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Cage feeding of Atlantic mackerel (*Scomber scombrus*): effect on muscle lipid content, fatty acid composition, oxidation status and vitamin E concentration

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Abstract

Wild Atlantic mackerel, *Scomber scombrus*, were kept in net cages and fed a high energy salmon diet rich in (n–3) polyunsaturated fatty acids for 8 months. Analyses of whole body and muscle were performed at regular intervals on 1 and 2-year-old fish. The percentage of lipid and dry matter increased in whole body and muscle as the fish weight increased from catch to market size over the course of the following year. In all groups of fish examined the sum of fatty acids (n–3) as the percentage of total lipid in muscle decreased from 33 to 26 %, while the sum of monoenoic acids increased with 10 % from 39 to 49 %. Vitamin E concentration of muscle increased substantially during feeding. The oxidation status of the fish muscles was very good at the end of the feeding period, with thiobarbituric acid values of less that 3 μmol kg^{-1}. At the end of the feeding experiment large fish to be sold at market were starved for two weeks. Analyses of the nutritional and oxidative state of muscle showed that transport, slaughter and storage did not affect the lipid content or the fatty acid composition. Low and stable thiobarbituric acid values were observed, while vitamin E content significantly decreased during processing and storage at –30 °C, which indicates that vitamin E was an effective antioxidant in mackerel muscle.

Keywords: Atlantic mackerel, feeding, captivity, nutrient composition, muscle storage quality.

Alimentation du maquereau (Scomber scombrus) *élevé en cage : effets sur les lipides du muscle, sur la composition en acides gras, sur le niveau d'oxydation et sur la concentration en vitamine E.*

Résumé

Du maquereau sauvage, *Scomber scombrus*, élevé en cages a été nourri d'un aliment pour saumon riche en acides gras poly-insaturés (n–3) durant 8 mois. Les analyses du muscle et de l'ensemble de la carcasse ont été effectuées à intervalles réguliers sur des poissons âgés d'un et deux ans. Le pourcentage de lipides et de matières sèches augmentent entre le moment de la capture et celui où le poisson atteint la taille marchande, et ceci tout au long de l'année. Dans tous les groupes étudiés, la somme des acides gras (n–3) comme le pourcentage des lipides totaux du muscle diminuent de 33 à 26 %, tandis que la somme des acides mono-insaturés augmentent de 10 %, de 39 à 49 %. La concentration en vitamine E du muscle augmente de façon substantielle durant l'alimentation. Le niveau d'oxydation des muscles du poisson est bon à la fin de la période d'alimentation avec des valeurs d'acide thio-barbiturique de moins de 3 μmol.kg^{-1}. A la fin de la période expérimentale d'alimentation, les poissons les plus gros ayant atteint la taille marchande sont mis à jeun pendant 2 semaines. Les analyses de l'état nutritionnel et d'oxydation du muscle montrent que le transport, l'abattage, et le stockage à –30 °C n'affectent pas la composition en acides gras. Des valeurs basses et stables d'acide thio-barbiturique sont observées, tandis que la vitamine E diminue significativement durant le « filetage » et le stockage à –30 °C, ce qui indique que la vitamine E est un antioxydant efficace du muscle du maquereau.

Mots-clés : Maquereau atlantique, alimentation, composition alimentaire, qualité de conservation du muscle.

INTRODUCTION

Lipid content is said to affect the taste, texture, flavour and nutritional quality of fish muscle (Ackman and Eaton, 1971; Espe *et al.*, 1997). In wild mackerel muscle lipid content varies, depending on the season and the catch area from less than 5 % in spring to above 30 % in autumn (Hardy and Keay, 1972). A muscle lipid content close to 30 % is favoured by the market. Previous studies on captive mackerel kept without feeding has shown the same seasonal variation with respect to muscle composition as found in wild stocks, also substantial weight losses has been found in captive mackerel when not offered feed (unpublished results, Institute of Marine Research, Norway).

Studies on fish species other than mackerel have indicated that tissue lipids reflect the fatty acid profile of the diet (Lie *et al.*, 1988, 1992). The human health benefits of a high intake of eicosapentaenoic (20:5 n–3) and docosahexaenoic acid (22:6 n–3) have been reported in numerous studies, (Hansen, 1994; Sanders, 1994; Willumsen *et al.*, 1996; Frøyland *et al.*, 1996). Because these fatty acids are characteristic of foods obtained from the marine environment, nutritional policies in several countries aim to increase the populations' intake of seafood, especially of fat fish like mackerel.

Polyunsaturated fatty acids (PUFA) are highly sensitive to oxidation (Hamre *et al.*, 1994). Marine lipids high in PUFA are, therefore, susceptible to rapid development of rancid tasting flesh. This oxidation process can be measured accurately by thiobarbituric acid (TBARs) values (Schmedes and Hølmer, 1989). To prevent internal damage as a consequence of oxidation of PUFA, all living tissues require natural antioxidants, especially vitamin E. The vitamin E concentration in fish muscle has been shown to depend on the vitamin E content of the diet during feeding (Hamre and Lie, 1995; Hamre *et al.*, 1997). In Atlantic salmon a clear effect on product quality, *e.g.* a rancid taste, was found to depend on the intake of PUFA and vitamin E during rearing (Waagbø *et al.*, 1993). Muscle TBARs values increased rapidly during storage at –20 °C, while only minor increases in TBARs values were detected during storage of fish at –30 °C or colder (Tarr, 1948; Ke *et al.*, 1976; Hamre *et al.*, 1997).

The aim of the present study was to elucidate changes in nutritional composition of muscle from captive mackerel when maintained on a commercial diet for 8 months, after slaughter and a subsequent storage at –30 °C for 6 months. Nutrients evaluated were total lipid and dry matter of the whole fish, and muscle concentrations of lipid, fatty acids and vitamin E. The oxidative state of fish muscle was evaluated by TBARs analyses.

MATERIALS AND METHODS

Fish and diets

Wild caught Atlantic mackerel were kept in 7 m deep, 12 × 12 m square standard salmon sea cages at the Austevoll Aquaculture Research Station (Norway) from Sept. 1994 until July 1995. The mackerel were divided into groups of 1 and 2-year-old (1+ and 2+) fish, aged by otolith readings (for details, Juell *et al.*, 1997). Each group was replicated (a total of 4 sea cages). For more details on catching and maintaining fish, *see* Juell *et al.* (1997). The fish were fed in excess every day. The commercial feed used (Bio-Optimal, Biomar, Norway) was energy-dense, with a dry matter of 91 % and a lipid content of 33 %, and a supplemented vitamin E content of 150 mg kg^{-1} (dry weight). The lipid source was of pure marine origin, which gave the feed a high content of polyunsaturated fatty acids (PUFA). At the end of January and until April the fish cages were submerged to ensure survival during the cold water period, as sea water temperature below 5 °C is shown to be lethal to mackerel (Olla and Studhome, 1978). During the submerged period feeding was performed through plastic pipes connected to the feeders, and feed intake controlled by video. Samples were collected monthly except during the submerged period. At each sampling 100 fish from each cage were randomly selected and weighed (for details, *see* Juell *et al.*, 1997), from which a subsample of 10 small plus 10 large 1-year-old, and 10 small plus 10 large 2-year-old fish were collected. After the last sampling in June, the remaining fish were gathered in a large cage and starved for 2 weeks. Thereafter a selected sample of large fish was transported by boat (1-2 h) for slaughter and processing at Austevoll Fiskeindustri AS (Austevoll Norway). Simultaneously, samples for analyses were taken before and immediately after transport and slaughter, after filleting, after 24 h storage on ice, and after 1 and 6 months storage at –30 °C. Each muscle sample was composed of one whole homogenised muscle, kept frozen at –80 °C after homogenisation until analysed for total lipid, fatty acid composition, vitamin E and TBARs contents.

Chemical analyses

The dry weight of muscle was determined gravimetrically after freeze-drying homogenised samples. Lipid content was determined after ethyl acetate extraction of dry sample homogenates as described by Lie *et al.* (1988). Fatty acids were determined in wet muscle homogenates as described by Lie and Lambertsen (1991), vitamin E (α-tocopherol) by the method of Lie *et al.* (1994), and TBARs (wet muscle homogenates) according to Schmedes and Hølmer (1989). The method applied for determination of TBARs measures mainly the amount of free malondialdehyde in muscle tissue.

Data analyses

Correlation between lipid, fatty acid composition in fish and feed, vitamin E and TBARs, and selected fatty acids were detected by a Pearson Product Moment Correlation Analyses.

ANOVA for repeated samples was used to test for significant differences at $p < 0.05$ within each group

and between sampling times, and ANOVA was used to test for significant differences at $p < 0.05$ between groups. Software used was CSS Statistica ™ (Statsoft Inc. 1991).

RESULTS

Weight and age correlation and lipid levels

High correlation was found between live weight of mackerel and whole body dry matter content (r^2 = 0.89, $p < 0.01$) and whole body lipid content ($r^2 = 0.88$, $p < 0.01$) independent of age (Table 1). The increases in whole body dry matter were significantly correlated with increased whole body lipid contents ($r^2 = 0.95$, $p < 0.001$). Significant weight increases ($p < 0.05$) were only registered during the late spring 1995. In none of the groups a weight reduction was seen during winter. A significant increase in dry matter with more than 25 % ($p < 0.01$) in 1-year-old, and from 10 to 15 % ($p < 0.05$) for 2-year-old fish were found from catch and during winter feeding (Table 2). The muscle lipid levels (wet weight) of 1-year-old mackerel started at 6.5 % and increased to 23.5 % (small 1+) and from 13.5 to 35.3 (large 1+), while 2 year old increased from 17.5 % to 24.8 % (small 2+) and from 21.9 % to 29.9 % (large 2+) (Table 2). The increases in muscle lipid corresponded to the increases in live weight and lipid content of whole body homogenates (Table 1).

The influence of the diet composition

Steady decreases in EPA ($r^2 = -0.7$, $p < 0.05$) from 7 to 6 % of lipid, and DHA ($r^2 = -0.9$, $p < 0.01$) from 14 to 9 % of lipid, and the ratio (n–3)/(n–6) ($r^2 = -0.9$, $p < 0.01$) from 12 to 8 were observed in total muscle from all groups from September and during the 8-month feeding trial (Table 2). The contents of oleic acid (18:1 n–9) and 22:1(n–11) increased ($r^2 = 0.5$ $p < 0.05$) dur-

Table 1. – Weight, % dry matter and % lipid (wet weight) of whole body during captivity. * indicates significant difference ($p < 0.05$) between mackerel sampled at different time, and belonging to the same group. 1-year-old mackerel at catch were kept separate from from 2-year-old during captivity and feeding. Selected sampling dividing between small and large fish from each group was done in Sept., Oct., Nov., Jan., May and June. Values are given as average of 5 fish ± S.E.M. (standard error of mean).

Sampling time	Live weight (g)	% Dry matter	% Lipid	Live weight (g)	% Dry matter	% Lipid
1-year-old mackerel	Small	Small	Small	Large	Large	Large
At catch in Sept. 1994	134 ± 1	31.7 ± 0.9	11.7 ± 1.0	237 ± 4	40.3 ± 0.8	22.4 ± 0.5
October 1994	151 ± 5	32.2 ± 0.9	12.2 ± 1.1	291 ± 11	41.0 ± 0.5	22.3 ± 0.8
November 1994	159 ± 2	32.1 ± 0.6	12.9 ± 0.6	325 ± 5	42.7 ± 0.8	26.2 ± 0.9
January 1995	168 ± 2	33.6 ± 1.3	15.0 ± 1.6	311 ± 8	46.0 ± 0.8	28.5 ± 1.0
May 1995	191 ± 18	31.4 ± 2.5	13.2 ± 2.6	402* ± 22	43.4 ± 2.0	25.8 ± 2.2
June 1995	288* ± 22	40.9* ± 2.1	23.4* ± 2.7	530* ± 25	49.8* ± 1.0	33.5* ± 1.1
2-year-old mackerel	Small	Small	Small	Large	Large	Large
At catch in Sept.1994	238 ± 4	41.7 ± 1.4	22.6 ± 1.4	419 ± 14	48.1 ± 0.4	29.6 ± 0.7
October 1994	253 ± 5	39.1 ± 0.5	20.3 ± 0.5	505 ± 35	45.7 ± 0.8	27.9 ± 1.2
November 1994	270 ± 4	38.9 ± 0.6	20.2 ± 0.7	418 ± 4	45.0 ± 0.6	27.6 ± 0.6
January 1995	284 ± 17	36.7 ± 0.6	19.9 ± 0.8	467 ± 4	50.6* ± 0.7	36.2* ± 0.6
May 1995	284 ± 19	34.5 ± 1.6	15.7 ± 2.0	526 ± 24	46.7 ± 1.0	29.2 ± 1.3
June 1995	346* ± 22	38.7 ± 2.3	25.2* ± 4.5	655* ± 23	50.7* ± 1.6	32.6 ± 1.5

Table 2. – Muscle composition, dry matter, lipid, 18:1(n–9), 22:1(n–11), 20:5(n–3), 22:6(n–3), sum of monoenes, sum of polyenes (PUFA), (n–3)/(n–6) ratio, sum saturated fatty acids, vitamin E and TBARs (thiobarbituric acid) values. The fatty acids are given as % of total lipid. Values are presented as ranges, where the first value in the column is the average Sept. 1994 value, and the last value in the same column is the average June 1995 value. Samplings were done in between these dates, and linear developments were seen in all nutrients (n = 7 samplings in each group, of 5 fish). Different columns represent 1-year-old small and large fish (selected sampling), and 2-year-old small and large fish (selected sampling). Pooled S.E.M. is given in parentheses.

	1-year-old – small	1-year-old – large	2-year-old – small	2-year-old – large
% dry matter	28.0-52.4 (2.8)	28.0-59.1 (3.3)	36.9-47.3 (1.2)	37.6-55.3 (2.0)
% lipid	6.5-23.5 (2.6)	13.5-35.3 (4.0)	17.0-24.8 (1.3)	21.9-29.9 (4.0)
18:1(n–9)	9.2-14.9 (0.6)	9.2-16.5 (0.9)	7.7-14.4 (0.8)	8.5-15.3 (0.8)
22:1(n-11)	12.0-15.3 (0.3)	11.6-15.0 (0.4)	12.9-16.7 (0.4)	12.5-15.6 (0.3)
Sum monoenes	39.1-49.4 (1.1)	39.1-49.3 (1.1)	40.6-50.2 (1.1)	40.6-49.9 (1.2)
20:5(n–3)	6.9-5.7 (0.1)	6.8-6.0 (0.1)	6.8-5.2 (0.4)	7.4 -5.8 (0.1)
22:6(n–3)	14.4-9.3 (0.5)	14.4-9.5 (0.5)	13.2-9.3 (0.5)	13.2-9.2 (0.5)
Sum PUFA	33.5-26.6 (0.8)	33.5-26.0 (0.8)	33.4-24.3 (0.9)	34.0-25.8 (1.0)
(n–3)/(n–6) ratio	11.9 -7.6 (0.5)	12.0-7.7 (0.5)	12.7-7.8 (0.6)	12.9-7.6 (0.7)
Sum saturated fatty acids	25.2-22.5 (0.3)	21.9-25.0 (0.3)	23.8-22.6 (0.1)	21.8-23.4 (0.1)
Vitamin E. mg kg^{-1}	5.8-18.1 (1.4)	5.7-24.9 (2.1)	5.8-19.4 (1.6)	5.5-22.6 (2.0)
TBARs (June only, µmol kg^{-1})	2.6 (2.3)	2.3 (4.2)	1.8 (2.9)	1.7 (4.0)

ing captivity, from initially 7-9 % to 14-17 % after 8 months of feeding (Table 2), in all size and age groups of mackerel. The total amount of monoenoic acids increased during captivity and feeding from 39 to 49 % of total lipid concentration in all groups. The saturated fatty acid content of muscle lipids did not change during captivity.

At the end of the experimental period the vitamin E concentrations in muscle increased more than three-fold in all groups over the level present at capture (Table 2). The TBARs values observed in the fresh mackerel muscle at the end of the feeding experiment were very low (Table 2).

Quality of mackerel muscle during processing

Analyses of nutrients and oxidation status showed that treatment by transport of live fish, slaughter and storage on ice for 24 h storage, or frozen at –30 °C for 1 and 6 months did not affect lipid content or fatty acid composition of the muscle (Table 3). During storage at –30 °C stable and low TBARs values were found, while the vitamin E content decreased dramatically (82 %) (Table 3).

DISCUSSION

Weight and age correlation to whole body and muscle lipid

The high correlation between body weight, whole body dry matter and whole body lipid levels indicates that by weighing a wild catch of mackerel it is possible to predict the body contents of dry matter and lipid, as also concluded in other studies on mackerel (Hemre *et al.*, 1997). The fact that the fish did not lose weight during winter (for details, *see* Juell *et al.*, 1997), and maintained whole body lipid levels between 20 and 30 %, show that quality in terms of lipid levels can be maintained during captivity by feeding. This is further confirmed by the steady increases in muscle lipid contents. An improved quality as concerned muscle lipid levels were seen during feeding in 1-year-old mackerel. Compared to wild caught spring mackerel the captive mackerel in this study had about 15 % higher lipid levels (Ackman and Eaton, 1971). This indicates that it may be favourable for quality to feed small mackerel for a period before marketing, and demonstrates the possibility to expand the market period for fresh mackerel. The catch of mackerel in Norway normally takes place from August to early November. However, captive mackerel obtains 4-fold prices when sold fresh during early spring periods, a fact which has interesting commercial aspects.

Feed composition and influence on muscle fatty acid composition, vitamin E content and rancidity

The feed contained high concentrations of eicosapentaenoic (EPA) and docosahexaenoic (DHA) acids. In addition to oleic acid these are currently the fatty acids of most interest in human health (Frøyland *et al.*, 1996). For other fish species *e.g.* Atlantic salmon (*Salmo salar*) and cod (*Gadus morhua*) the muscle fatty acid composition has been found to reflect the fatty acid composition of the feed (Lie *et al.*, 1988). This suggest that the natural diet of mackerel contains even higher levels of EPA, DHA and total PUFA, than the feed used in this study. In spite of a reduction in (n–3) fatty acids, 200 g (one portion) of mackerel muscle from the June sampling would provide 14 g of (n–3) fatty acids, which is enough to cover the dietary requirement for two weeks for a human being (Groom, 1993). Low and stable levels of saturated fatty acids may further underline a positive health effect by the consumption of mackerel (Groom, 1993). The (n–3)/(n–6) ratio decrease was caused both by a decrease in (n–3) and an increase in (n–6) fatty acids (data not

Table 3. – Muscle levels of dry matter, lipid (wet weight), sum of monoenes, 20:5(n–3), 22:6(n–3), sum polyenes, saturated fatty acids, (n–3)/(n–6) ratio, vitamin E concentrations and TBARs values in mackerel muscle after all fish groups were gathered and starved for 2 weeks (in cage). The fatty acids are given as % of total lipid. Composition at slaughter, after storage of muscle on ice for 24 h and after freeze storage for 1 and 6 months at –30 °C are also given. Each value represent one pooled sample of muscle from 10 fish.

Composition of muscle	In cage	At slaughter	After slaughter and 24 h storage on ice	After 1 month storage at –30 °C	After 6 months storage at –30 °C
Dry matter %	51.4	57.1	56.5	54.0	53.9
Lipid %	36.6	43.3	42.7	38.7	38.1
Sum monoenoic fatty acids, % of lipid	49.6	49.3	48.3	49.2	48.8
20:5 (n–3), % of lipid	5.8	5.5	6.0	5.9	6.0
22:6 (n–3), % of lipid	8.9	8.7	9.0	8.7	9.1
Sum polyenes fatty acids, % of lipid	25.1	24.3	25.4	24.6	25.6
Sum saturated fatty acids, % of lipid	23.1	24.2	23.9	23.9	23.3
(n–3)/(n–6) ratio, % of lipid	7.2	6.6	7.3	7.2	7.6
Vitamin E, mg. kg^{-1}	30.5	35.9	34.3	16.2	6.3
TBARs, µmol. kg^{-1}	6.6	6.1	6.0	4.3	5.4

shown). As the feed was composed of a marine protein and lipid source very low in (n–6) fatty acids, the increase in (n–6) fatty acids may partly be explained by the content of these fatty acids in wheat and corn grits which were used as binder and carbohydrate sources.

The increased retention of 22:1(n–11) and 18:1(n–9) may be of importance as the mackerel increased its body and muscle lipid levels during feeding. These fatty acids are claimed to be of great importance for animals possibility to β-oxidise fatty acids (Lie *et al.*, 1986; Frøyland *et al.*, 1996). Most likely peroxisomes shorten 22:1(n–11) to oleic acid, which can then be taken up by the mitochondria and β-oxidised (Murata and Higashi, 1979; Osumi and Hashimoto, 1984; Moyes *et al.*, 1990). Besides liver (Frøyland *et al.*, 1996), red muscle is found to be the most active organ in β-oxidation (Moyes *et al.*, 1990). No studies so far have evaluated the capacity to β-oxidise lipids in mackerel with respect to organ.

The initial muscle level of vitamin E was in the same range as reported in other studies with wild Atlantic mackerel (Ackman and Cormier, 1967; Bhuiyan *et al.*, 1993). The three-fold increase in vitamin E during feeding in the present study indicates that the content of α-tocopherol acetate in the feed was readily available for the fish. In addition, mackerel muscle may be an important storage organ of lipid soluble vitamins, in accordance with other studies on Atlantic mackerel (Ackman and Timmins, 1995), and Atlantic salmon (Waagbø *et al.*, 1993; Hamre and Lie, 1995). Vitamin E is known as an effective biological antioxidant which stabilises membrane fatty acids in living animals (Hamre *et al.*, 1994), and a significant correlation between vitamin E concentrations and rancid taste has been found in fish muscle (Ke *et al.*, 1976; Waagbø *et al.*, 1993).

The very low TBARs values at the end of the feeding period indicate a high quality product with respect to rancidity. TBARs values of more than 20 μmol. kg^{-1} are usually found in rancid fish muscle by the method applied, and the present results show that the mackerel did not contain oxidised lipid in the muscle when slaughtered in June (Schmedes and Hølmer, 1989).

Quality of mackerel muscle during processing

No changes in lipid or dry matter, or fatty acids composition and no increases in TBARs values during processing and the following frozen storage showed that the mackerel muscle maintained a high quality independent of treatment. This was most probably caused by the effective protective role of α-tocopherol, which markedly decreased. Similar results have been found by Ackman and Timmins (1995) evaluating the role of α-tocopherol during processing by smoking and subsequent storage for 12 weeks, and by Ke *et al.* (1976) investigating processing and properly preservation of frozen mackerel. The results in mackerel are in contrast to storage experiments with farmed Atlantic salmon (Ackman and Timmins, 1995; Hamre *et al.*, 1997) and wild caught Atlantic herring (*Clupea harengus harengus*) muscle at –30 °C, where the decrease in muscle vitamin E concentration was very modest (less than 30 %). TBARs values in herring muscle increased from less than 10 to more than 30 μmol. kg^{-1} after two weeks of storage, and stayed high for the rest of the storage period (K. Hamre, unpublished). Although TBARs in salmon muscle stayed below 10 μmol. kg^{-1} there was a slow but steady increase during storage at – 30 °C for six months (Hamre *et al.*, 1997). The differences may point to different mechanisms of oxidation in the three fish species, and that vitamin E is more efficiently utilised as a chain breaking antioxidant in mackerel muscle than in salmon and herring. For more detailed discussion on the function of vitamin E as a chain breaking antioxidant see Hamre *et al.* (1997). The 6 months of frozen storage at –30 °C did not lead to an increase in muscle rancidity, in agreement with results from studies on frozen storage of fish muscle at this low temperature (Ke *et al.*, 1967; Hamre *et al.*, 1997).

CONCLUSION

Atlantic mackerel can be fed in captivity to maintain weight and a body lipid content between 20-30 % of wet weight during winter. Very lean and small mackerel at catch may get improved quality as concerns lipid levels and increased live weight by feeding.

Muscle composition of lipids showed high levels of EPA, DHA and PUFA, even though the concentrations of these fatty acids declined as lipid content increased. Muscle vitamin E concentrations increased threefold from catch and during feeding. No increases in TBARs values or changes in nutrient composition were found in mackerel muscle during frozen storage for 6 months at –30 °C, except for a decline in vitamin E.

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