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Fat deposition and flesh quality in seawater reared, triploid brown trout (Salmo trutta) as affected by dietary fat levels and starvation

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Abstract:

Three isoproteic (crude protein content : 56%) diets with different fat levels (11, 20 and 26 %) were fed to triplicate groups of triploid brown trout (initial average body weight of 1.5 kg), reared in seawater. At the end of three months of feeding, fish fed the high-fat diet were split into two groups : a triplicate group of fish received the low-fat diet and another triplicate group was kept unfed for a further two month period. Fish initially fed the low-fat diet during the first period were continued to be fed the same diet. Fish fed the medium-fat diet during the period 1 were eliminated for the period 2. At the end of each period, comparative whole body analyses, sensory and instrumental (texture and colour) analyses were made on fresh and smoked fillets. During the first period, increasing dietary fat level had no significant effect on growth or feed utilisation, but increased whole body fat content (14.6 to 17.9%, on wet weight basis) and muscle (8.3 to 11.0%). During the second period, the fish fed the low-fat diet had similar growth performance irrespective of previous nutritional history, whereas starvation led to significant loss of weight and fillet yield. Whole body fat content did not differ between groups (around 15 %) at the end of period 2. In fish initially fed the high-fat diet, both starvation and feeding a low-fat diet led to a reduction in muscle lipid content. Sensory analyses revealed few differences between treatments, in terms of visual colour aspects, for both cooked and smoked fillets at the end of period 1. A positive relationship between instrumental colour analyses (L*, a*, b* values) and dietary fat levels was observed, but no difference was observed for instrumental texture measurements. At the end of period 2, a significant increase in parameters of colour was observed in unfed fish. Although both feed withdrawal and feeding a low-fat diet 2 months before slaughtering led to a reduction in fat content, starvation had the disadvantage of leading to significant weight loss.

1. INTRODUCTION

Since the early findings of Lee and Putman (1973) on the beneficial effects of dietary fat in protein sparing in salmonids, it has become a common practice to use high fat diets (Hillestad et al., 1998). There is evidence that high dietary lipid levels increase fat deposition in fish and alter flesh quality in terms of freshness, storage stability, processing yields and organoleptic and physical properties (Sheehan et al., 1996; Gjedrem, 1997; Einen and Skrede, 1998). According to species and age, fat depots can be located in different tissues or organs (Corraze and Kaushik, 1999) and affect flesh quality variably. In salmonids, lipids located in the visceral cavity lead to decreased slaughter yield and the part of fat accumulated in muscle may modify flesh quality (Fauconneau et al., 1993). Studies with other salmonids have shown that nutritional factors such as dietary fat sources (Thomassen and Røsjø, 1989; Greene and Selivonchick, 1990), fat levels (Hillestad and Johnsen, 1994; Bjerkeng et al., 1997; Hemre and Sandnes, 1999), or vitamin E (Boggio et al., 1985) can influence physical and organoleptic quality. Since starvation is known to induce fat mobilisation (Jezierska et al., 1982; Takeuchi and Watanabe, 1982), in recent years, farmed salmon are occasionally starved prior to slaughter in order to stimulate lipid catabolism and mobilisation and thus and improve flesh quality (Blokhus, 1986; Lie and Huse, 1992; Bonnet et al., 1996; Einen et al., 1998).

Seafarmed brown trout are of commercial interest in France. Earlier studies have evaluated the effects of growth rates (Bauvineau et al., 1993) and of dietary lipids (Arzel et al., 1994) on flesh quality. *Post-mortem* changes in flesh quality of brown trout have also been studied to some extent (Bonnet et al. 1996; Laroche et al., 1996a, b).

An increase in dietary lipid levels are known to improve protein utilisation in brown trout (Gabaudan et al., 1989; Arzel et al., 1994) as in many other fish (Lee and Putman, 1973; Alliot et al., 1979; Cho and Kaushik, 1990). Lipid-rich diets are also known to depress the activities of enzymes involved in lipid synthesis in coho salmon (Lin et al., 1977b), Atlantic salmon (Arnesen et al., 1993), rainbow trout (Alvarez et al., 1998) and seabass (Dias et al., 1998).

The aims of this study were to evaluate (1) the effects of different dietary fat levels and (2) the effects of pre-slaughter feeding procedures (starvation or a low-fat diet) in sea reared brown trout on growth, chemical composition, fat synthesis and deposition, plasma metabolites, and sensory and physical flesh quality.

2. MATERIAL AND METHODS

2.1 Experimental diets

Three isoproteic diets (crude protein : 56% of dry matter) were formulated containing graded levels of fish oil to obtain total crude fat levels of 11, 20 and 26%. Mineral and vitamin mixes were added to meet the requirements of marine fish (Kaushik and Cuzon, 1999). Based on formulations provided, extruded diets (9 mm diameter) were manufactured by a commercial feed company (Le Gouessant Aquaculture, 29 Lamballe, France). Ingredient and chemical composition of the diets are reported in Table 1.

2.2 Growth study

The growth trials were conducted during December 1997 to May 1998 in our experimental sea cage-culture facility (SEMII, 29 Camaret sur Mer, France). Triplicate groups of 140

triploid all-female brown trout, *Salmo trutta* (initial average body weight : 1489±17g) were allotted to each of nine floating cages of 60 m^3. Each diet was randomly assigned to triplicate groups which were fed by hand three times a day to visual satiety and the feed amount distributed was recorded. Water temperature was recorded each day at a depth of 2 metres and varied between 9 to 12°C, while salinity remained constant at 35 ‰. Each treatment group was weighed every 3 weeks to follow growth and feed utilisation. At the end of an initial growth period lasting 12 weeks, fish fed the high-fat (HF) diet were split into two groups of 60 fish : a triplicate group of fish received the low-fat diet (LF') and the other triplicate group was kept unfed for a further pre-harvest period of eight weeks (period 2). Fish initially fed the low-fat (LF) diet during the first period were continued to be fed with the same diet but the number of fish was reduced to 60 fish per cage. Fish fed the medium-fat (MF) diet during the period 1 were eliminated for the period 2.

2.3 Samplings

At the beginning of the growth study, a representative sample of 14 fish from an initial pool was withdrawn and stored at -20°C for analyses of whole body composition. At the end of each period, the same protocol of slaughter was strictly followed for each group. Fish were fasted for two days before slaughter. Thirteen fish from each cage were stunned with a thick round rod on the head, bled in cold seawater with ice and covered with ice before dissection. Gutting and filleting were realised within 30 min to 1 h after slaughter when fish were still in a pre-rigor state. Five whole fish per cage were sampled for whole body composition analyses (water, ash, protein, fat and energy) and nutrient retention calculation. Eight fish per cage were withdrawn to weigh the liver and the digestive tract (including visceral fat) for calculating hepatosomatic index (HSI) and viscerosomatic index (VSI) and for the following analyses : three fish for sensory analyses (left fillet smoked and right fillet cooked), three fish

for instrumental analyses of texture and colour (left fillet cooked and right fillet raw) and finally two fish were withdrawn for lipid analyses in muscle (left whole fillet). On six fish from each treatment group, liver and viscera were analysed for total lipids and hepatic activities of glucose-6-phosphate dehydrogenase (G6PD, EC 1.1.1.49) and fatty acid synthetase (FAS, EC 2.3.1.38). Whole muscles and organs for lipid analyses were frozen in liquid nitrogen and stored at - 80°C.

Immediately upon capture and stunning, blood samples (2 ml) were withdrawn by cardiac puncture from 13 fish per replicate cage using heparinised syringes. After centrifugation (1200 g, 10 min, 5°C), plasma was separated and stored frozen at - 20°C as separate aliquots for analyses of triglyceride and total cholesterol concentrations.

2.4 Analytical methods

Proximate composition of diets and chemical composition of whole body and tissues were determined by the following standard procedures (AOAC, 1984) : dry matter after desiccation in an oven (105 °C for 24 h), ash combustion (incineration at 550°C for 12 h), crude protein (Dumas, nitrogen analyser, Fisons instrument, N×6.25), crude fat (dichloromethane extraction by Soxhlet's method) and gross energy (IKA adiabatic calorimeter C4000A). Plasma total cholesterol concentrations and plasma triglyceride concentrations were determined using commercial kits (Boehringer n°1442341, Mannheim, Germany and bioMérieux n°PAP150, France, respectively). For lipid analyses of tissues, extraction was done according to Folch et al. (1957), chloroform being replaced by dichloromethane (Chen et al., 1981).

For assays of hepatic lipogenic enzyme activities, liver samples were homogenised in three volumes of ice-cold buffer (0.02 M Tris-HCl, 0.25 M sucrose, 2 mM EDTA, 0.1 M sodium

fluoride, 0.5 mM phenylmethylsulphonylfluoride, 0.01 M β-mercaptoethanol, pH 7.4) and the homogenates were centrifuged at 20 000 g at 4°C for 20 min. Soluble protein content of liver homogenates was determined by the method of Bradford (1976) using bovine serum albumin as the standard. Enzyme activities were assayed on supernatant fractions according to Bautista et al. (1988) for the glucose-6-phosphate dehydrogenase (G6DP) and according to Hsu et al. (1969) for fatty acid synthetase (FAS). Enzyme activity units (IU) defined as µmol substrate converted to product per min at assay temperature (30°C), were expressed either per mg hepatic soluble protein or per g liver tissue (wet weight).

2.5 Flesh quality evaluation

Sensory profiling (Stone et al., 1974; ISO 11035) was performed on cooked and smoked fillets by a trained internal sensory panel (IFREMER, Nantes, France) consisting of 20 individuals selected for their interest, availability and sensorial capacities of memorising stimuli or discriminating intensities. All were volunteers and received regular training sessions to develop their sensory performances and knowledge of marine products. Sessions were conducted in an air-conditioned room designed for sensory analysis divided into ten individual boxes with standardised light (T=6500°K) and equipped with a computerised system (Fizz, Biosystèmes, Dijon). These conditions were conducive to concentration and avoided communication between assessors and disturbance by external factors (AFNOR V-09-105, 1995). The raw samples (coming from the middle part of fillet) were cooked for 2.5 min in a microwave oven (Panasonic NN8550, 850W) in closed bowl before analyses and the smoked fillets (traditional smoking : salting during 3.5 h at 10°C, drying during 2 h at 20°C and smoking during 6 h at 20°C) were sliced and kept at ambient temperature. Products were assigned 3-digit numbers, randomised and served simultaneously. The samples were evaluated using a continuous scale presented on a computer screen from 0 (low intensity) to

10 (high intensity) for the following attributes : intensity and salmonid odour, pink colour, visual compact aspect, salty flavour, intensity of flavour, firmness, smooth, fat and damp (impression of moisture) texture and exudation (corresponding to a loss of water) for cooked fillet and smoky and salmonid odour, pink and orange colour, colour homogeneity, salty flavour, salty and smoky aftertaste, firmness and fat texture for smoked fillet (see Tables 6 and 7). The odour attributes were assessed immediately after opening the bowl, while flavour and texture in mouth were evaluated after cutting the samples. The data were immediately transferred by the network to a central computer for statistical processing.

Instrumental colour and texture analyses were performed 7 days after slaughter on fillets kept in ice in vacuum sealed packing after threading and were done on raw and cooked (1 h at 70 °C in a double boiler in vacuum sealed packing) fillets. For texture, a Kramer shear press (64mm × 64mm) was used with compression up to breaking using an universal testing machine (INSTRON, model 4501) with a load cell of 5kN and during this test at constant speed of 1 mm/s into the fillets. Samples were taken from the anterior part of flesh (corresponding approximately to the part used in sensory analyses) and measured 64 mm long and fillet size in width. For each sample, the weight was recorded to calculate the specific resistance expressed as maximal force divided by sample weight (Szczesniack et al., 1970). Instrumental colour analysis of fillets was made with a Dr Lange colorimeter using light source D65 and 10°-observer angle. Measures were made on the internal part of raw fillet and on cooked minced flesh. Data were expressed in L* a* b* system, representing lightness, redness and yellowness respectively as recommended by CIE (1976). The instrumental analyses were performed according to the procedures described by Laroche et al. (1996b).

2.6 Statistical analysis

All data except sensory analyses were subjected to one-way analysis of variance to test the effects of experimental diets. In cases where significant differences occurred (significance level <0.05), the means were compared using Student Newman-Keuls test. The statistical tests were performed using the STAT-ITCF (ITCF, 1988) software. The results of sensory analyses were subjected to two-way analysis of variance to test the effects of experimental diets and assessors. In cases where significant differences occurred, the means were compared using Duncan test with the FIZZ, Biosystèmes software.

3. RESULTS

3.1 Growth performance and whole body composition

During the first three months (period 1), growth performance were high for all fish with no differences between the groups (Table 2). A slight but not significant increase in growth rate was observed with increased dietary fat levels. No significant differences were found among treatments for condition factor (K), feed efficiency (FE) and protein efficiency ratio (PER). Concerning whole body composition of fish fed during the period 1, higher contents of dry matter, fat and gross energy were observed in fish fed higher dietary fat levels (Table 3). Whole body protein content of fish fed the HF diet was significantly lower than protein content of fish fed the two other diets. A significantly lower HSI was found in fish fed the HF diet compared to fish fed LF and MF diets. The viscerosomatic index (VSI) did not differ between treatments.

During period 2, the growth performance was similar for the two groups (LF and LF') fed the low-fat diet (Table 2), whereas fish kept unfed lost weight and their condition factor decreased significantly ($P<0.05$). Feed and protein efficiency ratios were not different

(P>0.05) between the two groups of fed fish. At the end of period 2, dry matter, ash, fat and gross energy content were not affected by treatments (Table 3). A significant (P<0.05) decrease of protein content of whole fish was observed in unfed fish. Fat content of whole fish in period 2 was lower than fat content in period 1. Starvation led to a decrease in HSI in comparison to those of fed fish.

3.2 Nutrient utilisation

Daily protein gain was not significantly different between treatments (Fig. 1a). Daily whole body fat gain increased with increasing dietary fat levels. During period 2, significant body protein and fat loss occurred in unfed fish (Fig. 1b). For fish of LF' groups (transferred from a high-fat diet to a low-fat diet), daily protein gain was similar to the LF group and daily fat gain was just below zero and significantly different from LF and unfed groups.

3.3 Liver, viscera and muscle composition

In period 1, liver moisture and fat contents were not significantly affected by dietary fat levels (Table 4). Hepatic fat content varied between 8.7 to 9.9% (in wet weight basis). Visceral fat content varied between 38 to 47% and fish fed the HF diet had a significantly (P<0.05) higher fat deposition. In period 1, muscle fat content increased and varied between 8.3 to 11.0% and the values of fish fed the LF diet were significantly different from those of fish fed the diets MF and HF. During period 2, withdrawal of feed did not affect liver composition (Table 4). Dry matter and fat content of viscera was significantly lower in fish fed the LF diet than unfed fish or in fish previously fed the high-fat diet (P<0.05). Although moisture content of muscle increased in unfed fish, this had no significant effect on fat content.

3.4 Plasma cholesterol and triglycerides

At the end of the first period, plasma cholesterol concentrations increased with increasing dietary fat levels and were higher in fish fed diets MF and HF (Fig. 2a). In period 2, a significant decrease in plasma cholesterol concentrations was observed for fish kept unfed (Fig. 2b). Plasma triglyceride concentrations showed no differences between treatments in both periods.

3.5 Activities of lipogenic enzymes

At the end of period 1, the activity of hepatic G6PD in fish fed the low-fat diet was significantly lower than those of fish fed MF and HF diets (Table 5). Hepatic fatty acid synthetase (FAS) activities were low and showed a similar trend although without significant differences. At the end of period 2, both enzyme activities were found to be significantly lower ($P<0.05$) in unfed fish as compared to fed fish.

3.6 Gutted and fillet yields

During period 1, there was no significant effect ($P>0.05$) of dietary fat levels on gutted and fillet yield (Fig. 3). At the end of period 2, gutted yield did not differ between treatments (Fig. 3a). Fillet yield of unfed fish was significantly lower ($P<0.05$) than the two groups of fish fed the LF diet (Fig. 3b).

3.7 Sensory analyses

Sensory analyses were performed on cooked and smoked fillets (Table 6). No fillets were rejected by the sensory panel. At the end of period 1, few differences were observed for cooked fillets. Only compactness was significantly different, fillet from fish fed the HF diet presenting the lowest value. At the end of period 1, salty flavour and salty aftertaste in smoked fillets of fish fed the low-fat diet seemed to be significantly higher than in the other

groups ($P<0.05$). At the end of period 2, cooked fillets from unfed fish versus fed fish were significantly different in terms of colour and texture in mouth (Table 7). Intensity of red colour was more pronounced and fillets appeared more smooth and damp in unfed group. Cooked fillets from fish fed the low-fat diet during the whole trial had a firmer texture and a lower exudation than the other groups ($P<0.05$). In smoked fillets, starvation did not affect sensory characteristics. Only a slight tendency of more yellowness and less of redness was noted in fillets from fish kept unfed for two months.

3.8 Instrumental colour analysis

After period 1, higher values for all parameters of colour (L* =lightness, a* =redness and b* = yellowness) were observed in fish fed MF and HF diets particularly in uncooked fillets (Table 8). On cooked fillets, only C* (saturation) values presented a significant difference between treatments. Starvation induced an intensification of colour. Values of C*, a* and b* were significantly higher in unfed fish than the others in both raw and cooked fillets ($P<0.05$). In fish fed the low-fat diet only in period 2 (group LF'), the values of L* and a* of raw fillets were significantly different from those of fish fed the LF diet during the whole study. Instrumental colour analysis did not show any differences between cooked fillets from the two groups (LF and LF') fed the low-fat diet during the finishing period.

3.9 Instrumental texture analyses

No significant effects of dietary fat levels were observed for any of the parameters of instrumental texture analyses on raw or cooked fillets at the end of period 1 (Table 9). At the end of the study, maximal force of raw fillet was significantly higher for fish kept unfed than fed fish. The work expressed as mJ/g were lower for fish fed the HF diet during period 1 and

then switched to the LF diet in period 2 (LF') than in the two other groups. No differences between treatments were observed for maximal force of cooked fillet.

4. DISCUSSION

Growth rate of fish in this study were higher than those reported by Arzel et al. (1994) for brown trout of similar size grown over the same season (winter). Increased dietary fat levels were found to improve feed and protein utilisation in brown tout by Gabaudan et al. (1989) and Arzel et al. (1994). Present data do not reveal any significant difference in feed efficiency between treatments; since it is difficult to record feed intake under cage culture conditions, there might have been some feed losses, despite which values for feed efficiency were very good. Withdrawal of feed for two months prior to slaughter led to a significant weight loss here as in studies with other salmonids (Takeuchi and Watanabe, 1982; Lie and Huse, 1992; Einen et al., 1998). But, body length did not change significantly in unfed fish contrary to observations of Bonnet et al. (1996) in brown trout. Lie and Huse (1992) showed that body length of Atlantic salmon increased in fish starved 35 and 78 days. Einen et al. (1998) found that body length did not change significantly in Atlantic salmon starved for 30 days or less and increased in those starved beyond 58 days. Initial condition factors (K) of fish as well as possible seasonal influences might possibly explain such differences.

The increase in whole body fat deposition with the increase of dietary fat levels as observed here are in accordance with earlier data from brown trout (Arzel et al., 1994) as well as those from other species : Atlantic salmon (Hillestad and Johnsen, 1994; Bjerkeng et al., 1997; Hemre and Sandnes, 1999), rainbow trout (Storebakken and Austreng, 1987; Alvarez et al., 1998), seabass (Alliot et al., 1979) or gilthead seabream (Vergara et al., 1996). At the end of period 2, although unfed fish had a lower liver size (HSI), neither starvation nor a switch to a low-fat diet of fish initially fed with the high-fat diet (LF') led to a decrease in VSI. A reduction in muscle fat was however observed in these fish. These results differ from those of

Jezierska et al. (1982) and of Storebakken et al. (1991) in rainbow trout where viscera and liver were found to be more susceptible to fat mobilisation than carcass and muscle. In Atlantic salmon, the visceral fat content stays stable during starvation of 3 to 86 days (Einen et al., 1998). In the present study, reduction in whole body protein content was much lower (5%) than that in lipid content (12%), suggesting that at least under the conditions prevailing, brown trout could better conserve their protein than lipid when kept unfed. Based on the respective changes in gross energy and total nitrogen in unfed fish, the contribution of protein for energy purposes appears to range between 2.0 to 3.4 mgN/kJ, values comparable to those found in other species (Kaushik and Luquet, 1977; Kaushik and Médale, 1994). The slight differences in body composition of fish maintained under the low-fat dietary treatment at the end of the two periods possibly reflects changes occurring with increasing body size.

Plasma cholesterol concentrations were comparable to values found in rainbow trout (Alexis et al., 1985; Kaushik et al., 1995). According to Fremont and Leger (1981), plasma cholesterol concentrations depend on the nutritional status. Kaushik et al. (1995) observed that soy protein had a possible hypocholesterolemic effect. In Atlantic salmon fed different dietary fat levels, Hemre and Sandnes (1999) found no changes in plasma cholesterol or triglyceride levels. Starvation induced a decrease of plasma cholesterol concentrations as in rainbow trout where starvation was accompanied by significant decreases in serum glucose and blood cholesterol concentrations reflecting a decrease in feed intake or an increase in general lipid metabolism (Heming and Paleczny, 1987).

Lipogenic processes in fish are similar to those in mammals (Iritani et al., 1984). The hepatic tissue is recognised as the preferential site of *de novo* fatty acid synthesis in fish (Lin et al., 1977a; Sargent et al., 1989). Dietary non-protein energy sources are known to affect G6PD,

malic enzyme and FAS activities in rainbow trout, channel catfish and European seabass (Lin et al., 1977a and b; Likimani and Wilson, 1982; Arnesen et al., 1993; Alvarez et al., 1998; Dias et al., 1998). The values of G6PD activities in brown trout as found here were similar to those recorded in rainbow trout (Barroso et al., 1994; Alvarez et al., 1998; Dias et al., 1999). The decrease in G6PD activities with increasing dietary fat levels reflects most reasonably the effects of the concomitant decrease in dietary carbohydrate levels. The absence of significant changes in the activities of FAS with increase in dietary fat levels is also noteworthy and corresponds well with a lack of significant differences in overall daily fat gain. The decrease in G6PD and FAS activities observed in unfed brown trout possibly results from a change in metabolic flux as seen in other species (Lin et al., 1977b; Barroso et al., 1993).

Even with the accumulation of perivisceral fat (Table 4), there was no reduction in gutted yield, the values of which as observed here are in the range of values found in other salmonids (Einen et al., 1998; Hillestad et al., 1998). In Atlantic salmon, starvation increases the slaughter yield (Lie and Huse, 1992; Einen et al.,1998), whereas our data suggest only a slight and not significant increase. However, the decrease in fillet yield under unfed conditions was also observed in Atlantic salmon (Einen et al., 1998).

Among the most important quality attributes of animal or fish products from a consumer's point of view are sensory attributes such as colour, texture, odour and flavour (Boggio et al., 1985). Sensory assessment showed no clear differences between groups except that smoked fillet of fish fed the low-fat diet was less fat and judged as more salty after smoking. Starvation induced modifications on sensory parameters such as smooth and damp texture and colour intensity confirmed by the instrumental colour analyses. In rainbow trout, starvation of 1 or 2 months did not significantly affect the odour or taste of cooked fillets (Johansson and

Kiessling, 1991). Einen and Thomassen (1998) found that starvation decreased the fresh flavour of cooked fillets of Atlantic salmon. These results show that the currently available data on sensory analyses are a bit contradictory and suggest that at least a standardisation of methodologies would be most useful.

In salmonids, flesh colour is an important parameter of quality for the consumers conferring an « elite » image to these fish. Increasing dietary fat levels induced an intensification of colour of fillets, particularly of raw fillets. Values of saturation C* increase with the increase of white muscle pigment concentration (Choubert, 1982). Better pigmentation with an increase of dietary fat levels have been already found in rainbow trout (Torrissen, 1985; Choubert et al., 1991) and in Atlantic salmon (Bjerkeng et al., 1997; Einen and Roem, 1997; Einen and Skrede, 1998). In Atlantic salmon, Einen and Skrede (1998) found that increasing fat levels of the fillets significantly increased redness (a*) and yellowness (b*) values of the raw fillets. Also, Nickell and Bromage (1998) found in rainbow trout that lightness (L*) values were significantly correlated with flesh lipid content when dietary lipid level increased from 8 to 27%. Whether the increase in values of colour parameters observed in unfed fish are due to an internal redistribution of the pigment in fillets in the absence of dietary pigment intake (Choubert, 1985) is also worth investigating, especially since there was a significant drop in muscle lipid content of fish after 2 months of fast.

Given that texture is a multiple parameter attribute (Sigurgisladottir et al., 1997), we employed different parameters like maximal force and work. Changes in dietary fat levels did not cause any noticeable difference in the parameters of instrumental texture evaluation, neither of cooked fillets nor of raw fillets. Very early, it as suggested that when fat content in muscle is high, texture of the fillet becomes more tender (Dunajski, 1979). Kunisaki et al.

(1986) also found a relation between fat content and muscle hardness in horse mackerel. In rainbow trout, while parameters of texture of raw fillet are conditioned by flesh fat content, those of cooked fillet are independent of fat content (Fauconneau et al., 1993). In fasted brown trout, an increase in maximal force was observed. After long-term starvation, an increase in pH (at day 4 and 12) and in hardness of muscle texture has been observed in Atlantic salmon (Einen and Thomassen, 1998). In the present study, the hardness of cooked fillets was significantly higher only in brown trout fed the low-fat diet during the whole study. This effect is probably due to a different lipid distribution in muscle rather than overall muscle lipid content.

In conclusion, high dietary fat levels lead to increased lipid deposition in the whole body and muscle of brown trout as in other salmonids. Both feeding a low-fat diet or feed withdrawal for two months prior to slaughter leads to a reduction in whole body as well as muscle fat content, without however having a clear effect on the sensory quality of flesh. But, compared to fasting, feeding a low-fat diet has the definite advantage of conserving growth performance.

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Table 1. Ingredient and proximate composition of the experimental diets

	Experimental diets		
	LF	MF	HF
Ingredients (%)			
Norseamink fish meal [1]	46.0	45.0	45.0
Whole wheat	28.7	17.4	8.5
Wheat gluten	17.9	20.7	21.7
Fish oil	6.6	16.1	24.0
Mineral and vitamin premix [2]	0.5	0.5	0.5
Choline chloride	0.2	0.2	0.2
Funginib 2A[3]	0.1	0.1	0.1
Rovimix stay C[4]	0.04	0.04	0.04
Chemical composition			
Dry matter (DM), %	91.2	91.5	90.9
Ash, % DM	10.2	9.6	9.5
Crude fat, % DM	11.4	19.5	26.3
Crude protein, % DM	56.5	55.3	56.2
Energy, kJ/g DM	21.3	23.2	23.8

[1] Norseamink, Norsildmel, Minde, Norway.

[2] Mineral mixture in kg of diet : KCl, 90; KI, 0.04; $CaHPO_4.2H_2O$, 500; NaCl, 40; $CuSO_4.5H_2O$, 3; $ZnSO_4.H_2O$, 4; $CoSO_4.7H_2O$, 0.02; $FeSO_4.7H_2O$, 20; $MnSO_4.H2O$, 3; $CaCO_3$, 215; $MgCO_3$, 124; NaF, 1.

Vitamin mixture in mg or UI/kg of diet : retinyl acétate, 10000 UI; cholecalciferol, 1000 UI; all-rac-α-tocopheryl acétate, 40; menadione sodium bisulfide, 1; thiamin, 10; riboflavin, 25; D-calcium pantothenate, 50; pyridoxine,10; vitamin B_{12}, 0.06; niacin, 100; folic acide, 5; biotin, 1; myo-inositol, 1000.

[3] Antifungal agent

[4] Ascorbate polyphosphate, Hoffmann LaRoche

Table 2. Growth performance, feed and protein efficiency in brown trout at the end of the two growth periods [1]

	Experimental diets		
Period 1	LF	MF	HF
IBW (g) [2]	1446±23	1486±31	1533±14
FBW (g) [3]	2529±28	2654±64	2724±39
K [4]	1.42±0.04	1.50±0.02	1.51±0.03
SGR [5]	0.66±0.01	0.68±0.01	0.68±0.03
FE [6]	0.80±0.01	0.81±0.02	0.82±0.01
PER [7]	1.42±0.02	1.47±0.03	1.46±0.03
Period 2	LF	unfed (HF)	LF' (HF)
IBW (g)	2511±55^{b}	2747±13^{a}	2697±53^{a}
FBW (g)	3018±83^{a}	2532±37^{b}	3178±29^{a}
K	1.47±0.04^{a}	1.30±0.02^{b}	1.51±0.03^{a}
SGR	0.33±0.01^{a}	-0.15±0.02^{b}	0.29±0.03^{a}
FE	0.56±0.02	-	0.58±0.04
PER	0.99±0.03	-	1.03±0.08

Values are means ± standard deviations (n=3). Values in the same row with different superscripts are significantly different ($P<0.05$)

[1] Period 1 corresponds to an initial duration of 12 wks during which fish were fed different dietary fat levels. Period 2 corresponds to another 8 wks during which fish fed the HF diet were subsequently either kept unfed or fed the LF diet.

[2] IBW= initial body weight.

[3] FBW= final body weight.

[4] K, condition factor = (FBW/length^{3})

[5] SGR, specific growth rate =100×((ln FBW - ln IBW)/ days).

[6] FE, feed efficiency = 100×(wet weight gain/dry feed intake).

[7] PER, protein efficiency ratio= 100×(wet weight gain/crude protein intake).

Table 3 : Whole body composition (% wet weight), hepatosomatic (HSI) and viscerosomatic index (VSI) of brown trout at the end of the two growth periods [1]

		Experimental diets		
Period 1	initial	LF	MF	HF
Water, %	67.4	64.9±0.3[a]	63.2±0.6[ab]	62.7±0.6[b]
Ash, %	2.1	1.9±0.0	1.9±0.1	1.7±0.1
Protein (N×6.25), %	19.3	21.0±0.1[a]	21.3±0.5[a]	19.4±0.4[b]
Fat, %	12.5	14.6±0.5[a]	16.8±0.8[b]	17.9±0.5[b]
Energy (kJ/g)	8.8	9.8±0.1[a]	10.2±0.3[a]	10.9±0.2[b]
HSI, %	-	1.3±0.0[a]	1.3±0.0[a]	1.2±0.0[b]
VSI, %	-	7.8±0.2	8.0±0.21	8.0±0.2
Period 2		LF	Unfed (HF)	LF' (HF)
Water, %		63.7±0.8	64.3±0.4	63.3±0.1
Ash, %		1.9±0.0	2.1±0.0	1.9±0.1
Protein (N×6.25), %		19.3±0.1[a]	18.5±0.1[b]	19.0±0.1[a]
Fat, %		15.5±0.6	15.7±0.4	15.4±0.4
Energy (kJ/g)		10.3±0.3	10.2±0.2	10.2±0.2
HSI, %		1.1±0.0[a]	0.9±0.0[b]	1.1±0.0[a]
VSI, %		6.6±0.1	6.8±0.2	7.0±0.2

Values are means ± standard deviations (n=3). Values in the same row with different superscripts are significantly different (P<0.05).

[1] See footnote to Table 1 for description of periods

Table 4. Moisture and total lipid content (% wet weight) of liver, viscera and muscle in brown trout at the end of the two growth periods [1]

	Experimental diets		
Period 1	LF	MF	HF
Liver			
Moisture	68.0±0.6	69.9±0.7	68.8±0.5
Total lipid	9.9±0.7	8.7±0.6	8.8±0.7
Viscera			
Moisture	44.0±1.5^{a}	39.5±1.7^{a}	32.6±2.8^{b}
Total lipid	37.9±1.8^{a}	41.8±2.2^{ab}	47.2±1.8^{b}
Muscle			
Moisture	69.0±0.4	67.3±0.8	67.5±0.5
Total lipid	8.3±0.3^{a}	10.4±0.8^{b}	11.0±0.6^{b}
Period 2	LF	Unfed (HF)	LF' (HF)
Liver			
Moisture	71.7±0.7	72.5±0.7	71.4±0.8
Total lipid	6.2±0.6	6.3±0.5	6.3±0.7
Viscera			
Moisture	45.3±2.5^{a}	33.1±2.1^{b}	36.3±1.9^{b}
Total lipid	38.2±3.3^{a}	50.4±2.7^{b}	47.9±1.5^{b}
Muscle			
Moisture	67.9±0.4^{a}	69.4±0.3^{b}	67.5±0.7^{a}
Total lipid	8.8±0.4	8.5±0.5	9.4±0.8

Values are means ± standard deviations (n=6). Values in the same row with different superscripts are significantly different ($P<0.05$).

[1] See footnote to Table 1 for description of periods

Table 5. Activities of glucose 6 phosphate dehydrogenase (G6PD) and fatty acid synthetase (FAS) in the liver of brown trout at the end of the two growth periods [1]

		Experimental diets		
Period 1		LF	MF	HF
G6PD	IU/ g liver	23.54±1.69[a]	17.43±0.88[b]	18.65±0.68[b]
	IU/mg protein	0.50±0.04[a]	0.39±0.02[b]	0.37±0.01[b]
FAS	mIU/ g liver	3.19±0.14	3.01±0.53	2.69±0.32
	mIU/mg protein	0.08±0.01	0.07±0.01	0.06±0.01
Period 2		LF	Unfed (HF)	LF' (HF)
G6PD	IU/ g liver	19.28±3.71[a]	7.56±0.57[b]	15.21±1.60[a]
	IU/mg protein	0.33±0.06[a]	0.17±0.01[b]	0.33±0.03[a]
FAS	mIU/ g liver	2.33±0.17[a]	0.54±0.17[b]	2.23±0.18[a]
	mIU/mg protein	0.04±0.01[a]	0.01±0.00[b]	0.04±0.01[a]

Values are means ± standard deviations (n=6). Values in the same row with different superscripts are significantly different ($P<0.05$).

[1] See footnote to Table 1 for description of periods

Table 6. Sensory analyses (scores of 1 to 10) of brown trout at the end of period 1 [1]

	Experimental diets			ANOVA
	LF	MF	HF	(p)
Cooked fillet				
Odour intensity	4.68	5.43	5.79	0.066
Salmonid odour	4.86	5.41	5.17	0.62
Pink Colour	5.39	5.31	5.62	0.78
Compact aspect	6.52[a]	6.61[a]	5.94[b]	0.023
Flavour intensity	5.08	5.31	4.68	0.27
Salty flavour	3.22	3.42	3.24	0.84
Firmness	5.18	4.51	4.54	0.20
Smooth texture	4.04	4.32	4.24	0.83
Damp texture	4.36	4.46	4.06	0.75
Fat texture	2.94	2.92	2.81	0.94
Exudation	3.97	3.94	4.26	0.74
Smoked fillet				
Smoky odour	5.97	6.08	5.67	0.73
Salmonid odour	2.40	2.30	2.13	0.76
Pink colour	1.45	1.42	1.53	0.87
Orange colour	6.72	6.73	6.32	0.28
Colour homogeneity	6.21	6.91	6.60	0.067
Salty flavour	4.40[a]	3.84[b]	3.39[b]	0.022
Salty aftertaste	3.74[a]	2.90[b]	2.99[b]	0.015
Smoky aftertaste	4.75	4.33	4.62	0.59
Firmess	3.51	3.67	3.44	0.90
Fat texture	3.68	3.38	4.18	0.12

Values in the same row with different superscripts are significantly different.

[1] See footnote to Table 1 for description of periods

Table 7. Sensory analyses (scores of 1 to 10) of brown trout at the end of period 2 [1]

	Experimental diets			ANOVA
	LF	Unfed (HF)	LF' (HF)	(p)
Cooked fillet				
Odour intensity	5.37	5.22	5.54	0.77
Salmonid odour	5.71	5.96	5.81	0.88
Pink Colour	4.69[a]	5.68[b]	5.35[a]	0.017
Compact aspect	6.31	6.04	6.72	0.11
Flavour intensity	4.32	5.20	5.25	0.12
Salty flavour	1.91	2.54	2.48	0.21
Firmness	5.85[a]	4.14[b]	4.51[b]	0.001
Smooth texture	2.98[a]	4.25[b]	3.13[a]	0.03
Damp texture	3.57[a]	5.02[b]	4.45[a]	0.046
Fat texture	1.92	2.24	2.59	0.15
Exudation	2.96[a]	4.39[b]	4.04[b]	0.01
Smoked fillet				
Smoky odour	5.72	5.96	5.45	0.54
Salmonid odour	3.11	2.89	2.83	0.70
Pink colour	2.31	2.05	2.43	0.06
Orange colour	6.45	6.80	6.06	0.08
Colour homogeneity	5.67[a]	6.16[b]	6.15[b]	0.037
Salty flavour	3.08	3.11	2.94	0.90
Salty aftertaste	2.51	2.78	2.23	0.29
Smoky aftertaste	4.04	4.60	4.44	0.59
Firmess	3.91	4.37	3.94	0.47
Fat texture	4.35	4.54	4.82	0.39

Values in the same row with different superscripts are significantly different.

[1] See footnote to Table 1 for description of periods

Table 8. Parameters of instrumental colour analyses of brown trout fillets at the end of the two growth periods [1]

		Experimental diets		
Period 1		LF	MF	HF
Raw fillet	L* [2]	43.8±0.3[a]	44.4±0.3[ab]	45.1±0.4[b]
	a* [3]	17.1±0.2[a]	19.4±0.5[b]	19.9±0.2[b]
	b* [4]	13.3±0.2[a]	14.6±0.3[b]	15.2±0.2[b]
	C* [5]	21.7±0.3[a]	24.3±0.5[b]	25.1±0.3[b]
	H* [6]	37.8±0.2	37.0±0.4	37.4±0.2
Cooked fillet	L*	75.5±0.2	75.0±0.4	74.8±0.3
	a*	19.0±0.5	20.1±0.5	20.5±0.4
	b*	17.3±0.2	18.0±0.4	18.1±0.2
	C*	25.7±0.3[a]	26.9±0.6[b]	27.4±0.5[b]
	H*	42.3±0.5	41.9±0.3	41.6±0.2
Period 2		LF	Unfed (HF)	LF' (HF)
Raw fillet	L*	40.6±0.5[a]	43.2±0.3[c]	41.9±0.2[b]
	a*	16.7±0.4[a]	19.2±0.4[c]	17.8±0.3[b]
	b*	12.2±0.2[a]	13.5±0.4[b]	12.4±0.3[a]
	C*	20.7±0.3[a]	23.6±0.5[b]	21.7±0.4[a]
	H*	36.1±0.4	35.0±0.7	34.9±0.2
Cooked fillet	L*	73.9±0.3[a]	72.9±0.2[b]	73.6±0.3[ab]
	a*	20.3±0.4[a]	21.6±0.3[b]	19.9±0.3[a]
	b*	18.5±0.3[a]	19.4±0.2[b]	18.6±0.2[a]
	C*	27.5±0.5[a]	29.0±0.3[b]	27.3±0.5[a]
	H*	42.4±0.4	41.8±0.4	43.1±0.2

Values are means ± standard deviations (n=9). Values in the same row with different superscripts are significantly different ($P<0.05$).

[1] See footnote to Table 1 for description of periods
[2] L* : lightness
[3] a* : redness
[4] b* : yellowness
[5] C* : saturation = $\sqrt{(a^{*2}+b^{*2})}$
[6] H* : hue = $(180/\pi)\times\text{Arctan}(b^*/a^*)$

Table 9. Parameters of instrumental texture analyses of brown trout at the end of the two growth periods [1]

		Experimental diets		
Period 1		LF	MF	HF
Raw fillet	Max. force (N/g)	6.3±0.3	5.9±0.3	5.9±0.3
	Work (mJ/g)	76.7±3.6	75.8±3.8	72.7±3.9
Cooked fillet	Max. force (N/g)	30.7±1.6	27.6±2.1	29.1±0.9
	Work (mJ/g)	249.0±8.6	233.7±11.5	246.8±12.5
Period 2		LF	Unfed (HF)	LF' (HF)
Raw fillet	Max. force (N/g)	6.1±0.2[a]	7.1±0.2[b]	5.5±0.3[a]
	Work (mJ/g)	98.3±4.0[a]	104.4±5.7[a]	83.1±3.2[b]
Cooked fillet	Max. force (N/g)	27.3±1.6	27.2±1.6	25.7±1.6
	Work (mJ/g)	286.3±7.6[a]	248.3±13.5[b]	251.9±14.1[b]

Values are means ± standard deviations (n=9). Values in the same row with different superscripts are significantly different (P<0.05).

[1] See footnote to Table 1 for description of periods

Legends to Figures

Figure 1. Daily protein and fat gain in brown trout

Errors bars are standard deviations (n=3). Different superscripts are significantly different (P<0.05). ABW : Average body weight : (IBW + FBW)/2

Figure 2. Plasma total cholesterol and triglyceride concentrations of brown trout

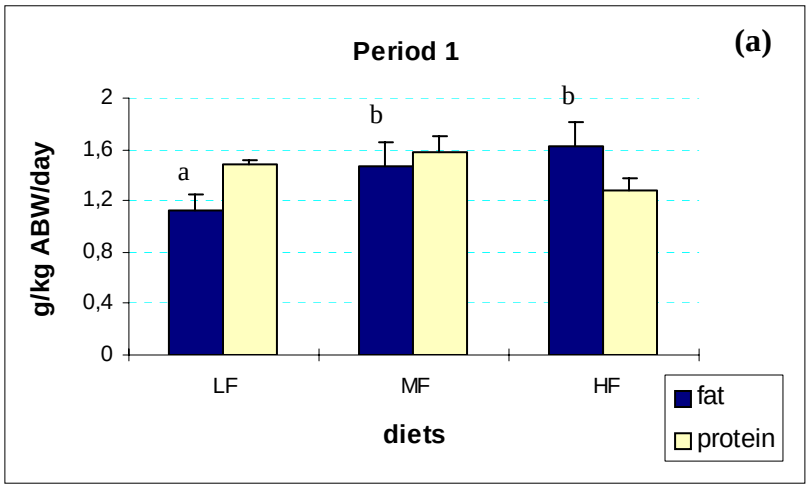
Errors bars are standard deviations (n=13). Different superscripts are significantly different (P<0.05).

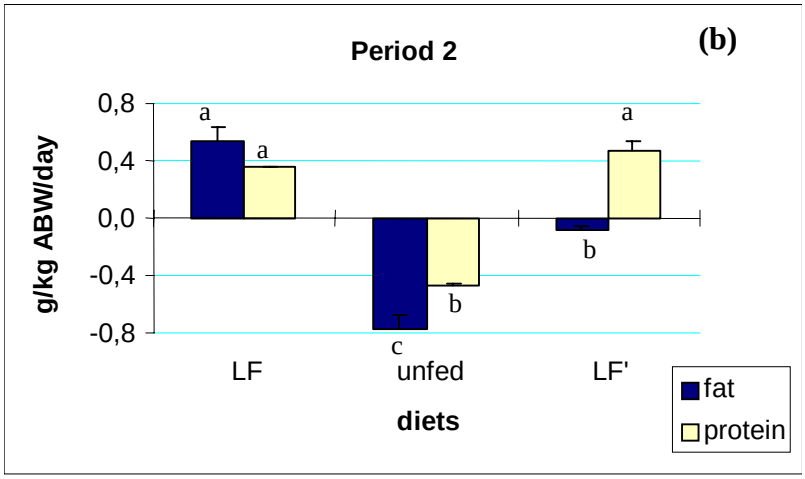
Figure 3. Gutted [1] (a) and fillet [2] (b) yields in brown trout

Errors bars are standard deviations (n=9). Different superscripts are significantly different (P<0.05).
[1] Gutted yield = gutted carcass weight / fish weight; [2] Fillet yield = fillet weight / gutted fish weight

Figure 1. Daily protein and fat gain in brown trout

Errors bars are standard deviations (n=3); Different superscripts are significantly different (P<0.05). ABW : Average body weight : (IBW + FBW)/2





a

Figure 2. Plasma total cholesterol and triglyceride concentrations of brown trout

Errors bars are standard deviations (n=13). Different superscripts are significantly different ($P<0.05$).

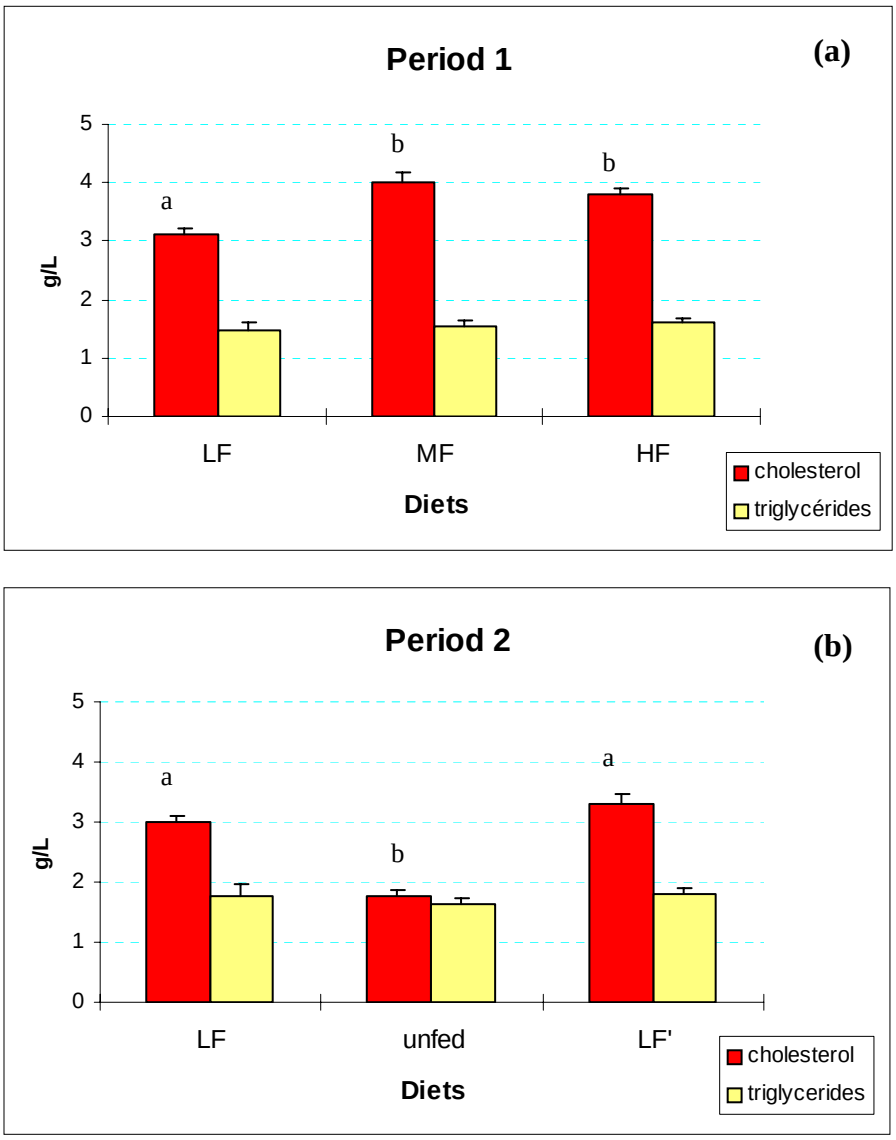
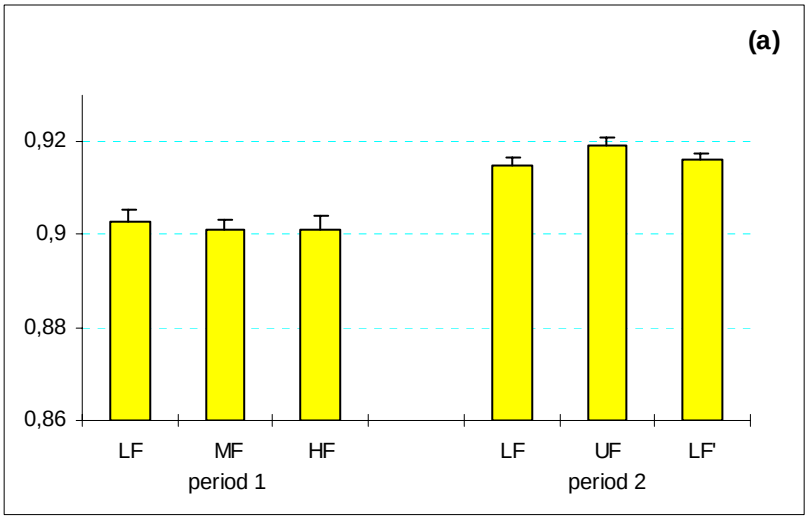
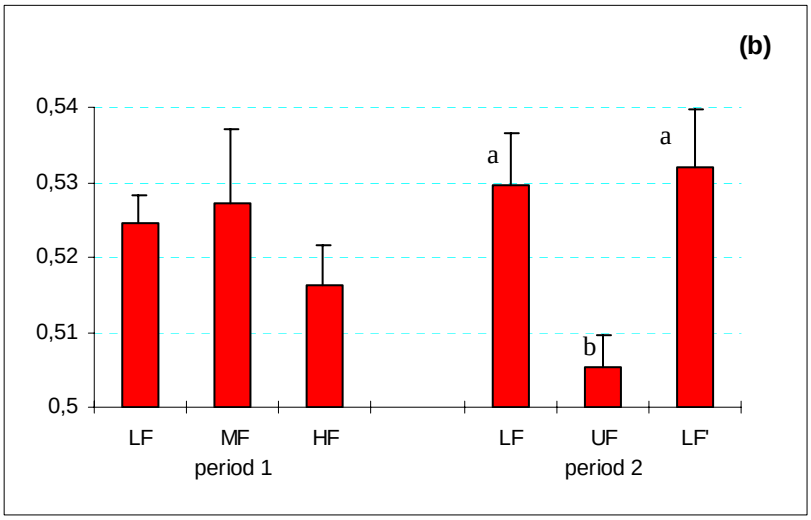


Figure 3. Gutted [1] (a) and fillet [2] (b) yields in brown trout

Errors bars are standard deviations (n=9). Different superscripts are significantly different (P<0.05).





[1] Gutted yield = gutted carcass weight / fish weight
[2] Fillet yield = fillet weight / gutted fish weight