Adding Value To Underutilised Fish Species

ADDING VALUE TO UNDERUTILISED FISH SPECIES

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SUMMARY

Tightening fish quotas and supply shortages for conventional species are causing major difficulties for both fishermen and seafood processors. There is a need, therefore, to explore the potential of underutilised fish species both as fillets or portions and as added-value products. The current project at Ashtown Food Research Centre (AFRC) addressed this issue for a number of underutilised species via (a) *sous vide* processing (with savoury sauces), (b) marinating (salt- and sugar-based marinades) and (c) via a combination of freeze-chilling and modified atmosphere packaging (MAP). A range of physico-chemical and sensory tests was conducted on the products and their shelf-life status was also determined.

Seven underutilised fish species (albacore tuna, cardinal fish, orange roughy, blue ling, redfish, roundnose grenadier and Greenland halibut) were cooked by the *sous vide* process in 12 savoury sauces. Sensory results showed that *sous vide* cooked albacore tuna, cardinal fish and blue ling were the most acceptable species and tikka, tomato+pesto, arrabbiata and hollandaise the preferred sauces. Greenland halibut and roundnose grenadier were too soft after *sous vide* cooking. Freezing after *sous vide* cooking did not influence product quality and gave the additional benefit over chilling of an extended shelf-life.

Preparing marinades is a highly convenient way of adding value to fish portions and requires relatively simple in-factory facilities. Albacore tuna and blue ling portions were marinated (3h at 4°C) in aqueous solutions (10, 20, 30% w/v) of six commercial salt- and sugar-based marinades respectively. Sensory acceptability scores [6-cm scale from unacceptable (0) to very acceptable (6)] for tuna fish portions marinated at the optimum marinade concentrations (between 10 and 30% w/v) and stored at 4°C overnight, indicated that Cajun, tandoori, lemon+lime, arrabbiata and southern fried were all highly acceptable with panel scores >3.0 (mid-point of the scale). However, smoke marinade scored poorly due to its salty flavour. Sensory acceptability scores for blue ling portions in 30% sugar-based marinades were

highest for piri piri and chilli+coriander and lowest for orange glaze. The latter received a particularly low acceptability rating (1.78) and was classed as too acidic in taste. In these tests, nine out of 12 samples (*i.e.* six of marinated tuna and six of blue ling) received sensory scores >3.0. This was a positive finding indicating that both albacore tuna and blue ling were suitable species for marinating.

Freeze-chilling confers logistical benefits while modified atmosphere packaging (MAP) often confers additional shelf-life to raw fish fillets. Hence, the two technologies were combined in these trials. Samples of six species were packed in trays in air and in $30\%O_2/40\%CO_2/30\%N_2$ and were subjected to a freeze-chill regime (chilled component of 2-4°C for 7 days). The results showed that freeze-chilling with MAP is a suitable combination of technologies for extending the shelf-life of pre-packaged portions of black scabbard, faux siki, redfish, cardinal fish, roundnose grenadier and blue whiting. The six species received good sensory acceptability scores of 4.54 (cardinal fish), 4.48 (black scabbard), 4.40 (blue whiting), 4.27 (roundnose grenadier), 3.92 (redfish) and 3.34 (faux siki) for chilled samples at 4°C on a scale with end-points of 0 (unacceptable) and 6 (very acceptable). The data are means for days 0, 3 and 5. Values for MAP *vs* air for the six species were 4.76 *vs* 4.32 (cardinal fish), 4.90 *vs* 4.01 (black scabbard), 4.60 *vs* 4.20 (blue whiting), 4.33 *vs* 4.21 (roundnose grenadier), 4.01 *vs* 3.73 (redfish) and 2.96 *vs* 3.72 (faux siki). In practical terms, this means a 1 to 3-day extension of shelf-life due to MAP with the exception of faux siki. These findings were supported by the total volatile base nitrogen (TVBN), total viable count (TVC) and odour perception data. MAP gave higher drip (both gravity and centrifugal) values than the air-packed samples. However, the gravity drip values were not of a magnitude that required in-pack drip pads with the exception of blue whiting. Roundnose grenadier, faux siki, redfish, black scabbard and cardinal fish had an excellent white flesh; blue whiting had a more translucent appearance.

The results from these trials were presented to seafood and related companies at three major industry workshops (one in each year of the project) together with sample tasting and round-table discussions. As a result, further applied R&D is ongoing with a number of companies.

INTRODUCTION

The market for seafood products in Europe has grown significantly in recent years, fuelled by increases in the average unit value of seafood products. The growth of value-added products has the potential to create considerable demand for underutilised non-quota fish species, especially given the supply constraints due to quotas (Price Waterhouse Coopers, 2001) and to dwindling stocks of traditional species. This shortfall has created a demand for high quality fillets in addition to seafood products. Many underutilised fish species yield high quality fillets which are comparable to those from commercial species (Gormley and Fagan, 2005). There is a need, therefore, to explore the potential of underutilised fish species both as fillets or portions and as added-value products. The current project addressed this issue for a number of underutilised species via (a) *sous vide* processing (with savoury sauces), (b) marinating (salt- and sugar-based marinades) and (c) via a combination of freeze-chilling and modified atmosphere packaging (MAP). A range of physico-chemical and sensory tests was conducted on the products and shelf-life status was also determined.

Sous vide technology has considerable potential as a method for processing value-added seafood products (Fagan and Gormley, 2005a,b). Raw or par-cooked food is sealed in a laminated plastic pouch or container which is under partial vacuum, heat-treated by controlled cooking, rapidly chilled and then reheated for service after a period of chilled or frozen storage (SVAC, 1991). The quality of *sous vide* final products is often superior to foods cooked or processed in more conventional ways (Sornay, 1990). The minimum recommended thermal process for *sous vide* products is 90°C for 10 minutes or its time-temperature equivalent (SVAC, 1991).

Marinating involves the introduction of flavours into raw fish fillets, which can then be packaged and retailed as chilled, frozen or freeze-chilled products. It involves soaking water-rich solid products such as fish in concentrated aqueous solutions of salt, sugar or other osmotic agents thereby producing (a) water outflow from the product to the solution, (b) solute transfer from the solution to the product and (c) leaching of product solutes (sugars, organic acids, minerals, vitamins) (Raoult-Wack, 1994). Marinades can be purchased fully made (liquid) or as water-soluble powders and can be formulated to particular specifications *e.g.* salt-based or sugar-based as required.

Freeze-chilling offers logistic benefits in terms of streamlining production, enabling chilled products to reach distant markets and in reducing the number of product recalls (Redmond *et al.,* 2004). It is highly suitable for extending the shelf-life of seafood products especially when combined with MAP (Fagan *et al.*, 2003, 2004). The frozen component of the freeze-chill process can be weeks, months or even years while the chill phase is normally 3-5 days at 2-4°C. The additional application of MAP can extend this to 5-8 days depending on fish species.

MATERIALS AND METHODS

Sous vide processing

Seven underutilised fish species *i.e.* orange roughy *(Hoplostethus atlanticus),* albacore tuna *(Thunnus alalunga),* cardinal fish *(Epigonus telescopus),* deepwater redfish *(Sebastes mentella)*, roundnose grenadier *(Coryphaenoides rupestris),* blue ling *(Molva dypterygia)* and Greenland halibut *(Reinhardtius hippoglossoides)* were sourced during fishing trials by Bord Iascaigh Mhara (BIM: Irish Sea Fisheries Board). The samples (on ice) were filleted and delivered to Ashtown Food Research Centre within 24h of landing. They were vacuum-packed, blast-frozen at -35°C for 2.5h and stored at -20°C until required (up to 5 weeks) for *sous vide* processing.

One water-based and eleven oil-based sauces were sourced from ingredient suppliers. The sauces were: tomato+pesto, Szechuan, Cajun, arrabbiata, bearnaise, hollandaise, mushroom (from Knorr, UBF Food Solutions, Ireland); toskana, tomato+basil, Italian, rosemary+garlic (from Raps, UK); tikka (water-based) (from Allinall Ingredients Ltd., Ireland). The sauces were ready-to-use and were added to the fish at a 1:1 ratio.

Fillets were thawed overnight at 2-4ºC, portioned (*circa* 200g) and vacuum-packed (± sauce) in anti-fog vacuum bags (200 x 250; 15/45) (Millerpack Ltd, Dublin, Ireland). Trial 1 was conducted without sauce and Trials 2 and 3 with sauce. The samples were cooked in a Barriquand Steriflow retort and the time to achieve a process temperature equivalent to 90ºC/10min was determined (Ellab TM9608 temperature recording system). The cooked samples were blast-frozen (-35°C) and stored at -20°C for one week before testing. Some samples were also held at 4°C before testing. A range of physico-chemical, sensory and microbiological tests was conducted on the product range (see details below).

Marinating trials

Albacore tuna *(Thunnus alalunga)* and blue ling *(Molva dipterygia)* were sourced and pre-treated as for the *sous vide* samples above. Thawed portions (120g) were marinated (3h at 4ºC) in aqueous solutions (10, 20, 30% w/v) of six commercial salt- and sugar-based marinades respectively. The salt-based marinades were Cajun, smoke, tandoori, lemon+lime, arrabbiata and southern fried. The sugar-based were chilli+coriander, sweet+sour, lemon pepper, Chinese mix, piri piri and orange glaze. All were sourced from ingredient companies in Dublin. The marinated products were stored in cling film at 2-4ºC for 1-2 days prior to being subjected to a range of physico-chemical, sensory and microbiological tests (see details below).

Freeze-chilling with MAP

Tests were conducted on black scabbard *(Aphanopus carbo),* faux siki *(Centrophorus squamosis),* deepwater redfish *(Sebastes mentella),* cardinal fish *(Epigonus telescopus),* roundnose grenadier *(Coryphaenoides rupestris).* and blue whiting *(Micromesistius poutassou).* The first four species were sourced and pre-treated as for the *sous vide* samples above. Blue whiting samples were sourced as block frozen fillets, individually quick-frozen (IQF) fillets and as fillets from previously-frozen round fish (*i.e.* entire fish with gut-in). The samples came from the same commercial catch and were landed in Killybegs, Co. Donegal. The block-frozen and IQF fillets were tempered to chill in the MAP packs and the thaw water was measured as gravity drip (GD) on the different test days. The round fish were thawed in-factory, filleted and sent chilled to the AFRC for inclusion in air or MAP packs; in this case the thaw water was not included in the GD value. In addition, the thawed round fish fillets were 1 day in chill during transit to the AFRC which means that test days 0, 3, 5 and 9 were (in reality) days 1, 4, 6 and 10 for the round fish fillets of blue whiting. This should be borne in mind when interpreting the data in the Results and Discussion section. The thawed (tempered at 4ºC) samples (150-200g) of the six species were pre-packed in trays [110 x 150 x 55mm (Dynopak Ltd)] (Dyno AF 320 anti-fog film) using an MAP machine (MECApac 500) in air or in 30%O_2/40%CO_2/30%N_2. The samples were evaluated on days 0, 3, 5, and 7 (days 0, 3, 5 and 9 for blue whiting) from chill storage at 4ºC. All samples were freeze-chilled as they originated from frozen fillets or round fish and were then tempered to chill for these tests. The exception to this was black scabbard which was tested as chilled fillets or portions (± MAP) and also as freeze-chilled (± MAP). The freeze-chilling regime for this species was blast freezing (-30ºC), holding at -20ºC for 1 day followed by thawing and storage for 7 days at 4ºC.

Physico-chemical, sensory and microbiological tests

Moisture content, colour (Hunter Lab), total volatile base nitrogen (TVBN) and centrifugal/gravity drip were determined as described by Fagan *et al.* (2003). Total viable count was determined by standard procedures and salt (in the marinated products) by Mohr's method (James, 1995). Texture tests were conducted using a Kramer shear press with 100g samples (standard test cell). Cooking loss in *sous vide* samples was calculated by weighing the fish samples before and after cooking. pH values of the fish flesh and the savoury sauces (in the *sous vide* and marinating trials) were determined with a 420Aplus bench-top pH/ISE meter (Thermo Electron Corporation, USA). Sensory acceptability of the samples in the different trials was assessed on a 6-cm line with end-points of 0 (unacceptable) and 6 (very acceptable) using 10-25 tasters. All the samples for tasting were heated using a microwave oven

(700W/2 min). Fish odour was assessed as outlined by Fagan *et al.* (2003) using a 6 cm scale with end-points of 0 (fresh seaweed-like odour) and 6 (spoiled odour). Four to six trained assessors were used in the odour panels. The marinade concentration (10, 20 or 30% w/v) delivering the ideal level of flavour in the fish was determined by a sensory panel using a 6cm line scale with end-points of 0 (flavour too weak) and 6 (flavour too strong) with the mid-point (3) of the scale representing the ideal level of delivered flavour in the fish. Ideal fish texture in the *sous vide* tests was determined using a similar 6cm scale with the mid-point (3cm) representing ideal texture.

The results from all the trials were tested by analysis of variance (ANOVA) using SAS (Version 6.12, SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

Sous vide processing with sauces

The cooking times (Ellab TM9608) equivalent to 10min/90°C (P_{90}>10) used in these trials in the Barriquand retort system were 40min/85°C, 20min/90°C and 15min/95°C. Process time and temperature did not influence product texture with mean sensory texture scores of 2.76, 2.89 and 2.82 respectively. However, there were large differences between species with albacore tuna having an over-firm texture and roundnose grenadier and Greenland halibut a soft texture. *Sous vide* cooked orange roughy, cardinal fish, redfish and, to a lesser extent, blue ling had texture scores in the ideal range *i.e.* circa 3. The different time/temperature process treatments had no effect on cooking loss, shear values, colour, centrifugal drip and moisture content of the fish portions. Processing for 20min/90°C (P_{90}>10) gave a wide range ($P<0.001$) in centrifugal drip values and moisture contents between the seven species. Albacore tuna had the lowest centrifugal drip value (4.1% w/w) and Greenland halibut the highest (18.9% w/w). Albacore tuna had a much lower moisture content (63.9% w/w) compared to the other species (range 70.5-80.3% w/w). It also had a firmer texture (5.12kN *vs* a range of 1.15-2.23kN) and a lower cook loss (18.9% *vs* a range of 25.2-40.7% w/w) (Fagan and Gormley, 2005a). However, freezing versus chilling after *sous vide* cooking had no effect on mean cooking loss or shear values.

Sensory results showed that *sous vide* cooked albacore tuna, cardinal fish and blue ling were the most acceptable species and tikka, tomato+pesto, arrabbiata and hollandaise the preferred sauces. A comparison of these is given in Table 1 and most fish/sauce combinations received sensory scores >4 indicating good acceptability. *Sous vide* cooking seals in flavours, conserves nutrients, gives good texture and is convenient for the consumer since it only requires short microwave reheat times (Tansey *et al.*, 2003). In the current trials, the presence of sauce during *sous vide* cooking caused the softer-fleshed species (notably Greenland halibut and roundnose grenadier) to become soggy. Lipid and water account for up to 80% of fish muscle and shrinkage of the myofibrils at 40-50°C results in a loss of water as they shorten and denature. Liquid holding capacity is influenced by structural changes in the fish proteins including fibril swelling, muscle contraction and the distribution of fluid between intra- and extracellular locations. Fish muscle contracts during cooking and water is expelled causing toughening of the flesh. However, the presence of sauce in the packs during *sous vide* cooking may cause a stewing effect which further weakens the structure of the meat resulting in a softer bite or mouthfeel**.** Freezing after *sous vide* cooking did not influence product quality and gave the additional benefit over chilling of an extended shelf life.

Table 1: Taste panel acceptability scores[a] for sous vide cooked (20min/90°C; P_{90} >10min) fish portions with sauces

	Sauce type				
Species	Tikka	Hollandaise	Arrabbiata	Tomato+pesto	Mean
Albacore tuna	4.20	4.20	4.52	4.81	4.31
Cardinal fish	4.73	3.90	3.77	4.94	4.13
Blue ling	4.47	3.84	3.88	4.18	4.06
Mean	4.47	3.98	4.07	4.64	

[a]6 cm scale with end-points of 0 (unacceptable) and 6 (very acceptable)

The pH of the sauces was in the range 3.96 (Cajun) to 5.42 (bearnaise) and mean pH values fell from 4.66 before *sous vide* cooking to 4.38 after cooking. Sauce colour also became lighter during *sous vide* cooking (with fish portions) as indicated by Hunter Lab colour values.

Marinating trials

Marinating in salt- and sugar-based marinades is a highly convenient way of adding value to fish portions and requires relatively simple facilities in-factory. Albacore tuna and blue ling portions were marinated (3h at 4°C) in aqueous solutions (10, 20, 30% w/v) of six commercial salt- and sugar-based marinades respectively (see Tables 2 and 3). The samples were stored at 4°C overnight and then tested. Sensory acceptability scores (6cm scale, as described above) for tuna fish portions marinated at the optimum marinade concentrations indicated that Cajun, tandoori, lemon+lime, arrabbiata and southern fried were all highly acceptable (Table 2) with panel scores >3.0 (mid-point of the scale). However, smoke marinade scored poorly due to its salty flavour. Different marinade concentrations were used (Table 2) depending on the marinade type as preliminary trials indicated that marinade concentration needed to be optimised with some marinades imparting a ‘too weak flavour’ at a 10% concentration while others were sufficiently strong at this concentration. Both marinade type and concentration affected mass transfer (gain or loss in weight) values which ranged from 2.5% (Cajun) to 12.5% (Southern fried) and from 7.3% (10% marinade concentration) to 10.4% (30% concentration). These weight gains are important from a commercial point of view for processors. There was an interaction between marinade type and concentration in that mass transfer was significantly higher in the 30% marinades than in 10% for Cajun, tandoori, lemon+lime, arrabbiata and southern fried while the reverse was the case for the smoke marinade. Tuna portions in Cajun marinade had the highest centrifugal drip loss (16.8% w/w) and smoke and arrabbiata marinades the lowest (1.39% and 2.38% w/w respectively). Centrifugal drip loss decreased as solution concentration increased with losses of 9.1, 7.2 and 5.2% w/w for marinade concentrations of 10, 20 and 30% respectively. Presumably the high salt content of the 30%

marinade resulted in increased water-binding. The exception was the smoke marinade which showed the opposite pattern. Smoke and Cajun marinades gave products with the lowest moisture content (66.8 & 68.0% w/w) and southern fried the highest (73.3% w/w). Tuna fish moisture content decreased (71.6, 70.5, 68.9% w/w) as marinade strength increased. (10, 20, 30% w/w).

Table 2: Taste panel (25 tasters) acceptability scores[a] for tuna fish portions marinated at ideal marinade concentration

Marinade	Concentration (% w/w)	Score[a]
Cajun	30	4.3
Smoke	10	2.6
Tandoori	20	3.8
Lemon+lime	30	3.8
Arrabbiata	10	4.2
Southern fried	10	3.7

[a]6 cm scale with end-points of 0 (unacceptable) and 6 (very acceptable)

Sensory acceptability scores for blue ling portions in 30% w/w sugar-based marinades were highest for piri piri and chilli+coriander and lowest for orange glaze; the latter received a particularly low acceptability rating (1.78) and was classed as too acidic in taste (Table 3).

These scores were, in general, lower than those given to tuna fish portions in the salt-based marinades. Preliminary tests indicated that a 30% w/w marinade concentration was necessary in order to deliver a sufficiently strong flavour. Blue ling portions in chilli+coriander, lemon pepper, Chinese mix and piri piri marinades showed small mass transfer gains (2.9 to 4.9% w/w) while samples in orange glaze (-2.5% w/w) and sweet+sour (-11.1% w/w) showed a weight loss. Centrifugal drip values ranged from 17.1 (piri piri) to 24.7%

Table 3: Taste panel (25 tasters) acceptability scores[a] for marinated (30% w/w) blue ling portions

Marinade	Score[a]
Chilli + coriander	3.24
Sweet + sour	2.58
Lemon pepper	3.14
Chinese mix	3.23
Piri piri	3.46
Orange glaze	1.78

[a]See footnote, Table 2

(sweet+sour) and moisture contents from 76.4 (sweet+sour) to 79% w/w (Chinese mix).

In the marinating trials, nine out of 12 samples (*i.e.* six of marinated tuna and six of blue ling) received sensory scores >3.0. This was a positive finding indicating that both albacore tuna and blue ling were suitable species for marinating. All the albacore tuna samples in the salt-based marinades gained weight which is an important finding commercially. Mass transfer was weakly correlated with marinade salt (r = + 0.43) and ash (r = + 0.48) contents. Marinating (osmotic dehydration) involves a water outflow from the product into the solution, a solute transfer from the solution to the product and a leaching of the product solutes. In the current trials, salt-based marinades were acidic (pH of 3.43 [lemon+lime] to 5.90 [southern fried]) and centrifugal drip values decreased as marinade concentration increased. The highest pH values for the sugar-based marinades were observed in fish portions immersed in chilli+coriander, piri piri and lemon pepper; in these marinades there was a net gain in weight. The shelf-life of these marinated fish products is of major significance to seafood companies and future work will focus on this aspect.

Freeze chilling ± MAP trials

The results for black scabbard and blue whiting are presented individually and those for faux siki, deepwater redfish, cardinal fish and roundnose grenadier as a group.

Black scabbard: Process treatments embracing a freezing step gave higher centrifugal and gravity drip values than chill-only treatments; MAP also gave higher drip values than packing in air (Tables 4 and 5). However, gravity drip values were much smaller than centrifugal drip figures and it is unlikely that in-pack drip pads would be required. The inclusion of MAP greatly reduced TVBN and TVC values (Tables 4 and 5); values for both these parameters increased over the 7-day test period. The TVBN values were below the upper limit of 35mg/100g (EC guidelines 95/149/EC) with the exception of the day 7 value (42mg/100g) for the chill + air treatment. The TVC values were high and virtually all were above the upper recommended limit of $\log_{10}5$ cfu/g for raw fish (Department of Health and Children, 1992). Process treatments had no influence on flesh pH values or colour (white/yellow ratios) but the pH value on day 7 was higher than on the previous days (Table 5). Flesh became less white over days 0, 3 and 5 but values rose again by day 7. The samples with MAP received better odour and sensory acceptability scores than those packed in air but there was little difference between the chilled and freeze-chilled samples. Sample odour disimproved over the 7-day test period and acceptability scores fell from 5.09 on day 0 to 4.3 on day 5.

Acceptability tests were not conducted on day 7 due to the high prevailing TVCs. Sensory scores and odour perception were highly correlated (0.86) while sensory scores were negatively correlated with TVBN (-0.47) and TVC (-0.45). Other correlations were: -0.86 (odour perception x TVBN), 0.71 (TVBN x TVC) and -0.60 (odour perception x TVC). The outcomes and trends for this species were similar to those found by Fagan *et al.* (2003, 2004) for fillets or portions of whiting, mackerel and farmed salmon.

Table 4: Effect of chilling, freeze-chilling and gaseous atmosphere on selected quality parameters (mean values)[a] of black scabbard fish portions

Parameter	Chill[b] + air	Chill + MAP[c]	F-C[d] + air	F-C + MAP
Centrifugal drip (% w/w)	11.1	11.4	15.8	22.5
Gravity drip (% w/w)	1.29	2.21	3.88	5.83
TVBN (mg/100g)[e]	22.1	12.9	16.9	11.9
TVC (log10cfu/g)[f]	6.57	5.22	6.53	5.03
Odour score[g]	2.87	0.78	2.93	1.17
Sensory acceptability[h]	4.21	4.98	3.92	4.82

[a]Means over 4 test days (see Table 5); $P<0.001$ for each parameter; [b]7 days at 4ºC; [c]30%O_2/40%CO_2/30%N_2; [d]-25ºC for 3 weeks and 7 days at 4ºC [e]Total volatile base nitrogen; [f]Total viable count [g]6cm line with end-points of 0 (fresh seaweed-like) and 6 (spoiled odour) [h]6cm line with end-points of 0 (unacceptable) and 6 (very acceptable)

Table 5: Effect of storage time (days) on selected quality parameters (mean values)[a,b] of black scabbard fish portions.

Parameter	Day 0	Day 3	Day 5	Day 7
Flesh pH	6.53	6.56	6.54	6.79
Colour (Hunter L/b)	39.9	24.5	15.5	26.9
Centrifugal drip (% w/w)	9.7	15.9	18.7	16.4
Gravity drip (% w/w)	0.0	4.00	4.43	4.78
TVBN (mg/100g)	9.7	12.7	16.6	24.7
TVC (log10cfu/g)	5.02	5.66	6.02	6.66
Odour score	0.64	1.10	2.89	3.11
Sensory acceptability	5.09	4.60	3.76	NT[c]

[a]Means over chill and freeze-chill treatments ± MAP (see Table 4); $P<0.001$ for each parameter
[b]See footnotes in Table 4; [c]not tested

Faux siki, redfish, cardinal fish, roundnose grenadier: The patterns in the cardinal fish graphs (Figures 1-4) for TVBN, TVC, odour perception and sensory acceptability are typical of the four species. They indicate that, in general, MAP prolongs shelf-life and maintains odour perception and acceptability scores during storage at 4°C for 7 days better than samples packed in air.

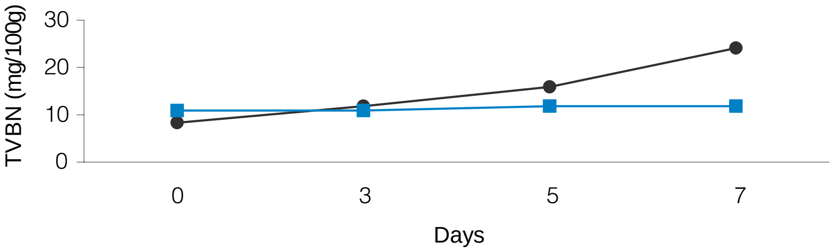

Figure 1. The effect of gaseous atmosphere and storage time (days at 4°C) on total volatile base nitrogen (TVBN; mg/100g) values of freeze-chilled cardinal fish portions. (●) Freeze-Chill + Air, (■) Freeze-Chill + MAP

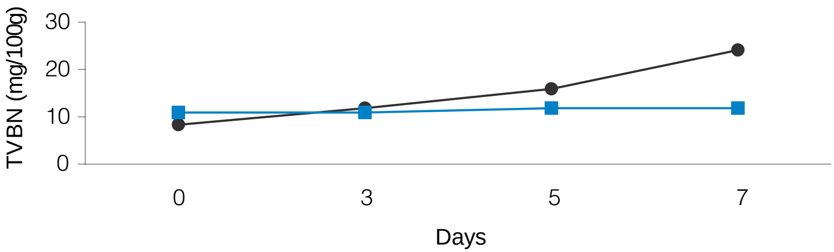

Figure 2. The effect of gaseous atmosphere and storage time (days at 4°C) on total viable count (TVC; $\log_{10}$cfu/g) values of freeze-chilled cardinal fish portions. (●) Freeze-Chill + Air, (■) Freeze-Chill + MAP

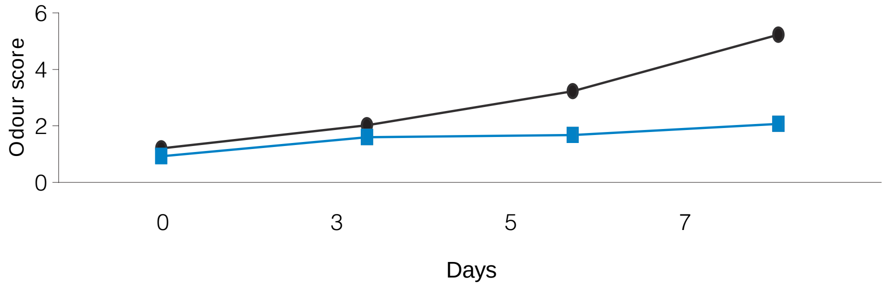

Figure 3. The effect of gaseous atmosphere and storage time at 4°C on odour scores for freeze-chilled cardinal fish portions. (●) Freeze-Chill + Air, (■) Freeze-Chill + MAP

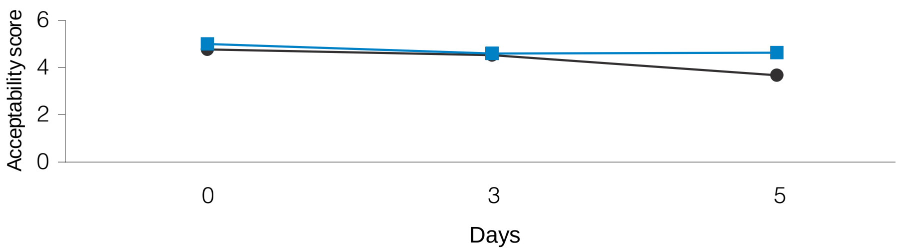

Figure 4. The effect of gaseous atmosphere and storage time at 4°C on sensory acceptability scores for freeze-chilled cardinal fish portions. (●) Freeze-Chill + Air, (■) Freeze-Chill + MAP

The day 5 shelf-life data for the four species are presented in Tables 6-10. Day 5 was chosen rather than day 7 as some of the day 7 samples were not tested for sensory acceptability due to high TVCs. Day 5 also represents a reasonable shelf-life point in the storage of the fish.

Fish whiteness (raw samples) was measured with a Hunter colour meter and day 5 whiteness (L values) was recorded. The samples packed in MAP were whiter than those packed in air with a difference of 4 Hunter L units being readily discernible by the eye. Roundnose grenadier (L = 67), faux siki (67) and redfish (61) had the whitest flesh of the four samples and the L values were similar to those of silver smelt (*Argentinus silus*) (61) and raw cod (65). Both these latter species are noted for their flesh whiteness. Cardinal fish flesh was less white (L = 55) but still had an excellent appearance.

Samples in MAP had lower pH values (with the exception of faux siki) than those in air presumably due to the presence of CO_2 in the gas mixture (Table 6). This should indicate a longer shelf-life for the MAP samples which was the case (see Tables 9 and 10). pH values rose with storage time for fish packed in both types of atmosphere but the increase was largest for the air-packed samples. Faux siki had the lowest pH of the four samples and roundnose grenadier the highest. pH has a large influence on water-binding capacity with the lowest capacity at a pH of *circa* 5. The correlations between pH values and the other test variables are given in Table 11.

Centrifugal drip values varied considerably between the four species and were particularly high for roundnose grenadier at *circa* 20% w/w. Centrifugal drip values were highest for the MAP treatment in redfish and cardinal fish but not in the other two species. The CO_2 component of MAP often increases drip in fish fillets (Fagan *et al.,* 2004). A large decrease took place in centrifugal drip values for the air-packed samples over the storage period and may be due to changes in the nature of the protein resulting in greater water-binding. However, this effect was not observed with MAP. The correlations between centrifugal drip values and the other test variables are given in Table 11.

Table 6: Effect of freeze-chilling ± MAP on the day 5 flesh pH values of four fish species stored at 4ºC[a]

Species	Freeze-chill+air	Freeze -chill+MAP	LSD[b] (P value)
Faux siki	6.30	6.30	0.16 (NS)
Redfish	6.97	6.53	0.08 (P<0.001)
Cardinal fish	6.70	6.60	0.02 (P<0.001)
Roundnose grenadier	7.17	6.83	0.21 (P<0.05)

[a]See footnotes in Table 4; [b]Least significant difference

Gravity drip values were generally much lower than their centrifugal drip counterparts with the exception of faux siki with mean day 5 values of 6.3 (faux siki), 5.3 (cardinal fish), 4.8 (redfish), and 4.3% w/w (roundnose grenadier). Corresponding moisture contents were 78.1, 76.0, 79.7 and 82.5% w/w. These data suggest that in-pack drip pads would not be required.

TVBN is a measure of protein degradation in fish and values in excess of 35mg/100g represent fish that is at or near the end of its shelf -ife. The day 5 data (Table 7) indicate that all values were well within this limit. MAP was particularly beneficial for redfish, cardinal fish and roundnose grenadier in keeping TVBN values low. However, when compared to air-stored samples, it did not influence the TVBN values of faux siki. These data indicate the benefits of MAP for extending the shelf-life of raw fish fillets. The correlations between TVBN values and the other test variables are given in Table 11.

MAP resulted in much lower day 5 TVC values compared to air for all species with the exception of cardinal fish for which the effect was more modest (Table 8). The TVC values were generally high and only the MAP samples of faux siki and roundnose grenadier were below the upper limit of $\log_{10} 5$ cfu/g for raw fish (Department of Health and Children, 1992). TVCs of the samples in air increased throughout the storage period while values in the

MAP packs remained relatively constant with time. The interaction ($P < 0.001$) is an indication of the different performance (in terms of TVC) of the air *versus* MAP packs. The correlations between TVC values and the other test variables are given in Table 11.

Table 7: Effect of freeze-chilling ± MAP on the day 5 total volatile base nitrogen (TVBN) values (mg/100g) of four fish species stored at 4ºC[a]

Species	Freeze-chill+air	Freeze-chill+MAP	LSD[b] (P value)
Faux siki	23.1	23.7	1.51 (NS)
Redfish	27.8	11.5	1.82 ($P<0.001$)
Cardinal fish	15.9	11.8	2.31 ($P<0.001$)
Roundnose grenadier	21.7	14.2	2.33 ($P<0.001$)

[a]See footnotes in Table 4; [b]Least significant difference

Odour is an excellent indicator of fish freshness and the samples were assessed for this parameter by sniffing the packs on opening. Many odour scales have been proposed by various authors but in the current trials a 6cm line scale was used with end-points of 0 (fresh seaweed-like) and 6 (spoiled odour). Odour perception was much better for the four species in MAP compared with their air-stored counterparts (Table 9).

Faux siki had the best odour of the four MAP samples (Table 9). The odour scores for samples packed in air were all above the mid-point of the 6-point scale indicating a moderate day 5 odour at best. This led to a significant interaction indicating the different performance (in terms of odour) of the air versus MAP packs. The correlations between odour values and the other test variables are given in Table 11.

With the exception of redfish, the day 5 acceptability scores (Table 10) were

Table 8: Effect of freeze-chilling ± MAP on the day 5 total viable count (TVC) values (log_{10}cfu/g) of four fish species stored at 4ºC[a]

Species	Freeze-chill+air	Freeze-chill+MAP	LSD[b] (P value)
Faux siki	7.47	4.00	1.05 (P<0.001)
Redfish	7.00	5.57	0.46 (P<0.001)
Cardinal fish	5.63	5.13	0.60 (P<0.001)
Roundnose grenadier	6.17	4.80	0.76 (P<0.001)

[a]See footnotes in Table 4; [b]Least significant difference

Table 9: Effect of freeze-chilling ± MAP on the day 5 odour scores (low values best)[a] of four fish species stored at 4ºC[a]

Species	Freeze-chill+air	Freeze-chill+MAP	LSD[b] (P value)
Faux siki	3.93	1.30	0.23 (P<0.001)
Redfish	4.63	1.87	0.72 (P<0.001)
Cardinal fish	3.23	1.67	0.63 (P<0.001)
Roundnose grenadier	3.73	1.77	0.50 (P<0.001)

[a]See footnotes in Table 4; [b]Least significant difference

good (*i.e.* above the mid-point of the 6cm scale). Scores for the MAP samples were higher than for samples packed in air with the exception of faux siki. These data are largely in agreement with the TVBN and TVC values. As expected, acceptability scores fell with length of storage and the effect was most pronounced for redfish. The day 5 air sample of redfish was not tasted in view of its high TVC value. The correlations between acceptability scores and the other test variables are given in Table 11.

Table 10: Effect of freeze-chilling ± MAP on the day 5 acceptability scores (high values best)[a] of four fish species stored at 4°C[a]

Species	Freeze-chill+air	Freeze-chill+MAP	LSD[b] (P value)
Faux siki	3.50	2.73	0.40 ($P<0.05$)
Redfish	NTc	2.97	———
Cardinal fish	3.67	4.63	0.50 ($P<0.05$)
Roundnose grenadier	3.30	3.87	0.52 (NS)

[a]See footnotes in Table 4; [b]Least significant difference; [c]NT = not tested

pH was strongly correlated with most of the other test variables for both species. The negative correlation with centrifugal drip was anticipated since water-binding improves (hence less drip) as pH moves from the isoelectric point (*circa* pH 5.2 for fish). The high correlations between pH and the test variables TVBN, TVC and odour score were expected since high TVBN means more free amines and a more alkaline pH. TVBN, TVC and odour score were highly inter-correlated (Table 11). TVBN and TVC increased with time as did odour scores. It is important to stress that in these tests low odour scores indicate the samples with the freshest odour (0 = fresh seaweed-like odour; 6 = spoiled odour) while for sensory acceptability low scores indicate the least acceptable samples (0 = unacceptable; 6 = highly acceptable). Sensory acceptability was negatively correlated with TVBN, TVC and with odour score but the magnitude of the coefficients was generally less than those found between some of the other test variables. The correlation coefficients for roundnose grenadier were not as large as those for redfish or cardinal fish partly due to the lower level of variability in the roundnose grenadier data. Roundnose grenadier correlation coefficients >0.50 were -0.80 (sensory acceptability score x odour score), 0.70 (odour score x pH), 0.64 (odour score x TVBN), 0.63 (odour score x TVC), 0.60 (TVC x pH), 0.59 (TVBN x pH) and -0.57 (sensory acceptability x pH). In the case of faux siki, significant correlations were found between odour score x TVC (0.84), acceptability score x gravity drip (-0.69), and odour score x TVBN (0.64).

Table 11: Correlation coefficient matrix for selected test variables (redfish = upper triangle; **cardinal fish = lower triangle**)

	CD[a]	TVBN	TVC	Odour	Accept.[b]	pH[c]
CD[a]		-0.92	-0.84	-0.86	0.07	-0.93
TVBN	**-0.53**		0.85	0.92	-0.47	0.94
TVC	**-0.30**	**0.83**		0.77	-0.18	0.80
Odour	**-0.64**	**0.94**	**0.81**		-0.57	0.94
Accept.[b]	**0.56**	**-0.71**	**-0.36**	**-0.83**		-0.45
pH[c]	**-0.53**	**0.94**	**0.88**	**0.93**	**-0.83**	

[a]Centrifugal drip; [b]Sensory acceptability; [c]Flesh pH

Blue whiting: Block frozen fillets were whitest (L = 50) and those from round fish the least white (47). MAP fillets were whiter (49) than those packed in air (47) and samples were whiter on days 3 (50) and 5 (51) than on days 0 (47) and 9 (47). This led to a statistically significant interaction. The mean whiteness value (L = 48) was lower than that of cod (65) or silver smelt (61). Gravity drip (GD) values were highest for fillets originating from blocks and lowest for those from round fish as were samples from MAP *versus* air (Table 12). These data suggest that freezing round fish may be the best option for minimising drip. However, this treatment gave the highest values for TVBN and TVC (Tables 13 and 14). The mean GD values were relatively similar from day to day but there were differences in this regard between MAP and air-packed samples leading to a statistically significant interaction. The data suggest that in-pack drip pads would be necessary for most of the treatments to soak up the resulting exudate.

Table 12: Gravity drip values (% w/w) for blue whiting fish fillets[a,b,c] held in air and modified atmosphere (MAP)[d] at 4ºC for 9 days ($P < 0.001$; LSD = 2.28)

	Block[a]		IQF[b]		Round[c]	
Day	Air	MAP	Air	MAP	Air	MAP
0	12.5	23.6	7.2	5.4	8.3	9.2
3	13.9	17.0	6.2	14.0	3.5	3.2
5	12.2	21.7	9.2	15.1	4.1	5.4
9	15.2	21.4	9.4	16.2	4.8	6.0
Main Effects						
Block (17.2) vs IQF (10.3) vs Round (5.5): $P < 0.001$; LSD = 0.81						
Air (8.9) vs MAP (13.2): $P < 0.001$; LSD = 0.66						
Day 0 (11.0) vs Day 3 (9.6) vs Day 5 (11.3) vs Day 9 (12.2): $P < 0.001$; LSD = 0.93						

[a]Block (block frozen fillets); [b]IQF (individually quick frozen fillets); [c]Round (fillets from frozen round fillets); [d]30% N_2; 40% CO_2; 30% O_2

Fillets originating from round fish had the highest TVBN values (Table 13) and, as expected, MAP samples had lower values than their air-stored counterparts. TVBN values increased over time but the values were not excessively high even by day 9 except for round fish packed in air. MAP out-performed air over time and this was manifested by a statistically-significant interaction.

Fillets originating as IQF had the lowest TVCs and round fish fillets the highest (Table 14). MAP samples had lower TVCs than air-packed samples and mean TVC values increased over the 9-day test period. However, MAP out-performed air over time in that the former kept TVCs lower for a longer time period than the latter (Table 14) and this led to a statistically-significant interaction.

Most samples received good acceptability scores (>4) (Table 15). Fillets originating from round fish had the lowest acceptability score and MAP samples received a higher score than their air-packed counterparts. Mean

Table 13: Total volatile base nitrogen (TVBN) values (mg/100g) for blue whiting fish fillets[a] held in air and modified atmosphere (MAP)[a] at 4°C for 9 days ($P<0.001$; LSD = 2.3)

	Block		IQF		Round	
Day	Air	MAP	Air	MAP	Air	MAP
0	13.9	11.3	10.7	9.1	12.6	12.3
3	13.7	13.0	15.1	13.7	15.8	12.3
5	16.4	14.7	17.4	15.5	21.4	15.8
9	20.2	16.0	21.0	15.9	53.2	20.7
Main Effects						
Block (14.9) vs IQF (14.8) vs Round (20.5): $P < 0.001$; LSD = 0.81						
Air (19.3) vs MAP (14.2): $P < 0.001$; LSD = 0.66						
Day 0 (11.7) vs Day 3 (13.9) vs Day 5 (16.9) vs Day 9 (24.5): $P < 0.001$; LSD = 0.94						

[a] See footnotes in Table 12

scores were equal for days 0 and 3 and fell by day 5. However, the overall differences between the treatments were small in practical terms. Correlation coefficients between the test parameters were generally small with the exception of TVC x sensory acceptability score (-0.71), TVC x TVBN (0.71), and TVBN x sensory acceptability score (-0.56).

Overall outcomes from freeze-chilling ± MAP tests: The results showed that freeze-chilling with MAP (30%O_2/40% CO_2/30%N_2) is a suitable technology for extending the shelf-life of pre-packaged portions of faux siki, black scabbard, redfish, cardinal fish, roundnose grenadier and blue whiting.

The six species received good sensory acceptability scores of 4.5 (cardinal fish), 4.5 (black scabbard), 4.4 (blue whiting), 4.3 (roundnose grenadier), 3.9 (redfish) and 3.3 (faux siki) for chilled samples at 4°C; the data are means for

Table 14: Total viable count (TVC) values (log_{10} cfu/g) for blue whiting fish fillets[a] held in air and modified atmosphere (MAP)[a] at 4ºC for 9 days ($P < 0.001$; LSD = 0.48)

	Block		IQF		Round	
Day	Air	MAP	Air	MAP	Air	MAP
0	4.23	3.72	4.15	4.31	4.55	4.39
3	4.13	4.59	4.31	3.93	6.17	4.98
5	6.11	4.75	5.91	4.47	7.41	5.29
9	7.30	5.32	6.58	5.20	7.90	6.96
Main Effects						
Block (5.02) vs IQF (4.85) vs Round (5.95): P < 0.001; LSD = 0.17						
Air (5.73) vs MAP (4.82): P < 0.001; LSD = 0.14						
Day 0 (4.22) vs Day 3 (4.68) vs Day 5 (5.65) vs Day 9 (6.54): P < 0.001; LSD = 0.20						

[a] See footnotes Table 12

days 0, 3 and 5. Values for MAP *vs* air for the six species were 4.90 *vs* 4.07 (black scabbard), 4.76 *vs* 4.32 (cardinal fish), 4.60 *vs* 4.20 (blue whiting), 4.33 *vs* 4.21(roundnose grenadier), 4.01 *vs* 3.73 (redfish) and 3.72 *vs* 2.96 (faux siki). In practical terms this means a 1 to 3-day extension of shelf-life due to MAP for five of the species. Faux siki was the exception and this may be due to the inherently high TVBN values for this sample. This finding for the five species was supported by the TVBN, TVC and odour score data. MAP gave higher drip (both gravity and centrifugal) values than the air-packed samples. However, with the exception of blue whiting, the gravity drip values were not of a magnitude that required in-pack drip pads. Faux siki (L = 66), roundnose grenadier (65), redfish (60), black scabbard (58) and cardinal fish (55) had an excellent white flesh with Hunter L values (whiteness) similar or close to that of cod (L = 65). Blue whiting had a more translucent appearance (L = 48). These data show that MAP extends the high quality shelf-life of the

Table 15: Sensory acceptability scores[a,b] for blue whiting fish fillets held in air and modified atmosphere (MAP)[a] at 4ºC for 5 days ($P < 0.001$; LSD = 0.59)

	Block		IQF		Round	
Day	Air	MAP	Air	MAP	Air	MAP
0	4.6	5.1	4.1	4.7	4.5	4.7
3	4.3	5.1	4.9	4.7	4.2	4.4
5	3.9	4.2	3.6	4.6	3.5	4.2
Main Effects						
Block (4.5) vs IQF (4.4) vs Round (4.2): P =0.05; LSD = 0.24						
Air (4.2) vs MAP (4.6): $P < 0.001$; LSD = 0.20						
Day 0 (4.6) vs Day 3 (4.6) vs Day 5 (4.0): $P < 0.001$; LSD = 0.24						

[a]See footnotes Table 12

[b]6cm line with end points of 0 (unacceptable) and 6 (very acceptable)

species (faux siki excepted) and that the species themselves have potential for sale as high quality added-value pre-packed fillets or portions.

Industrial applications

The results continue to be presented to seafood, food and food-related companies as well as other key groups or persons via industry workshops, one-to-one meetings and via phone, fax and e-mail contacts. Three major workshops for seafood companies on project outcomes took place at Ashtown Food Research Centre in July 2003, 2004 and 2005. There was a combined attendance of 103 persons and 28 seafood and related companies were represented. There was excellent dialogue and interaction, and extensive dissemination and technology transfer took place. As a result, R & D activity has been or is ongoing with 14 seafood companies as outcomes from the project results and workshops. Selected project results have also been presented at conferences and workshops, both national and international, and also to international and other groups visiting AFRC.

CONCLUSIONS

- Seven underutilised fish species (albacore tuna, cardinal fish, orange roughy, blue ling, redfish, roundnose grenadier and Greenland halibut) were cooked by the *sous vide* process in 12 savoury sauces. Sensory results showed that *sous vide* cooked albacore tuna, cardinal fish and blue ling were the most acceptable species and tikka, tomato+pesto, arrabbiata and hollandaise the preferred sauces.

- Marinating is a highly convenient method for adding value to seafood products. Sensory acceptability scores for marinated tuna fish portions indicated that Cajun, tandoori, lemon+lime, arrabbiata and southern fried were all highly acceptable with panel scores above the mid-point of the acceptability scale. Scores for blue ling portions in 30% w/w sugar-based marinades were highest for piri piri and chilli+coriander and lowest for orange glaze. These positive findings indicate that both albacore tuna and blue ling are suitable species for marinating.

- Freeze-chilling with MAP is a suitable technology for extending the shelf-life of pre-packaged portions of black scabbard, faux siki, redfish, cardinal fish, roundnose grenadier and blue whiting. The six species received good sensory acceptability scores over a 5-7 day period at 4°C. MAP increased the shelf-life from 1-3 days in comparison with air-packed samples with the exception of faux siki. Freeze-chilling also confers logistic benefits.

- Three major workshops for seafood companies on project outcomes took place at AFRC in July 2003, 2004 and 2005. There was a combined attendance of 103 persons and 28 seafood and related companies were represented. As a result, R & D activity has been and is ongoing with 14 seafood companies as outcomes from the project results.

- A number of underutilised fish species have considerable potential as added-value products based on the outcomes from this study and seafood companies are encouraged to make use of new species as supplies of conventional species dwindle and quotas tighten.

- *Sous vide* cooking followed by freezing is a safer alternative than *sous vide* plus chilling and gives an extended shelf-life to seafoods in savoury sauces. The seafood product range produced could serve as ready-meals when packed in compartmented containers with *sous vide* carbohydrates (potato, rice, pasta) and vegetables.

- Preparing marinades is a highly convenient way of adding value to fish portions and requires relatively simple facilities in-factory. A wide range of marinades is available from ingredient companies and only a few samples from the range were tested in the current study. The marinades have application to many fish species.

- Freeze-chilling with MAP offers logistic benefits and an extended shelf-life in seafood products. Freeze-chilling enables products to reach distant markets, streamlines production in-factory and reduces the number of product recalls. It is a relatively simple process to introduce to a factory. The inclusion of MAP increases the shelf-life of raw portions of some fish species by up to 50%.

- Protocols for the production of added-value products from underutilised fish species (also applicable to conventional species) are available from the authors.

OTHER RESEARCH ON SEAFOOD PROCESSING AT ASHTOWN FOOD RESEARCH CENTRE

Extensive trials have been conducted on the freeze-chilling of conventional fish species ± MAP. Trials with whiting and mackerel fillets or portions indicated no difference in odour scores (raw samples) between freeze-chilled and chilled samples; however, freeze-chilled salmon portions were inferior to chilled in terms of odour. Fresh fillets received the highest acceptability scores (as cooked samples) followed by frozen, chilled and freeze-chilled fillets (Fagan *et al.*, 2003). MAP packs for mackerel and salmon (60%N_2 /40%CO_2), and for whiting (30%N_2/40%CO_2/30%O_2) maintained their shape during freeze-chilling whereas packs with 100% CO_2 were imploded with concave sides. Typical shelf-lives in the chill phase for the freeze-chilled fillets were 5 (whiting and mackerel) and 7 (salmon) days (Fagan *et al.*, 2004).

Research is ongoing on the taurine content of fish species as part of the EU SeafoodPlus Integrated Project. Taurine benefits the cardiovascular system and the results show taurine content in the order plaice> cod > mackerel >farmed salmon. Tumbling and injection techniques were used to enrich tuna cubes and salmon sides, respectively, with taurine (1% in the flesh as eaten) (Neumann *et al.,* 2005).

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