). It is classified as a fatty fish with fat content ranging from 3% in spring to 14% in autumn (Bragadóttir, 2001). The nutrient composition of capelin is similar to that of the small pelagic fishes in Uganda thus it was selected for this study.

The goal of this project was to improve the storage stability of dried small pelagic fishes, in this case capelin, using appropriate packaging methods. From a Ugandan perspective, enhanced storage stability will increase marketability and utilisation of the abundant, low value small pelagic fishes for direct human consumption and ultimately curb malnutrition. More specifically, the project sought to evaluate, in relation to packaging methods of (a) air, (b) vacuum, (c) modified atmosphere, and (d) hessian bag, changes in dried whole capelin during storage in simulated ambient temperature and humidity conditions of Uganda. The attributes evaluated were;

- physicochemical stability (water content, pH, water activity, colour)
- lipid stability (lipid content, peroxide value - PV, thiobarbituric reactive substances - TBARS and free fatty acids - FFA)
- microbiological stability (total count - TC, Yeast and Mould count)

The project also investigated the feasibility of using near infrared spectroscopy (NIR) for rapid and non-destructive measurement of physicochemical properties of dried capelin

## 2. LITERATURE REVIEW

### 2.1 Capelin

Capelin (Figure 1) is a small pelagic fish species native to the northern hemisphere. It is especially abundant in the area that includes East Greenland, Iceland and Jan Mayen. Capelin shows migratory behaviour associated with seasonal variation in the environment, feeding and spawning requirements (Vilhjálmsson and Sigurjónsson, 2003; ICES, 2013).

**Figure 1: Capelin (Mallotus villosus)**

Capelin has mainly been utilised for production of fishmeal (Bragadóttir, 2001). The potential utilisation of capelin for development of value added products for human consumption such as oil, smoked and dried products has recently been reported (Bragadóttir, 2005; Odoli, 2015). The chemical composition of capelin has been reported to vary with season. Lipid content in particular has been shown to be highest during autumn and lowest during spring (Bragadóttir, 2001). The chemical composition of capelin is summarised in Table 1.

**Table 1: Chemical composition of capelin. Adapted from Bragadóttir (2001)**

| Parameter | Composition (%) |
|---|---|
| Water | 71.3 – 82.2 |
| Protein | 12.5 – 13.9 |
| Lipid | 3.1 – 13.9 |
| Salt | 0.4 – 0.7 |
| Ash | 1.6 – 1.9 |

## 2.2 Drying

Drying is one of the oldest methods of preserving fish. Particularly, open sun drying is widely practiced in the tropic and subtropical regions due to simplicity, convenience, abundance and low cost of application (Calicioglu *et al.*, 2002; Jain and Pathare, 2007). Drying is the evaporative removal of water from the product by application of heat (Fellows, 2000). Heat energy causes evaporation of water which is then transferred through the product and subsequently removed from its surface to effect drying. Drying ensures long term preservation of food by curtailing deteriorative microbial and biochemical processes (Arason, 2003). The drying process consists of two phases; during the first phase - constant rate drying, the product surface is fully saturated with moisture at the wet bulb temperature of air and drying rate is dependent on the relative humidity, velocity and temperature of air around the product as well as the product's surface area. Falling rate drying phase follows when all surface moisture has been removed. Drying rate is now dependent on resistance to migration of water from the internal matrix to the product surface. This is influenced by the physicochemical composition and temperature of the food product (Clucas, 1982; Arason, 2003). In Uganda, more than 90% of the small pelagic fishes landed are preserved by open sun drying. Drying is commonly done on bare ground however, the use of tarpaulin, mats and raised racks is on the rise particularly for products intended for human consumption (Masette, 2011). Uncontrolled, weather-dependent drying creates variability in the drying rates, duration (3 - 10 days) and final moisture content (10 - 60%) (Kabahenda *et al.*, 2009; Ofulla *et al.*, 2011).

The inefficiencies of sun drying have led to development of new technologies which ensure continuous drying, weather conditions notwithstanding (Akinola *et al.*, 2006). In Iceland, geothermal energy is utilised for indoor drying of fish. According to Arason (2003), geothermal hot water or steam heats up the drying air which is then blown over the fish to effect drying. Drying is a two-step operation entailing primary followed by secondary drying. In primary drying, air (18 - 25°C, RH 20 - 50%, velocity 3 m/s) is blown into a rack cabinet. Primary drying is complete when water content of the dried fish is 50-55% and this takes 24 – 40 hrs. This is followed by secondary drying where air (22 - 26 °C, RH 20 - 50%, velocity 0.5 - 1 m/s) is blown into the drying container until a final product water content of 15% is attained. This takes approximately 3 days.

## 2.3 Packaging

The primary role of packaging is to maintain the physical, sensory, microbiological and chemical quality of a food material (Han, 2005). This is mainly achieved by shielding against environmental conditions such as oxygen, moisture, light and aerobic microorganisms. Packaging technology is an important part of the food industry. In addition, proper packaging ensures safe delivery of high quality foods to the market (Kilcast and Subramaniam, 2000).

Modified atmosphere packaging (MAP) is a proven technology for extension of shelf life of various foods (Ashie *et al.*, 1996; Amanatidou *et al.*, 2000). Traditionally, MAP constitutes various partial pressure combinations of nitrogen, oxygen and carbon dioxide (Choubert and Baccaunaud, 2006; Ježek and Buchtová, 2007; Masniyom, 2011). This spectrum has been expanded to include argon, and other inert gases. Carbon dioxide provides preservative action against microorganisms. The antimicrobial effect of carbon dioxide is based on lowering pH due to formation of carbonic acid upon dissolution in water. However, it has limitations such as a mild pungent odour, drip loss and growth of anaerobic bacteria at higher concentrations (Bingol and Ergun, 2011; Velu *et al.*, 2013). Nitrogen is an inert gas and is important in delaying oxidative rancidity. It also inhibits growth of aerobic but not anaerobic bacteria.

Nitrogen maintains its volume within MAP because of its low solubility (Velu *et al.*, 2013). According to Parry (1993), the recommended gas composition for dried and roasted foods is 100% $N_2$. This composition is currently used in commercial applications (Dansensor, 2015). The shelf life of MAP fish and fishery products is influenced by several factors such as the species, raw material quality, handling and processing, gas composition, packaging material and storage temperature (Sivertsvik *et al.*, 2002; Goulas and Kontominas, 2007).

## 2.4 Spoilage and lipid degradation in dried fish

Dried fishes are considered as products with long shelf life. Spoilage is mainly associated with xerophytic fungi, particularly moulds. Moulds grow at water activity higher than 0.7, relative humidity at 75% and at temperature of 30 - 35 °C. Salting of fish prior to drying is an important step towards achieving low water activity. Traditional drying of small pelagic fish, in many parts of Africa, does not include salting as a pre-step. As a result, the dried fish is susceptible to mycotoxins produced by moulds such as *Aspergillus flavus*. Furthermore, presence of aflatoxins has been reported in some dried and cured fresh water fish (Diyaolu and Adebajo, 1994; Kilic, 2009).

Degradation of lipids in food proceeds via two reactions; oxidation and hydrolysis. Lipid oxidation is the main cause of deterioration during drying and storage of fish (Doe, 2002; Oduor-Odote and Obiero, 2009). It results in losses in the nutritional value, sensory quality of food and an accumulation of compounds which are potentially deleterious to human health (Kanazawa *et al.*, 2002; Wasowicz *et al.*, 2004; Özen *et al.*, 2011). Losses in sensory quality, especially characterised by undesirable flavours and odours developed as a result of lipid oxidation are encapsulated in the term oxidative rancidity (Fennema, 1996).

The oxidation of lipids in foods may be enzymatic or non-enzymatic however, the self-catalytic reaction between molecular oxygen and lipids generically referred to as auto-oxidation accounts for most oxidative degradation of lipids (Fennema, 1996). Lipid oxidation proceeds via a free radical mechanism involving the reaction between unsaturated fatty acids and molecular oxygen leading to formation of acyl hydroperoxides (Gray, 1978). As described extensively by Fennema (1996), the mechanism involves three steps namely; initiation, propagation and termination (Figure 2). Initiation entails abstraction of the methylenic hydrogen which detaches with ease due to the influence of adjacent double bond (s) to form free radical species. This reaction is prompted by an initiator which may be a metal catalyst or exposure to light among various postulations. The free radicals react with oxygen to form peroxy radicals which then abstract methylenic hydrogen from other lipid molecules to produce hydroperoxides and free radicals. The newly formed free radicals again react with oxygen and thus instigate the cyclic reaction. Decomposition of hydroperoxides yields alkoxy and hydroxyl radicals. Subsequently, homolytic cleavage on either side of the alkoxy group leads to formation of aldehydes, acids, esters, hydrocarbons, oxo-acids and oxo-esters.

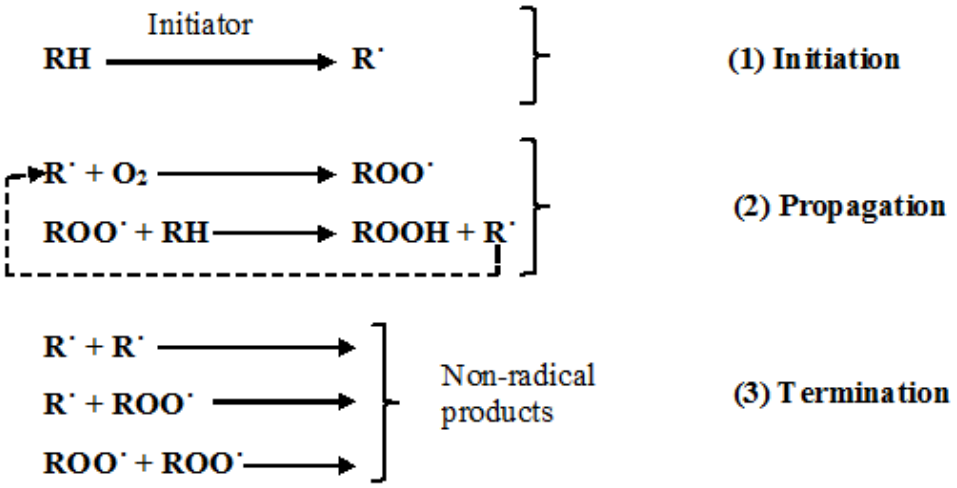


**Figure 2: Schematic representation of the three-step free radical reaction mechanism of lipid oxidation. Adapted from Fennema (1996).**

The heterogeneous mixture of low molecular weight, volatile products of hydroperoxide decomposition including aldehydes, hydrocarbons, esters, ketones, alcohols and furans contributes to rancidity (Frankel, 1984). Enzyme-catalysed lipid oxidation in fish mainly involves lipoxygenase, cyclooxygenase and peroxidase enzyme (Undeland, 1997). As reviewed by Ladikos and Lougovois (1990), lipid oxidation is enhanced by metal elements such as copper, iron and cobalt; haem proteins such as myoglobin and haemoglobin; and sodium chloride. Lipid oxidation of foods is also influenced by processing especially high temperature treatment; compositional factors such as degree of unsaturation of fatty acids. On the other hand, hydrolysis of lipids in fish is due to activity of the enzymes; lipase and phospholipase (Chaijan *et al.*, 2006). Heat and moisture may also be involved in lipolysis leading to production of free fatty acids (Fennema, 1996).

## 3. MATERIALS AND METHODS

### 3.1 Materials

Dried whole capelin was used for the study. Frozen whole capelin in blocks (26 kg) was purchased from Sidarvinnslan hf. (Neskaupstadur, Iceland). It was caught on 07.02.2015 and stored at -20 °C until processing on 16.11.2015. The capelin was dried by a local fish processor (Haustak hf., Reykjanes, Iceland). Polythene pouches (350 x 500mm, 90 microns) were used for Modified Atmosphere Packaging (MAP), and Vacuum Packaging (VP). Conventional polythene pouches (350 x 500 mm, 30 microns) were used for air packaging (AP). Hessian bags (HB) were purchased from Haustak hf (Reykjanes, Iceland). Industrial Nitrogen gas (99.9% purity) was purchased from AGA ehf. (Reykjavik, Iceland). All chemicals used during analysis of samples were of analytical grade, and purchased from Fluka (Buchs, Switzerland) or Sigma-Aldrich (Steinheim, Germany / St. Louis, MO, USA).

### 3.2 Experimental design

The study was carried out according to the flow diagram shown in Figure 3. The frozen capelin was thawed overnight at 0 - 2 °C. The commercial drying was done using geothermal energy

as described by Arason (2003). Frozen and freshly dried capelin were analysed for baseline composition (water, lipid, protein and salt contents, water activity, pH). The dried capelin was then divided into 4 groups based on packaging method: air, hessian bag, vacuum and MAP. Dried capelin in the respective packages was stored under temperature and humidity modelled on Uganda's climatic condition in a specialised storage chamber at Matis laboratories for 8 weeks. Day (30 °C, RH 54%) and night (17 °C; RH 83%) conditions were alternated every 24 hours and monitored by temperature and humidity data loggers. The physicochemical, lipid and microbiological stability of the dried capelin was monitored through analysis every 2 weeks for 8 weeks of storage.

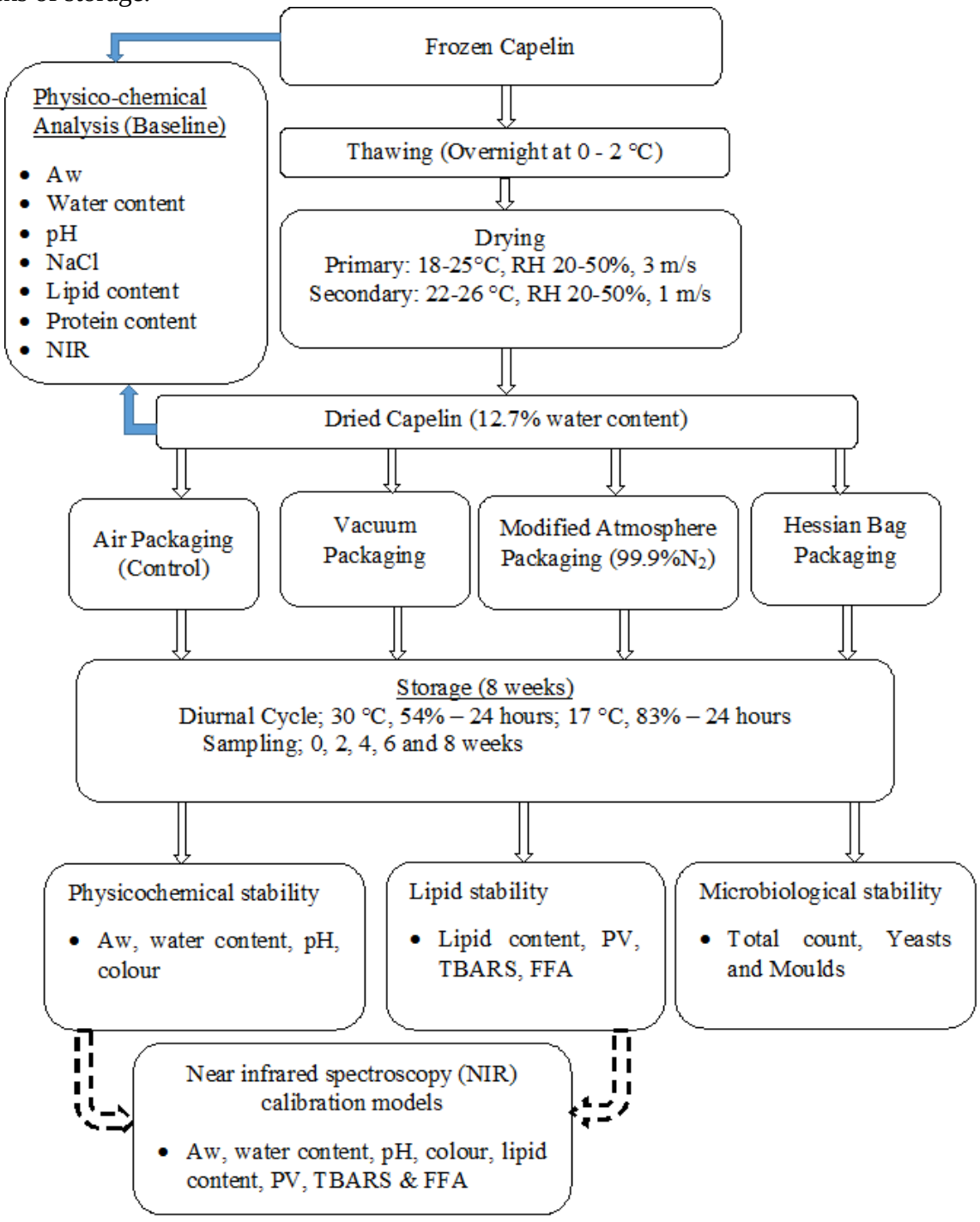


**Figure 3: Flow diagram showing design of experiments for evaluation of storage stability of dried Capelin using different packaging methods in simulated temperature and humidity conditions of Uganda.**

## 3.3 Sampling

Approximately 3.5 kg of frozen capelin was set aside for proximate analysis at the same time with the dried capelin. Dried samples (approximately 300g each) obtained from the different packaging methods were analysed at 0, 2, 4, 6 and 8 weeks of storage. All samples were analysed in triplicate (n=3)

## 3.4 Packaging methods

Vacuum packaging (VP) of dried whole capelin involved evacuating the 90-micron polythene pouches (99.9% vacuum) before automatic heat sealing. For MAP, a modified method of Arashisar *et al.* (2004) was used. The polythene pouches were evacuated (99.9% vacuum) before flushing with industrial Nitrogen gas (99.9% purity) to give a final volume ratio of approximately 2:1 (gas: capelin) prior to automatic heat-sealing. A multipurpose Webomatic Vacuum Packaging Machine (C10-H, Bochum, Germany) was used for vacuum and MAP packaging. In Air packaging (AP), polythene pouches (30 microns) containing dried capelin and normal atmospheric gas mixture were folded at the open end for a loose seal. Hessian bags (340 x 560 mm) containing dried capelin were fastened using hessian strings. All packages were then transferred to the storage cabinet.

## 3.5 Physicochemical analysis

Frozen and freshly dried capelin were analysed for baseline composition as the raw material. Approximately 300g from each group was minced with skin and used for all chemical analyses. All samples were analysed in triplicate (n=3). Any deviations from this protocol are included in the methods description.

### *3.5.1 Water content*

Water content was determined by the weight difference during drying of a 5 g minced capelin at 103 °C ± 1 °C for 4 h (ISO 6496, 1999). Results were calculated as g water/100 g sample.

### *3.5.2 Sodium chloride*

Sodium chloride (NaCl) content was determined using a standard method, Volhard titration (AOAC no.976.18., 2000).

### *3.5.3 Lipid content*

Total lipids (TL) of the fish samples were extracted according to the method of Bligh and Dyer (1959). The lipid content was determined gravimetrically and results expressed as g lipid / 100 g of the sample.

### *3.5.4 Protein content*

Crude protein content was determined using the Kjeldahl method (Kjeltex S*ystem-Texator, Hoganas, Sweden)* (ISO 5983-2, 2005).

### *3.5.5 Water activity*

Water activity was measured using a water activity meter (Aqua Lab, 4TE, Decagon Devices Inc., USA). Approximately 2g of homogenised sample was placed onto the sample cup (no more than half full) prior to taking of readings.

### *3.5.6 Colour*

Colour was analysed using Minolta Chroma meter CR-400 (Minolta Co., Ltd; Osaka, Japan). Colour measurements entailed; the *L* value, lightness on the scale of 0 to 100 from black to white; *a* value, (+) red or (-) green; *b* value, (+) yellow or (-) blue. The colour was measured at three points of the minced Capelin matrix.

### *3.5.7 pH*

A method described by Bragadottir *et al.*, (2007) was used to evaluate pH of dried capelin. The pH of samples was measured using a digital pH meter (Knick-Portamess 913 pH, Berlin, Germany). All samples were measured at room temperature. The pH value was the average of two readings.

### *3.5.8 Near Infrared Spectroscopy (NIR) analysis*

A method described by Karlsdottir *et al.*, (2014) was used for NIR analysis of dried capelin. The FT-NIR reflectance was measured using Bruker Multi-Purpose Analyser (MPA) system with a fiber probe (Bruker Optics, Rheinstetten, Germany). The readings were made over a wavelength range from 800 to 2500 nm. Five spectra were collected for each sample and the average spectrum used for analysis. All sample measurements were done in duplicate. OPUS spectroscopy software (v.6.5 Bruker Optics, Rheinstetten, Germany) was used for acquisition of spectra, instrumental control and treatment of data.

## 3.6 Lipid stability

### *3.6.1 Peroxide value (PV)*

A method according to Shantha and Decker (1994) was used to determine the peroxide value, a primary lipid oxidation product. 5 g of sample was homogenised (Ultra-Turrax T25 basic, IKA Labortechnik, Germany) with 10 ml of ice cold methanol: chloroform (1:1) solution, (containing 500 ppm BHT to prevent further peroxidation during the extraction process) in a centrifuge tube to extract total lipids. 5 mL of sodium chloride (0.5 M) was added and the mixture homogenised again for 30 sec prior to centrifuging at 5100 rpm for 5 min at 4 °C (TJ-25 Centrifuge, Rotor TS-5.1-500, Beckman Coulter, California, USA). 500 µl of the bottom layer (chloroform) was collected into Eppendorf tubes, and 500 µl of solvent (methanol: chloroform) added, followed by 5 µl of a mixture (1:1) of ammonium thiocyanate (4 M) and ferrous chloride solution (80 mM). After vortexing and incubation for 10 minutes at room temperature, 100 µl of the solution were pipetted onto a polypropylene microplate (Eppendorf, microplate 96/F-PP) and the absorbance read at 500 nm (Tecan Sunrise, Austria). A standard curve was prepared using cumene hydroperoxides. The results were expressed as µmol lipid hydroperoxides per kg of dried muscle.

### *3.6.2 Thiobarbituric reactive substances (TBARS)*

A method according to Lemon (1975) with some modifications was used to determine the thiobarbituric reactive substances, a secondary lipid oxidation product. 5g of sample was homogenised (Ultra-Turrax T25 basic, IKA Labortechnik, Germany) with 10 mL of trichloroacetic acid (TCA) extraction solution (7.5% TCA, 0.1% propyl gallate and 0.1% EDTA mixture prepared in ultra-pure water) at maximum speed for 10 s. The homogenate was then centrifuged (Beckman Coulter TJ-25, Rotor TS-5.1-500, USA) at 5100 rpm for 20 min. The collected 0.1 mL of the supernatant was mixed with 0.9 mL of thiobarbituric acid (0.02 M) and heated in a 95 °C water bath for 40 min. After cooling on ice, the mixture was immediately loaded onto 96-well microplates for reading absorbance at 530 nm (Tecan Sunrise, Austria). A standard curve was prepared using 1.1.3.3-tetraethoxypropane (TEP). The results were expressed as μmol of malonaldehyde diethyl acetal per kg of dry muscle.

### *3.6.3 Free fatty acids (FFA)*

FFA was determined by the method of Lowry and Tinsley (1976) with modification from Bernardez *et al.*, (2005) 3 mL of the lipid extract (Bligh and Dyer, 1959) were transferred into a screw cap tube. All residual solvent was then evaporated using nitrogen jet at 55 °C for 5 – 10 mins. The solvent-free lipid in the tubes was allowed to cool to ambient temperature and, to it was added 3 mL of cyclohexane followed by 1 mL of cupric acetate – pyridine reagent. The two phase system was vortexed for 30s followed by centrifugation at 2000 g for 10 min at 4 °C. The absorbance of the upper layer was read at 710 nm (UV-1800 spectrophotometer, Shimadzu, Japan). The concentration of FFA was calculated as μmol oleic acid based on a standard curve spanning a 2-22 μmol range. Results were expressed as grams FFA per 100 g of total lipids.

## 3.7 Microbiological analysis

### *3.7.1 Total count*

Total count at 30°C were determined by the method described by Downes and Ito (2001). Results were expressed as a logarithm of the number of colony-forming units per gram

### *3.7.2 Yeast and mould count*

A standard method described by Downes and Ito (2001) was used. 20 g of blended sample were weighed in a stomacher bag and 180 ml of maximum recovery diluent added, followed by homogenisation for 2 minute in a stomacher (Stomacher 400 Lab System, Seward Ltd, UK). Serial dilutions of the samples of up to $10^{-4}$ were made followed by inoculation of duplicate Dichloran Rose Bengal Chloramphenicol agar plates with 0.1 ml of each dilution and spread over the surface using a sterile L-shaped glass rod (hockey stick). The plates were incubated at 22 °C for 5 days. Yeasts and moulds were counted separately and the number per gram of sample calculated from the number of colonies counted on selected plates. Results were expressed as a logarithm of the number of colony-forming units per gram.

### 3.8 Data analysis

#### *3.8.1 Statistical analysis*

The statistical analysis system software package SAS (Version 9.3, 2011; SAS Institute Inc., Cary, NC, USA) was used for analysis of data. One-way ANOVA was used to compare data sets with Duncan's multiple range test. The significance level was set at $p \leq 0.05$. Furthermore, calculation of Pearson´s correlation coefficients between different variables was performed using Microsoft Office Excel 2013 (Microsoft Inc., Redmond, USA).

#### *3.8.2 NIR data analysis*

OPUS spectroscopy software (v.6.5 Bruker Optics, Rheinstetten, Germany) was used for treatment of data for determination of coefficient of determination for cross validation ($R^2_{cv}$), root mean square error of cross validation (RMSECV) and residual predictive deviation (RPD). RPD is the ratio between the standard deviation of the population reference values and the standard error of performance (RMSECV/RMSEP). A RPD value >2 indicates a stable and effective calibration. The RMSECV is the standard deviation of differences between spectral data and reference values in the calibration sample set. It is the error of prediction of a calibration model. The mean uncertainty of predictions of future samples is given by this value (Karlsdottir *et al.*, 2014) .

## 4. RESULTS

### 4.1 Chemical composition

The chemical composition of frozen and dried capelin is summarised in Table 2. Dried capelin had a significantly lower moisture content and higher protein, lipid and salt content compared to the frozen capelin.

**Table 2: Chemical composition (water, protein, lipid and salt content) of frozen and dried capelin**

| Parameter | Composition (%) | |
|---|---|---|
| | Frozen | Dried |
| Water | 72.2±4.0 | 12.7±4.0 |
| Protein | 14.5±3.0 | 51.0±3.0 |
| Lipid | 11.6±1.5 | 33.0±5.3 |
| Salt | 0.9±3.0 | 2.7±3.0 |

### 4.2 Profile of simulated temperature and relative humidity conditions during storage

The variation of temperature and relative humidity within the storage chamber throughout the storage period is shown in Figure 4. In the top compartment, relative humidity was in the range of 48.7 – 84.93% while temperature was 32.2 – 18.05 °C respectively. The middle compartment had RH of 52.2 – 97.2% and temperature of 30.4 – 16.0 °C.

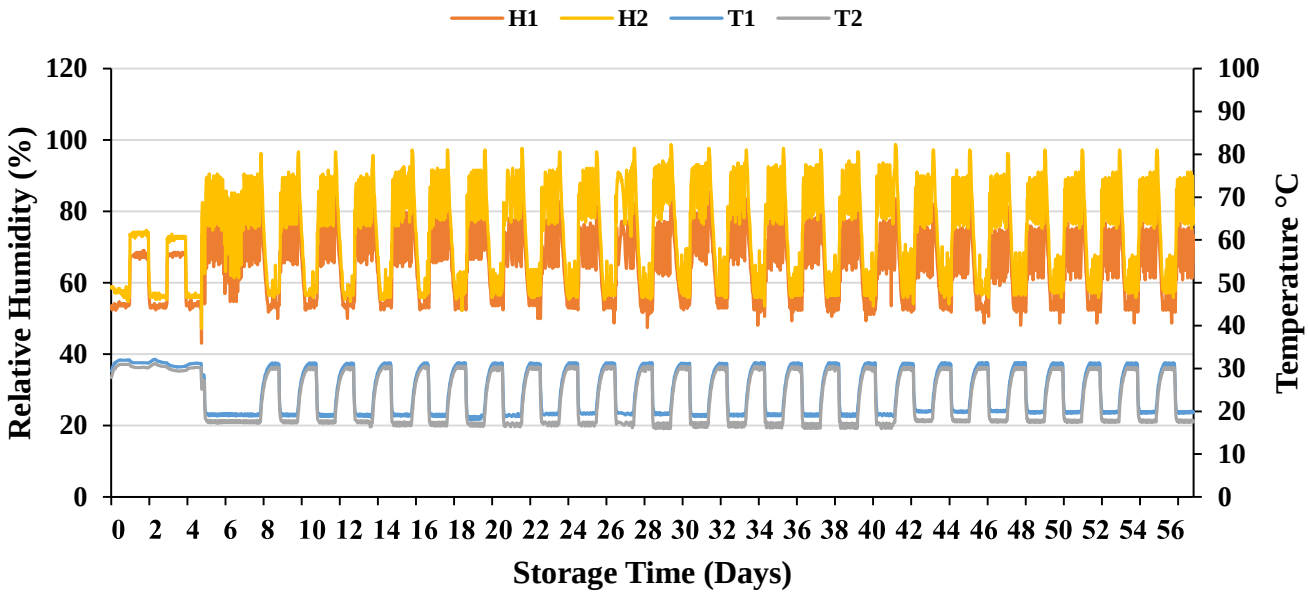


**Figure 4: Temperature and relative humidity profile within the storage cabinet over the 8 week storage period. (H1 – relative humidity top compartment; H2 – relative humidity middle compartment; T1 – temperature top compartment; T2 – temperature middle compartment)**

## 4.3 Storage stability of dried capelin under different packaging methods

### *4.3.1 Water content*

The water content of the dried capelin fluctuated but was not significantly different among AP, VP and MAP throughout storage (Table 3). However, the water content of dried capelin in HB increased with time and was significantly different compared to the other packaging methods.

**Table 3: Water content of dried capelin during the 8 week storage (RH ≈ 54 – 83%; Temperature ≈ 17 – 30 °C) using AP, VP, MAP and HB**

| Storage time (Weeks) | Water content (%) | | | |
|---|---|---|---|---|
| | AP | VP | MAP | HB |
| 0 | $^{aB}$12.70±0.00 | $^{aA}$12.70±0.00 | $^{aA}$12.70±0.00 | $^{aD}$12.70±0.00 |
| 2 | $^{bC}$12.15±0.07 | $^{bB}$11.90±0.00 | $^{cC}$11.4±0.14 | $^{aC}$15.65±0.07 |
| 4 | $^{bB}$12.85±0.21 | $^{cB}$11.95±0.07 | $^{cbBA}$12.35±0.07 | $^{aA}$17.60±0.14 |
| 6 | $^{bC}$12.05±0.07 | $^{bB}$12.00±0.14 | $^{bB}$12.00±0.14 | $^{aB}$16.75±0.07 |
| 8 | $^{bA}$13.75±0.07 | $^{cA}$12.55±0.21 | $^{cA}$12.65±0.07 | $^{aCB}$16.20±0.28 |

(AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging; HB - Hessian Bag)
Different letter indicates significant difference among means in the same row (lower case) and columns (upper case)

### *4.3.2 Water activity*

The water activity of the dried capelin was not significantly different throughout the storage period for AP, VP and MAP packed samples (Figure 5). However, the water activity increased significantly in HB packed dried capelin.

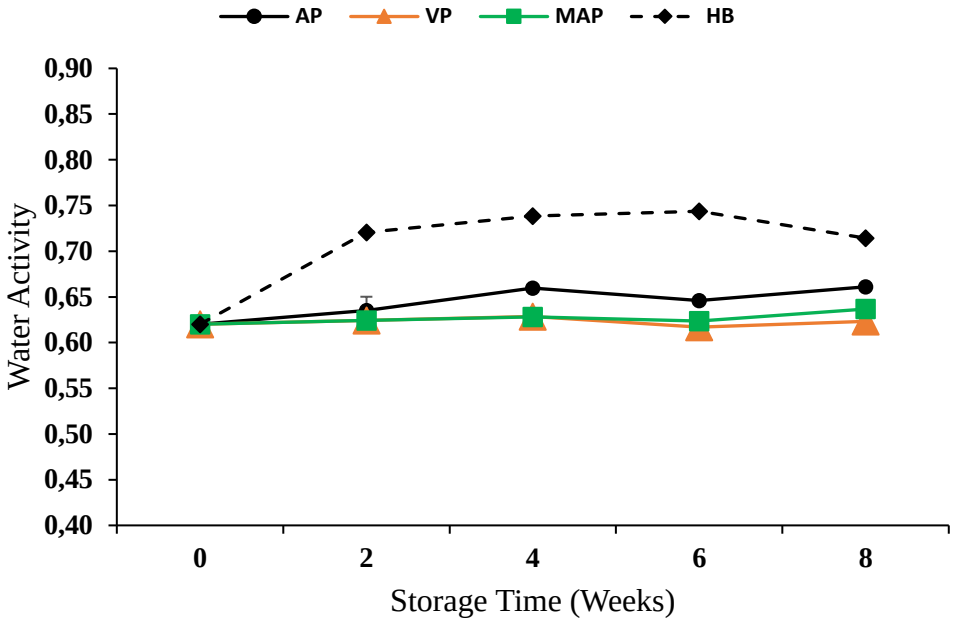


**Figure 5: Water activity of dried capelin during the 8 week storage (RH ≈ 54 – 83%; Temperature ≈ 17 – 30 °C) using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag**

*4.3.3 pH*

pH of the dried capelin decreased gradually for the first four weeks of storage, followed by slight increase in the sixth week before decreasing again at week 8 for all packaging methods (Figure 6). However, the variation in pH was not significantly different among packaging methods over the entire storage period for all packaging methods except for HB packed samples. HB packed dried capelin attained a minimum pH of 6.1 which was significantly different from the other packaging methods.

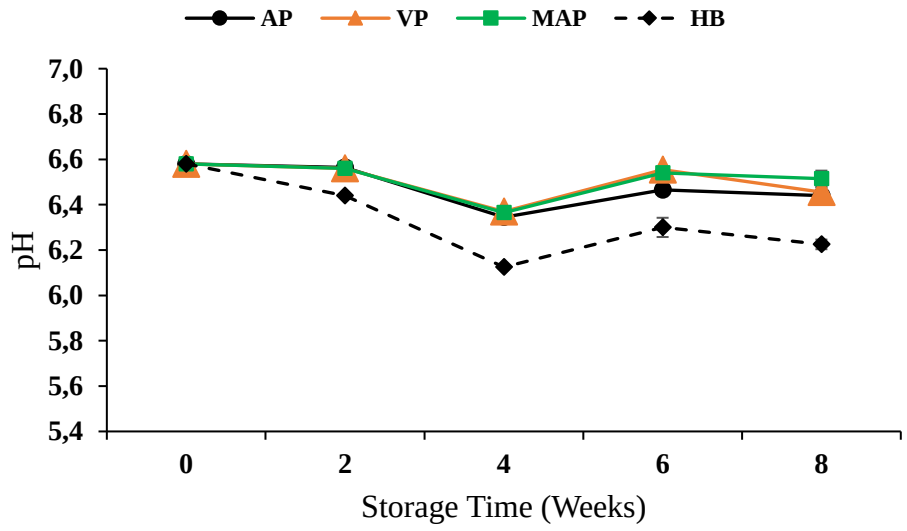


**Figure 6: pH of dried capelin during the 8 week storage (RH ≈ 54 – 83%; Temperature ≈ 17 – 30 °C) using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag**

### *4.3.4 Colour*

Colour (lightness, redness and yellowness) of the dried capelin was independent of packaging method throughout the storage period (Figure 7A-C). Lightness was within the range (40.26 – 34.63), redness (4.80 – 3.43) and yellowness (5.51 – 2.43). Yellowness of the dried capelin increased significantly at the second week of storage for all packaging methods before stabilising for the rest of the storage period.

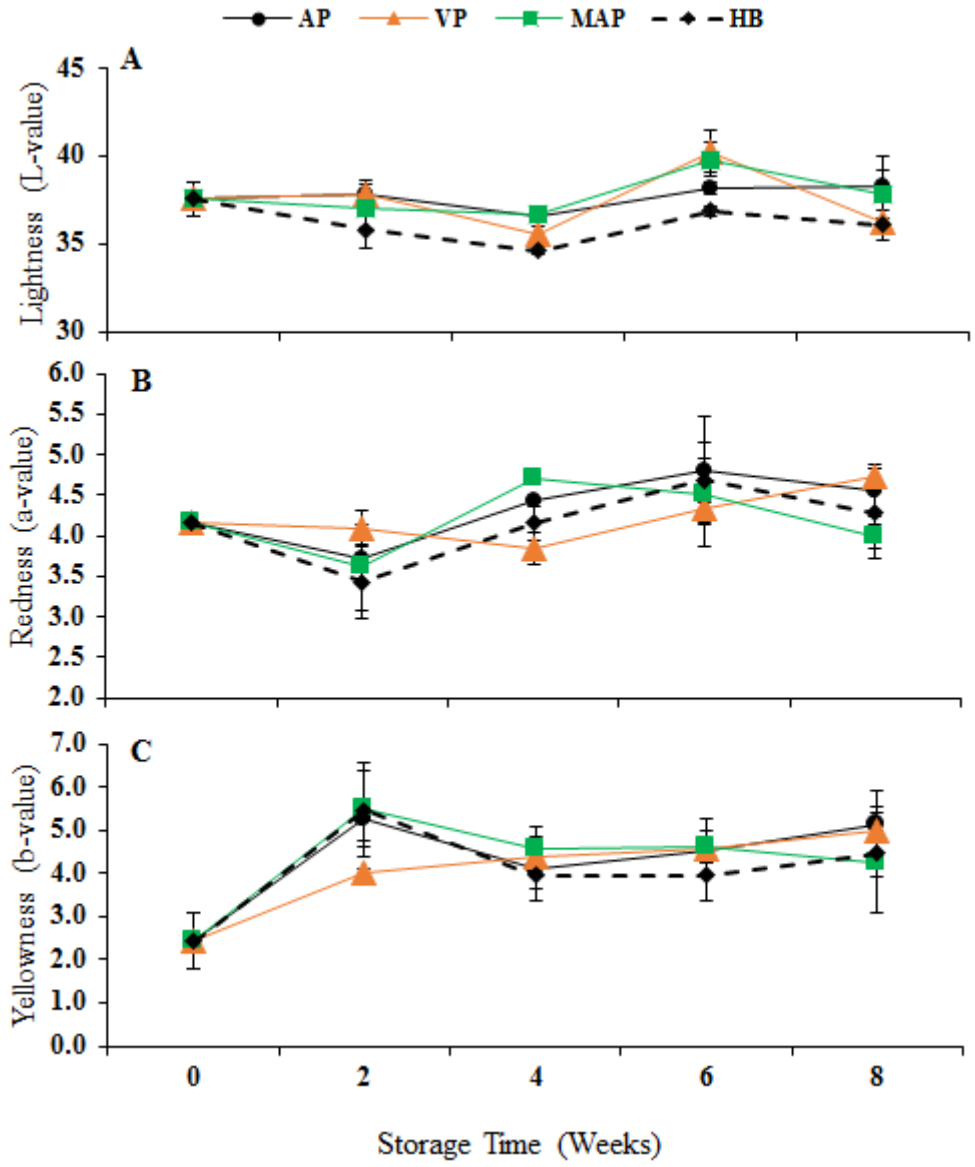


**Figure 7: Lightness (A), Redness (B) and Yellowness (C) of dried capelin during the 8 week storage (RH ≈ 54 – 83%; Temperature ≈ 17 – 30 °C) using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag**

### *4.3.5 Lipid content*

Lipid content of the dried capelin was in the range of 37.3% – 25.2% throughout the storage period (Figure 8). Generally, it decreased especially after week 4. No significant difference in lipid content was observed among packaging methods with the exception of the HB packed samples in week 8 (25.2% ± 0.0).

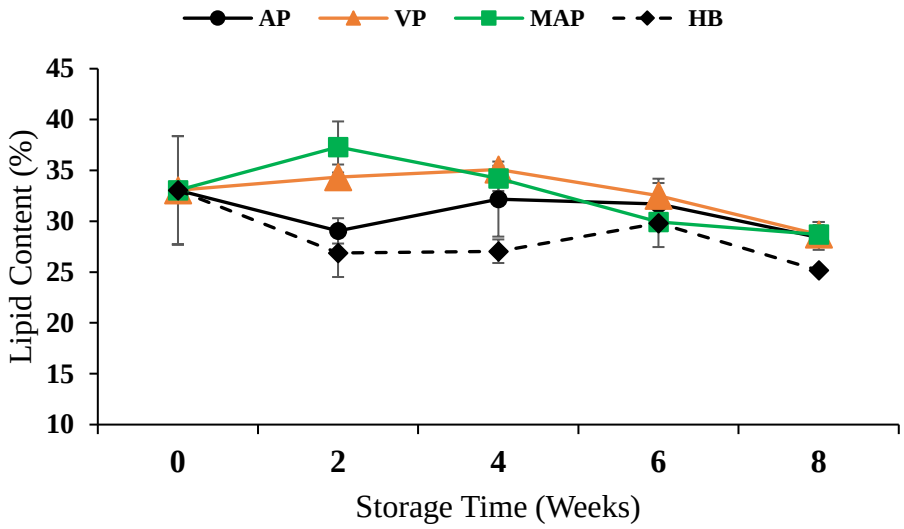


**Figure 8: Lipid content of dried Capelin during the 8 week storage (RH ≈ 54 – 83%; Temperature ≈ 17 – 30 °C) using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag**

*4.3.6 Peroxide Value (PV)*

Peroxide value (PV) of the dried capelin varied with packaging method as shown in Figure 9. The PV increased significantly during the first two weeks of storage for MAP, AP and HB packed samples in ascending order. The PV then decreased significantly at week 4 for MAP, AP and HB packed samples and did not vary significantly from this point to the end of storage time. The PV of VP packed dried capelin did not increase significantly throughout storage.

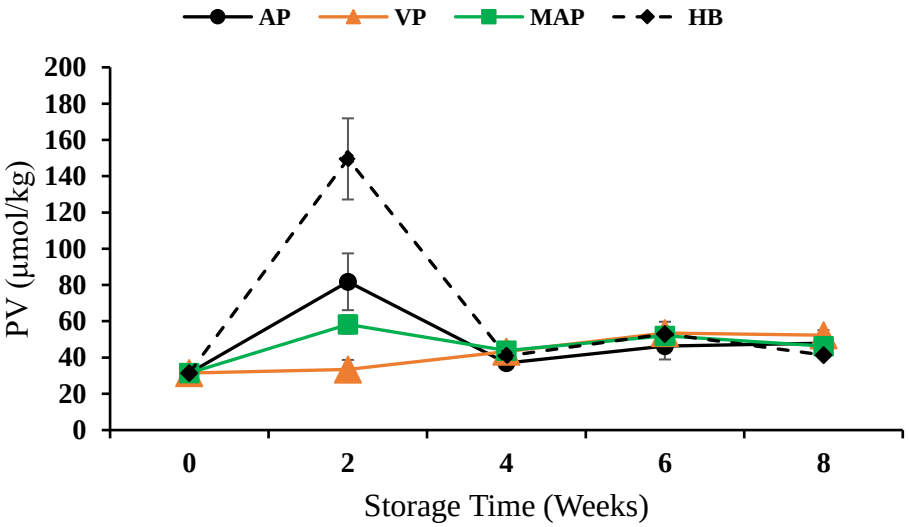


**Figure 9: Peroxide value (PV; µmol/kg sample) of dried Capelin during the 8 week storage (RH ≈ 54 – 83%; Temperature ≈ 17 – 30 °C) using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag**

### *4.3.7 Thiobarbituric Acid Reactive Substances (TBARS)*

TBARS content of dried capelin varied with packaging method as shown in Figure 10. Generally, TBARS content decreased during storage for all packaging methods with the exception being AP packed samples. The TBARS content of AP packed capelin increased during the first four weeks of storage before decreasing in the remaining four weeks. The highest TBARS content (313 µmol MDA/kg) was recorded in AP packed samples at week 4 and was significantly different compared to the other methods. The lowest TBARS content (152.85 µmol MDA/kg) was logged in MAP packed samples at the end of the storage period. TBARS content of the MAP packed dried capelin decreased throughout storage and was significantly different compared to other methods.

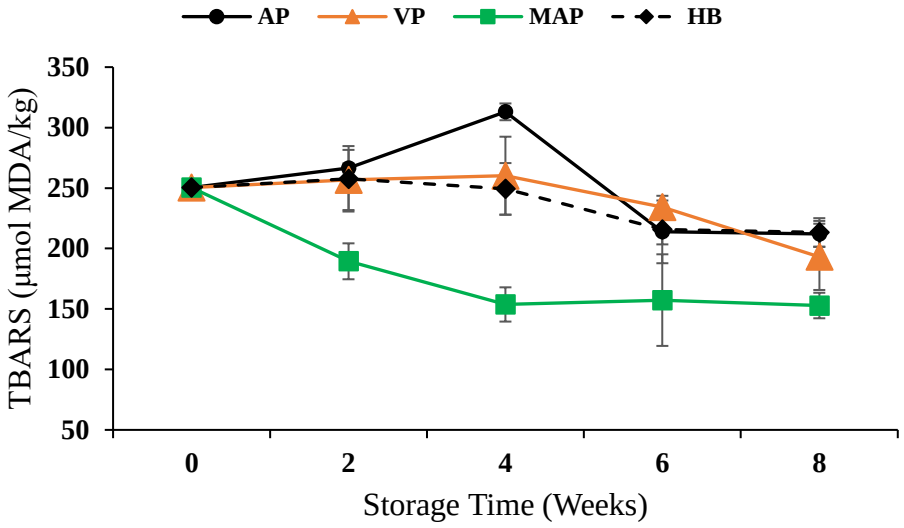


**Figure 10: TBARS of dried Capelin during the 8 week storage (RH ≈ 54 – 83%; Temperature ≈ 17 – 30 °C) using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag**

### *4.3.8 Free Fatty Acids (FFA)*

FFA content of dried capelin generally increased throughout the storage period regardless of packaging method (Figure 11). The FFA content increased significantly, especially in the eighth week of storage, for all packaging methods. The highest FFA content (17.99 g/100g Lipid) was obtained in HB packed dried capelin ($p<0.05$).

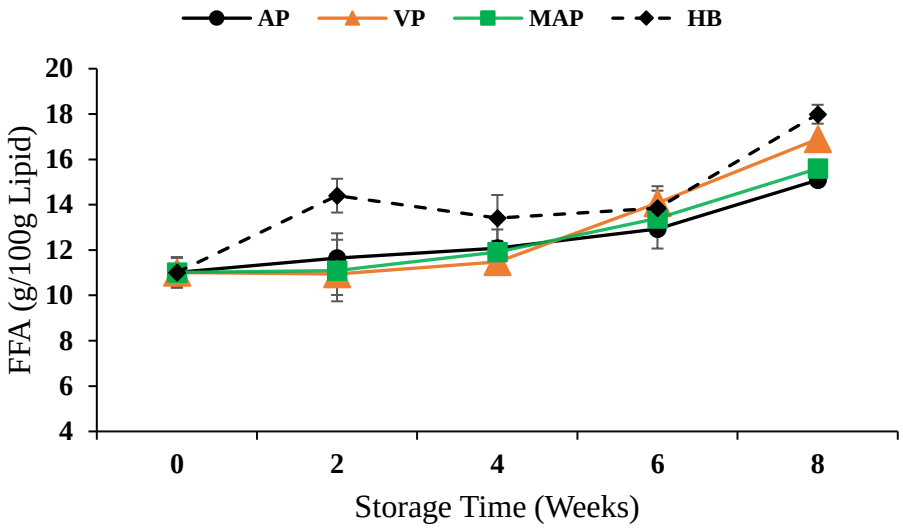


**Figure 11: Free Fatty Acid content of dried Capelin during the 8 week storage (RH ≈ 54 – 83%; Temperature ≈ 17 – 30 °C) using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag**

*4.3.9 Microbiological Stability*

Total count (TC) of dried capelin generally decreased with storage time for all packaging methods (Figure 12). The TC of the VP packed dried capelin decreased significantly throughout the storage period resulting in the lowest counts (3.55 Log cfu/g) whereas the highest TC were logged in AP packed dried capelin (5.96 Log cfu/g).

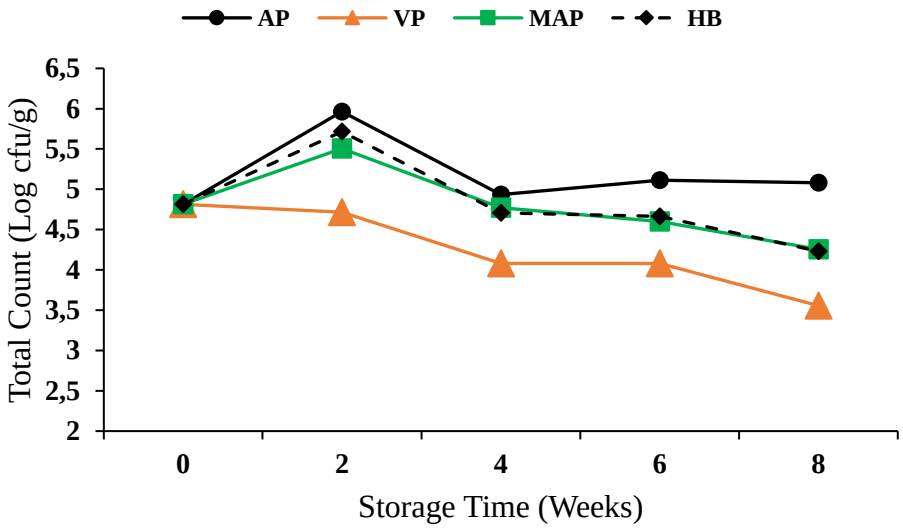


**Figure 12: Total count of dried Capelin during the 8 week storage (RH ≈ 54 – 83%; Temperature ≈ 17 – 30 °C) using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag**

Yeast count of dried capelin was low for most of the storage period for all packaging methods (Figure 13A). Yeast count of dried capelin in AP increased significantly during the first two

weeks of storage (1 - 2.75 Log cfu/g) and decreased over the next two weeks. Mould growth was most significant in HB packed dried capelin throughout the storage period (Figure 13B).

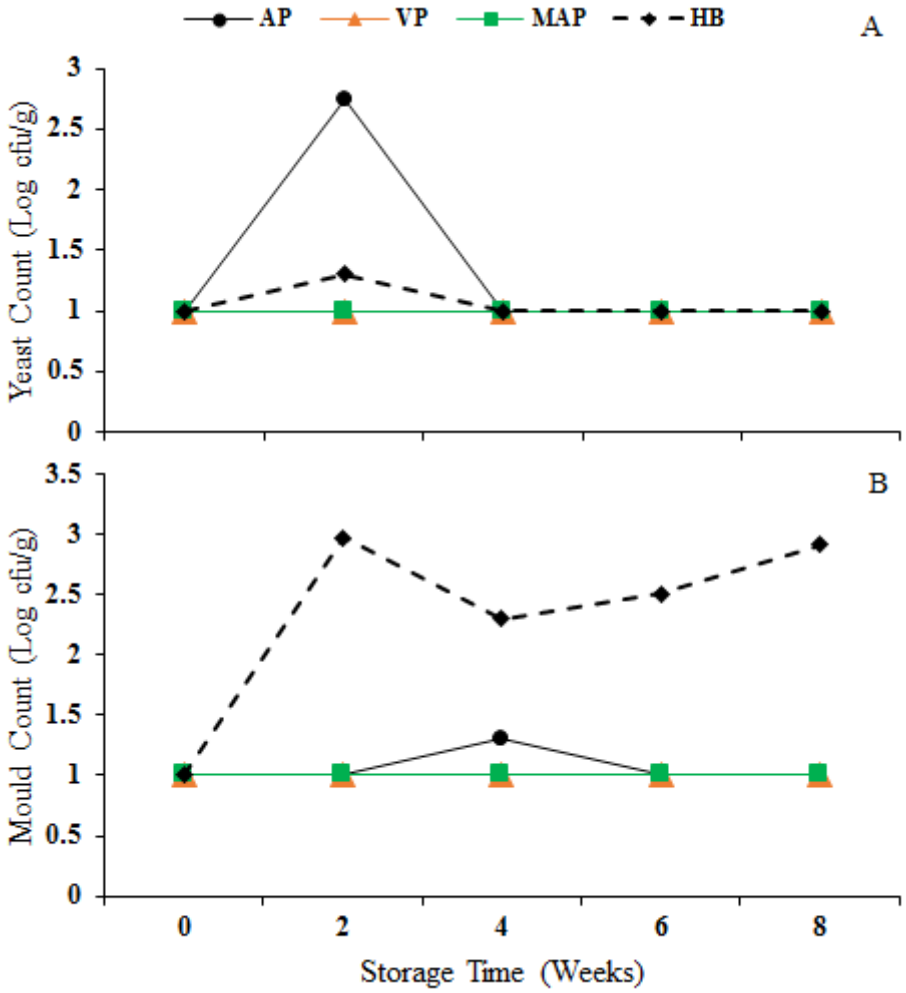


**Figure 13: Yeast (A) and Mould (B) Count of dried Capelin during the 8 week storage (RH ≈ 54 – 83%; Temperature ≈ 17 – 30 °C) using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag**

### 4.4 Near infrared spectroscopy (NIR) calibration models

In the present study, the feasibility of using NIR spectroscopy for rapid and non-destructive measurements of physicochemical properties of dried capelin was evaluated.

The calibration models developed for water content, water activity and pH had coefficients of determination for cross validation ($R^2_{cv}$) of 0.95, 0.96 and 0.92 respectively (Figure 14 A-C). Regarding calibration models for colour, the coefficients of determination for cross validation of lightness, redness and yellowness were 0.56, 0.67 and 0.65 respectively (Figure 15 A-C). Corresponding values for lipid content, TBARS, PV and FFA of dried capelin were 37.78, 34.90, -12.72, and 50.86 respectively (Figure 16 A-C).

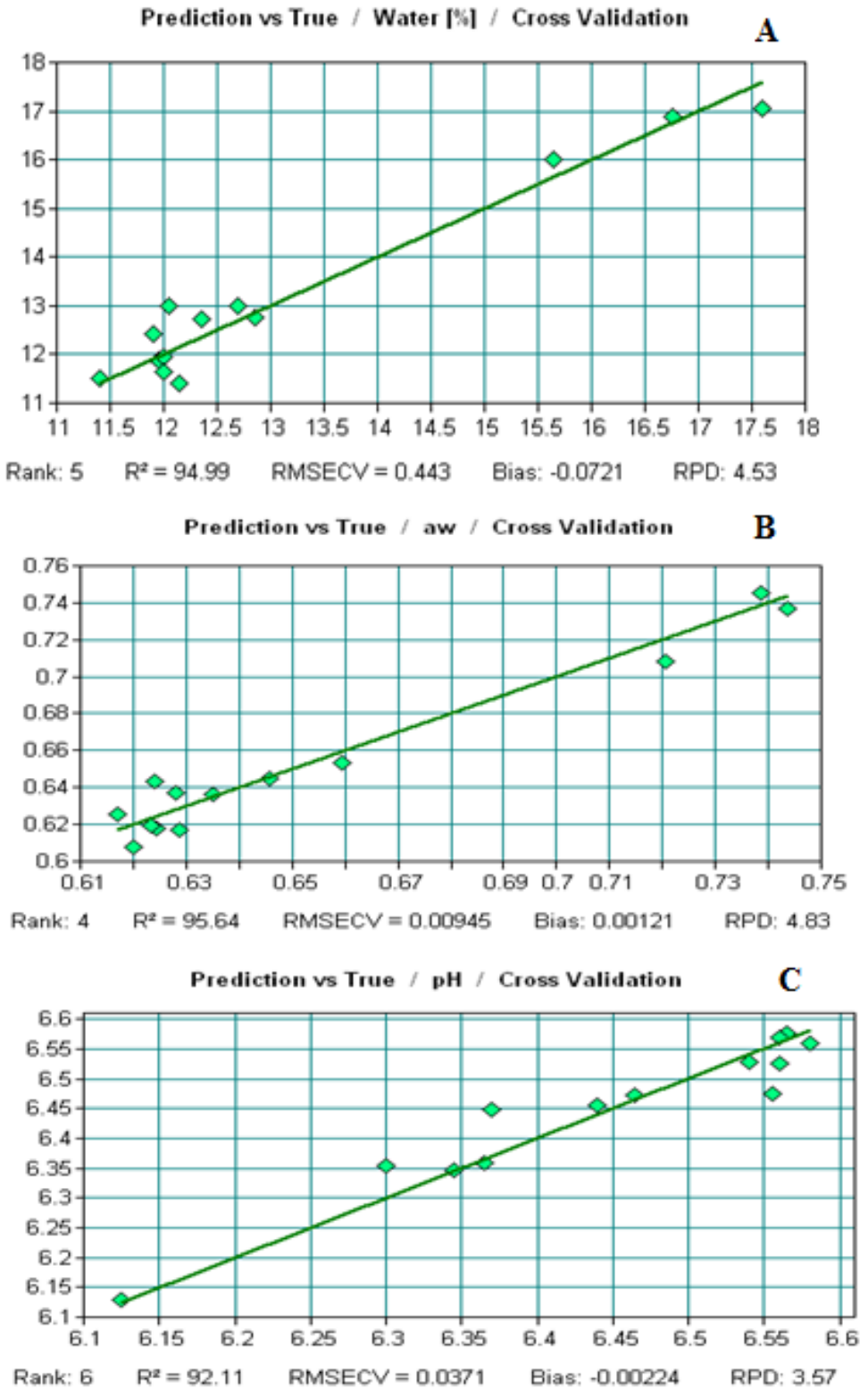


**Figure 14: Scatter plot of NIR vs reference values for water content (A), water activity (B) and pH (C) in the calibration models for dried capelin.**

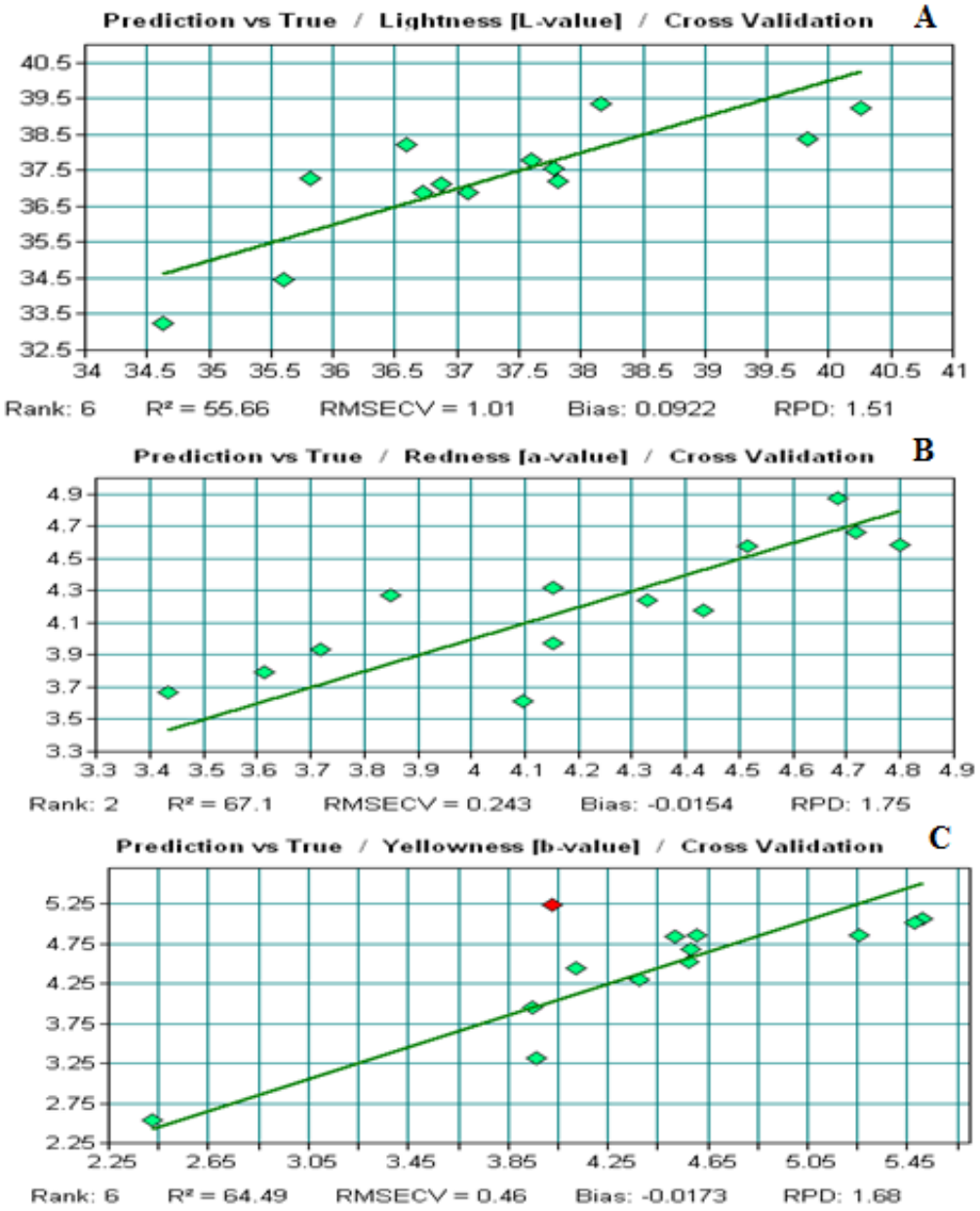


**Figure 15: Scatter plot of NIR vs reference values for Lightness (A), Redness (B) and Yellowness (C) in the calibration models of dried capelin**

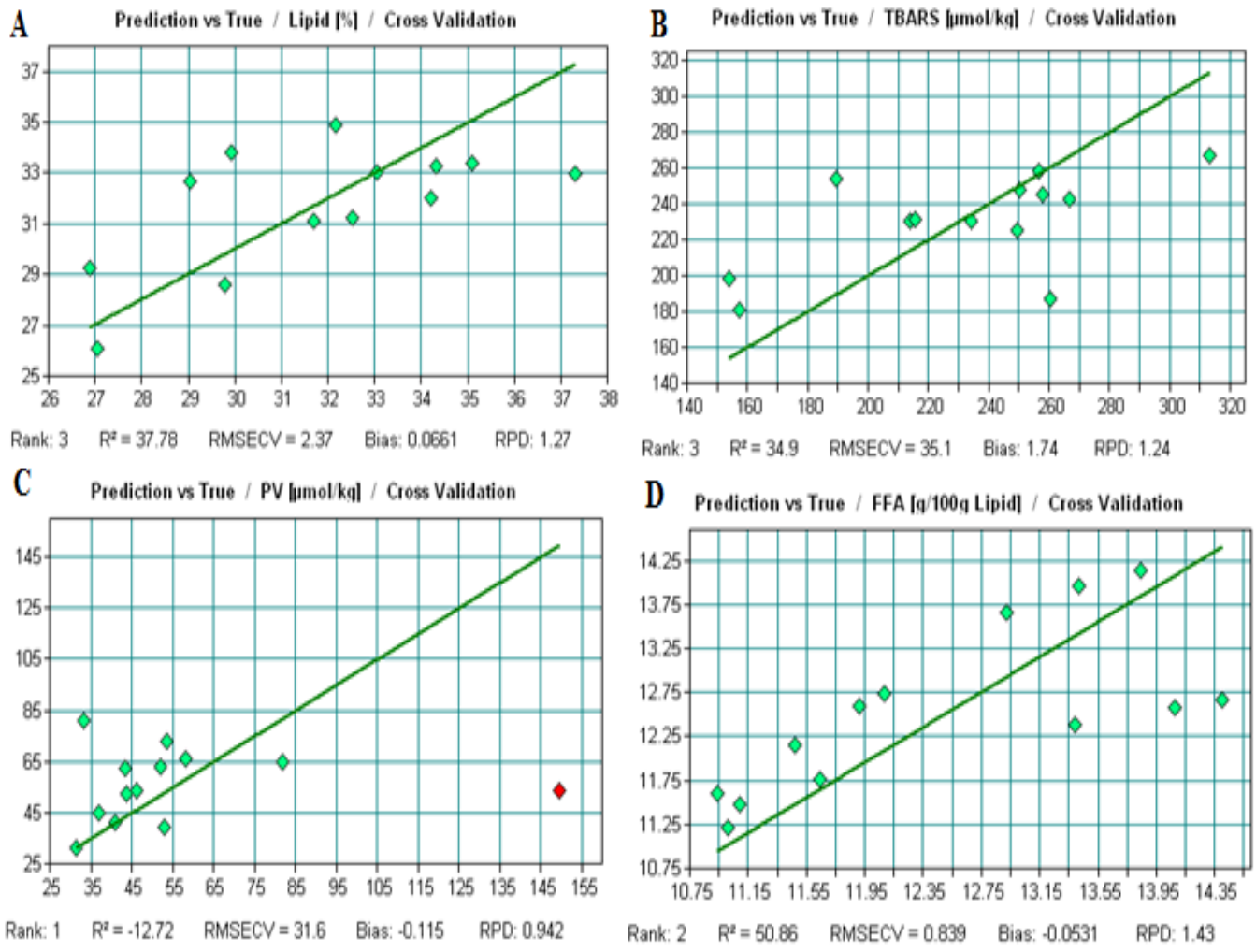


**Figure 16: Scatter plot of NIR vs reference values for lipid content (A), TBARS (B), PV (C) and FFA (D) in the calibration models of dried capelin**

# 5. DISCUSSION

## 5.1 Physico-chemical composition and stability

The proximate composition of frozen and dried whole capelin (Table 2) was similar to that reported by Bragadóttir (2001) and Odoli (2015). The drying process resulted in reduction of water content and this increased the salt, protein and lipid content on dry weight basis.

The pH of dried capelin generally decreased during the first four weeks of storage albeit insignificantly (Figure 6). This may be linked to the increase in FFA content since there was a strong negative correlation (r = -0.84, Appendix 1 - Table 4) between the two during this period. The increase in pH, albeit slightly, during the latter weeks of storage may be attributed to development of basic nitrogen compounds. Bragadóttir *et al.*, (1998) reported an increase in total volatile nitrogen of dried whole capelin after one month storage at 39 °C. More so, a similar observation was made by Ogongo *et al.* (2015) during storage of vacuum and controlled atmosphere packed dried sardines. Overall, the pH of the dried capelin was rather stable throughout the storage period for all packaging methods

The observed changes in water content and water activity of dried capelin under respective packaging methods were strongly correlated (r = 0.95, Appendix 1 - Table 5) throughout the storage period (Table 3 and Figure 5). The ventilated and adsorbent nature of the hessian bags resulted in a significant increase in water content and water activity of the dried capelin stored therein when storage relative humidity was increased over time (≈83%). The increase in moisture content and water activity of the dried capelin stored in HB can be explained by the adsorption and desorption behaviour of dried foods. Moisture diffusion into and out of a food product is primarily a function of vapour pressure gradient, composition and temperature (Singh and Heldman, 2009). Increase in the storage relative humidity (≈83%) resulted in migration of moisture down the vapour pressure gradient into the dried capelin (aw - 0.62) stored in the HB to a point of equilibrium. The reverse temperature and humidity cycle had little effect on moisture migration because at lower relative humidity water is tightly bound according to Sahin and Sumnu (2006). The cumulative effect of fluctuating temperature and humidity resulted in maximum equilibrium moisture content and water activity of the dried capelin in HB during the fourth week of storage. Water activity of food is important because it triggers microbial metabolism, enzymatic and chemical reactions. Generally, water activity <0.6 is sufficient to inhibit all microbial activity (Fellows, 2000). According to FDA (2001), dried fishery products under reduced oxygen packaging should maintain a minimum water activity ≤0.85 to be considered safe. This prevents growth and toxin production by *S. aureus* but more importantly the anaerobic *C. botulinum*. Water activity above 0.7 promotes growth of halophilic bacteria and xerophilic fungi (Ray and Bhunia, 2014). According to the draft East African Community (EAC) standards, the maximum moisture content requirement for dried fish is 14% (EAC, 2014). All packaging methods maintained safe storage moisture content and water activity except the HB. The implication of water activity on microbial growth is discussed further in section 5.3.

Colour is an important indicator of the composition and quality of food products. Colour perception influences the degree of acceptability of a given product by consumers (Sahin and Sumnu, 2006). In general, the colour of the dried capelin was stable throughout the storage period (Figure 7A-C). The differences among packaging methods were insignificant throughout storage. The colour of capelin is associated with its astaxanthin content. It varies from red, orange to yellow depending on season and more so feeding patterns (Bragadóttir *et al.*, 2002). Capelin has a high percentage of the stable diester astaxanthins in all seasons except summer (Bragadóttir, 2001). The decrease in lightness during the first four weeks of storage may be due

to formation of unstable brown compounds. Bragadóttir, *et al.* (2004) reported an increase in brown pigments of fish meal from capelin during early storage followed by a decline. Secondary products of lipid peroxidation especially malondialdehyde react with amino sugars to form heterocyclic compounds and polymers similar to melanoidins (Gómez-Sánchez *et al.*, 1990). Redness of dried capelin did not vary significantly during storage regardless of packaging method due to the stable astaxanthin. Yellowness correlated moderately (r=0.67, Appendix 1 - Table 4) with peroxide value in the first four weeks of storage. The observed trend in yellowness maybe associated with formation of products of lipid oxidation.

## 5.2 Lipid stability

Lipid content of dried capelin was generally stable but showed a decreasing trend towards the end of the storage period especially with the HB (Figure 8). The decrease in lipid content may be due to greater hydrolysis of lipids leading to formation of free fatty acids. Lipids in fish are hydrolysed by lipase and phospholipase to yield free fatty acids (Chaijan *et al.*, 2006). The marked increase in FFA content (Figure 11) during this period corroborates this assertion.

Peroxide value is a measure of primary oxidation of lipids. Lipid hydroperoxides are highly reactive and degrade rapidly to form secondary products such as aldehydes, alkyl radicals and oxo-esters (Fennema, 1996). Peroxides are produced in the early stages of lipid oxidation, rising to a peak before declining. This explains the observed increase in peroxide value within the first two weeks followed by a rapid decline in subsequent weeks of storage in AP and HB (Figure 9). This result was congruent with the findings of Odoli (2015) who reported an increase in PV of air packed cold smoked capelin followed by a decrease during chilled storage. Oxygen is a key proponent in the development of lipid hydroperoxide (Fennema, 1996) therefore reduced oxygen in VP and MAP resulted in the slow increase in PV compared to AP and HB. Oxygen involved in lipid oxidation diffuses from the food surface to the interior. Residual oxygen in the muscle contributes to the build-up of peroxides even during VP storage (Huang and Weng, 1998). Therefore, muscle oxygen may have contributed to the gradual increase albeit insignificant in PV of VP dried capelin during storage. The increase in PV of MAP dried capelin may be due to industrial nitrogen possibly containing low amounts of oxygen. Although similar, the low PVs at the fourth week of storage are due to limited oxidation in VP dried capelin whereas a decrease in unstable hydroperoxides is responsible for those observed in MAP, AP and HB. PV was most stable in VP dried capelin and this was in agreement with the findings of Odoli (2015) where PV of dried capelin was stable during vacuum storage at ambient temperature.

TBARS is a widely preferred method for measuring the degree of lipid oxidation as it has been reported to correlate strongly with sensory evaluation score (Fennema, 1996). The decrease in TBARS content of dried capelin in VP, HB and MAP during storage (Figure 10) was similar to the findings of Odoli (2015). According to Fennema (1996) and Undeland *et al.* (1999), reduction in TBARS content may be due to the reaction of malonaldehyde with proteins in an oxidising system, usually leading to formation of tertiary products of lipid oxidation. The trend of increase in TBARS content of AP capelin during the first four weeks of storage may be due to greater formation of malonaldehyde. Malonaldehyde may arise from the breakdown of prostaglandin-like endoperoxides during oxidation of polyunsaturated fatty acids as reported by Pryor *et al.* (1976). In principle, production of substantial quantities of TBA-reactive substances is linked to fatty acids with greater degree of unsaturation (Fennema, 1996). Ogongo *et al.* (2015) reported an increase in TBARS of dried sardine throughout storage using various packaging methods. However, different species, storage temperature (0 - 2 °C) and processing method (solar rack drying) were used. This might have contributed to the difference

in outcome. Nitrogen is an inert gas however it might have effected the deterioration of secondary products of lipid peroxidation throughout the storage period in MAP packed dried capelin.

FFA content of dried capelin increased throughout storage and was independent of packaging method (Figure 11). This was in agreement with Odoli (2015) who reported increase in FFA content of dried capelin during room temperature storage using open, sealed and vacuum packaging. Bragadóttir *et al.*, 1998) also reported significant increase in FFA content of dried whole capelin during an accelerated shelf life study. FFA are products of lipid hydrolysis catalysed by lipase and phospholipase (Toyomizu *et al.*, 1981; Pacheco-Aguilar *et al.*, 2000). According to Chaijan *et al.*, (2006) lipase and phospholipase activity in the muscle, digestive tract and microorganisms all contribute to increase in FFA. FFA and lipid content had a good negative correlation throughout the storage period (r = -0.80, Appendix 1 - Table 5). The greater formation of FFA in HB packed dried capelin may be due to the increase in moisture content and especially water activity. Adawiyah *et al.*, (2012) reported an increase in the amount of FFA of lipase-catalysed lipid hydrolysis in a food model system as a result of increase in moisture content. Water plays an important role in enzyme activation.

### 5.3 Microbiological stability

Microorganisms occur normally in the digestive tract, scales and skin of fish. However, fish may, in addition be contaminated from various sources such as air, soil, water and, during handling and processing via contact by humans and equipment (Ray and Bhunia, 2014). Packaging method influenced microbial stability of dried capelin during storage (Figure 12, 13A-B). The initial increase in TC of dried capelin in AP, HB and MAP was probably due to presence of Oxygen at different partial pressure. This facilitated growth of aerobic microorganisms. Unexpected increase in TC of MAP dried capelin was possibly due to microaerophilic microorganisms which withstand low oxygen partial pressure given that industrial nitrogen gas (≈99.9% purity) was used. TC of VP dried capelin decreased throughout the storage period because of unfavourable anaerobic conditions. The growth capability of microorganisms in food is dependent on availability or absence of oxygen and the redox potential of the food. Yeasts and moulds are basically aerobic and this explains their proliferation in AP and HB packed dried capelin. The growth of yeasts in AP at low water activity is an indicator of osmophilic yeasts whose minimum water activity is 0.6 - 0.7 (Ray and Bhunia, 2014). The proliferation of moulds in HB dried capelin is associated with increase in water activity during storage (Figure 5). According to Fellows (2000), water activity of less than 0.7 should be maintained to deter fungal activity. The continued proliferation of moulds in HB dried capelin also alludes to possible cross contamination from the bags.

### 5.4 Near infrared spectroscopy (NIR) calibration models

The $R^2_{cv}$ and RMSECV (root mean square error of cross validation) values of NIR calibration models for water content, water activity and pH of dried capelin were high and low respectively (Figure 14). This implies that these physicochemical properties can be predicted using NIR in an independent sample with a high degree of accuracy. In a recent study, Masoum *et al.* (2012) successfully demonstrated the use of NIR to evaluate moisture content of fishmeal. $R^2_{cv}$ value of colour (lightness, redness and yellowness) (Figure 15) was medium indicating moderate predictability. Regarding lipid stability (Figure 16), only FFA content had a moderate degree of accuracy for prediction. LC, PV and TBARS all had low $R^2_{cv}$, high RMSECV and therefore cannot be estimated with certainty using NIR at this point. This is contrary to Karlsdottir *et al.* (2014) who reported that lipid composition and degradation of saithe and hoki could be

predicted with good accuracy using NIR. The number of samples used in the calibration models probably account for differences with this study.

## 6. CONCLUSIONS

The present study showed that packaging methods greatly influenced storage stability of dried capelin in the simulated temperature and relative humidity conditions. Vacuum packaging enhanced the overall storage stability of dried capelin especially against primary lipid oxidation (low peroxide value) and microbial growth throughout the storage period. Also, modified atmosphere packaging enhanced lipid stability of dried capelin as evidenced by the significant reduction in secondary lipid oxidation products (TBARS) during the eight-week study. Air and hessian bag packaging were not effective in preventing lipid oxidation and growth of microorganisms. More so, the water content and water activity of dried capelin in the HB increased significantly leading to greater proliferation of moulds. Therefore, hessian bags are not ideal packaging materials for storage of dried capelin in conditions of high relative humidity. The colour and pH of dried capelin were relatively stable throughout the storage period. Free fatty acid content of dried capelin in AP, VP, MAP and HB increased steadily during the entire storage period indicating that packaging method alone is not an effective tool for controlling lipid hydrolysis.

Overall, the good quality of raw material and controlled indoor drying process were pivotal in ensuring that most quality indicators of dried capelin remained within acceptable specification limits throughout the storage period.

Near infrared spectroscopy (NIR) can be used to estimate water content, water activity and pH of dried capelin with a good degree of accuracy. NIR provides a rapid and non-destructive alternative means of measuring the physicochemical properties of dried capelin However, it is important to add more samples to the calibration models to validate these results.

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# APPENDICES

## Appendix 1: Summary of Pearson's correlation coefficients data

**Table 4: Pearson's correlation coefficients between physical, chemical and microbiological attributes of dried capelin packaged using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag during the first four weeks of storage (0 - 4 weeks).**

| | FFA | Lipid content | TBARS | PV | Water content | Water activity | pH | Lightness | Redness | Yellowness | Total counts | Yeasts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Lipid content** | -0.78 | | | | | | | | | | | |
| **TBARS** | 0.10 | -0.43 | | | | | | | | | | |
| **PV** | 0.48 | -0.56 | 0.04 | | | | | | | | | |
| **Water content** | 0.91 | -0.83 | 0.21 | 0.35 | | | | | | | | |
| **Water activity** | 0.97 | -0.81 | 0.23 | 0.54 | 0.93 | | | | | | | |
| **pH** | **-0.84** | 0.43 | 0.00 | -0.05 | -0.68 | -0.74 | | | | | | |
| **Lightness** | -0.90 | 0.52 | -0.14 | -0.27 | -0.77 | -0.87 | 0.92 | | | | | |
| **Redness** | -0.12 | 0.22 | -0.14 | -0.70 | -0.09 | -0.24 | -0.24 | -0.04 | | | | |
| **Yellowness** | 0.41 | -0.16 | -0.22 | **0.67** | 0.06 | 0.37 | -0.30 | -0.35 | -0.48 | | | |
| **Total counts** | 0.16 | -0.39 | 0.05 | 0.70 | 0.06 | 0.21 | 0.29 | 0.08 | -0.55 | 0.54 | | |
| **Yeasts** | 0.05 | -0.42 | 0.20 | 0.44 | -0.08 | 0.02 | 0.19 | 0.22 | -0.39 | 0.42 | 0.69 | |
| **Moulds** | 0.87 | -0.79 | 0.19 | 0.72 | 0.87 | 0.94 | -0.53 | -0.73 | -0.39 | 0.37 | 0.31 | 0.00 |

**Table 5: Pearson's correlation coefficients between physical, chemical and microbiological attributes of dried capelin packaged using AP – Air Packaging; VP – Vacuum Packaging; MAP – Modified Atmosphere Packaging and HB - Hessian Bag during the entire storage period (8 weeks)**

| | FFA | LC | TBARS | PV | Water content | Water activity | pH | Lightness | Redness | Yellowness | TC | Yeasts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LC** | **-0.80** | | | | | | | | | | | |
| **TBARS** | -0.38 | 0.06 | | | | | | | | | | |
| **PV** | 0.72 | -0.54 | -0.41 | | | | | | | | | |
| **Water content** | 0.53 | -0.70 | 0.13 | 0.13 | | | | | | | | |
| **Water activity** | 0.52 | -0.66 | 0.13 | 0.07 | **0.95** | | | | | | | |
| **pH** | -0.55 | 0.49 | -0.01 | -0.16 | -0.77 | -0.80 | | | | | | |
| **Lightness** | -0.15 | 0.25 | -0.30 | -0.07 | -0.58 | -0.58 | 0.69 | | | | | |
| **Redness** | 0.33 | -0.09 | -0.31 | 0.24 | 0.02 | -0.01 | -0.24 | 0.17 | | | | |
| **Yellowness** | 0.44 | -0.27 | -0.32 | 0.28 | 0.01 | 0.22 | -0.23 | -0.04 | -0.10 | | | |
| **TC** | -0.47 | 0.06 | 0.31 | -0.44 | 0.01 | 0.13 | 0.21 | -0.05 | -0.46 | 0.18 | | |
| **Yeasts** | -0.14 | -0.21 | 0.26 | -0.13 | -0.09 | -0.02 | 0.19 | 0.04 | -0.39 | 0.30 | 0.56 | |
| **Moulds** | 0.51 | -0.65 | 0.14 | 0.05 | 0.90 | 0.92 | -0.68 | -0.56 | -0.16 | 0.19 | 0.09 | -0.02 |

**Appendix 2: Pictures of frozen and dried capelin**


**Figure 17: Frozen capelin (A), dried whole capelin (B and C), dried capelin mince (D)**

**Appendix 3: Pictures of air packaging, vacuum packaging, modified atmosphere packaging and hessian bag packaging**


**Figure 18: Air packaging (A), vacuum packaging (B), modified atmosphere packaging (C) and hessian bag packaging (D)**

**Appendix 4: Pictures of storage chamber and packaging equipment**


**Figure 19: Storage chamber; empty (A), loaded (B) and middle compartment (C)**


**Figure 20: Temperature (A) and relative humidity (B) control panels of storage chamber**


**Figure 21: Webomatic vacuum packaging and gas flushing machine**


**Figure 22: Control panel of vacuum packaging and gas flushing machine**