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Effect of growth rate on quality traits and feed utilisation of rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*)

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Abstract

Rainbow trout (*Oncorhynchus mykiss*) of initial average weight 150 g and brook trout (*Salvelinus fontinalis*) initially weighing 124 g on average, were reared at different growth rates by feeding either a high (H, close to satiation) or low (L, half of H) ration of a commercial diet. Fish were reared for 6 to 15 weeks in order to reach same size class. Fast growth increased whole body lipid and dry matter ($P < 0.01$) but reduced ash in both species ($P < 0.01$). Brook trout were both more fat and had higher protein content, lower moisture and lower ash content than the rainbow trout ($P < 0.01$). Neither the feed conversion ratio (FCR = g feed intake · g weight increase^{-1}) nor protein retention efficiency (PRE) was affected by growth rate. The brook trout, however, were more efficient in retaining protein than the rainbow trout ($P < 0.01$). Enhanced growth increased fat content in fillets ($P < 0.01$). Like in whole body protein and dry matter was higher ($P < 0.01$) in brook trout fillets than in fillets from rainbow trout. Carcass percentage was in overall lower ($P < 0.01$) at high growth rates compared to slow growth while both carcass percentage ($P < 0.01$) and fillet yield ($P < 0.01$) was lower in brook trout than in rainbow trout.

Keywords: Growth rate; Quality; Rainbow trout; Brook trout; Feed utilisation; Protein retention efficiency

1. Introduction

The low prices on salmonids that has been experienced for years appear to be chiefly caused by large productions in salmonid aquaculture. The very effective production has

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been attained through establishing of breeding programmes, optimisation of feeds, improved disease treatment, etc. In addition to the positive elements, like reduced production time and less mortality, negative aspects such as low slaughter yield and high fat content are of potential improvement in modern salmonid aquaculture (Gjedrem, 1997) where fast growth is prevalent. A number of studies have considered the effect of feed composition on quality traits in salmonids (e.g., Wathne, 1995; Bjerkeng et al., 1997; Jobling et al., 1998). In addition, some attention has been drawn to quality of salmonids reared on different rations (e.g., Storebakken and Austreng, 1987; Johansson et al., 1995; Koskela et al., 1997) while studies on quality of fish grown to the same size are limited. This latter point is important since body composition changes with fish size (e.g., Weatherley and Gill, 1983b), and especially lipid content is an important feature of fish quality (Sigurgisladottir et al., 1997).

One potential strategy that enhances salmonid value is improvement of the quality. Another strategy could be more farming and marketing of species, like the brook trout, which are less popular for rearing than for instance Atlantic salmon and rainbow trout. Enhanced product diversity of that kind might increase consumers interest for salmonids if supported by sound marketing.

Quality in a broad sense involves the whole fish production process. Feed waste and nutrient discharge are consequently matters of concern from a quality perspective. ‘‘Environment-friendly’’ feed for trout, which specifically considers reduced discharges of nitrogen and phosphorous has been focused on (Alsted, 1989). In addition to the importance of fish farming on surroundings, there is an obvious interest for effective feed conversion and high protein utilisation for fish farmers since feed constitutes a large fraction of the total costs in salmonid aquaculture.

The present study encompasses quality both in terms of slaughter yield, proximate composition of whole body as well as the edible fraction. Furthermore, it takes into consideration the feed and nutrient utilisation of the rainbow trout and the brook trout at different growth rates. In order to reduce allometric influences on the parameters investigated fish were grown to about the same size.

2. Materials and methods

2.1. Fish husbandry

Rainbow trout (*Oncorhynchus mykiss* Walbaum) were obtained from Blæsborg Fiskeri while brook trout (*Salvelinus fontinalis* Mitchill) were supplied by Krastrup Dambrug. Fish were left to acclimatise for 3–4 weeks in our research facilities at the North Sea Centre, Hirtshals. During the acclimatising period fish were fed a ration of 1% of their average body weight per day with the application of band feeders. Throughout the acclimation and experimental periods fish were fed a dry, extruded and pelleted 3-mm commercial diet (BioMar, crude protein: 49%; crude lipid: 23%; gross energy: 22.9 $kJ \cdot g^{-1}$) and held under 12 h light conditions (0800–2000 h). Each tank

(600 l) was supplied with oxygenated, communal tap water. Oxygen and temperature were recorded in tanks twice per hour by a M + S data logger connected to an Oxyguard system (Oxyguard, Birkerød, Denmark). Oxygen was supplied in excess at average value 7.8 mg $\cdot$ O_2 l^{-1} (range: 6.4–11.0 mg $O_2 \cdot l^{-1}$). Temperature was on average 9.8°C (range: 8.4–11.2°C). Before starting the experiment, the fish were anaesthetised in a 0.005% benzocaine solution and each specimen was supplied with a passive integrated transponder (PIT tag, Fish Eagle, UK) in its buccal cavity. This allowed for individual recognition of the fish. Fish were weighed at experimental initiation and subsequently every third week as to adjust feeding regimes. Prior to weighing the fish were not fed for 3 days in order to avoid influences from stomach content. Based on individual initial and final weights the specific growth rates were calculated according to $\mathrm{SGR} = (\ln w_{\mathrm{final}} - \ln w_{\mathrm{initial}})100\%\ \mathrm{days}^{-1}$. The feed conversion ratio was determined for each tank as: $\mathrm{FCR} = \mathrm{g\ feed\ ingested} \cdot \mathrm{g\ weight\ increase}^{-1}$. Feed waste was observed in a few cases. On these occasions, waste pellets were siphoned and counted and the weight thereof subtracted from the amount of feed supplied. This was carried out in order to achieve a precise value for the feed amount ingested. Fish were sampled and groups were withdrawn from the experiment upon fulfilling two criteria: (a) reaching at least 200 g and (b) increasing weight with at least 70%. This procedure was followed in order to obtain both fish of about the same size and a reasonable large growth response. Group RT-H was therefore terminated after 42 days, group BT-H after 63 days and groups RT-L and BT-L after 105 days.

2.2. Feeding and experimental design

One hundred twenty rainbow trout of initial average weight 150 g and 120 brook trout of initial average weight 124 g were used in the experiment. Four treatment groups were studied in triplicate (i.e., 12 tanks) with 20 fish per tank in a fully random design. The two salmonid species, rainbow trout (RT) and brook trout (BT) were fed either high (H) or low ration levels (L). In a previous study (unpublished) under similar conditions we studied the maximal feed intake of rainbow trout, which were hand-fed till satiation twice daily. We obtained the following relation for average feed intake and fish weight: Feed intake (g) = (0.0130 $\cdot$ ww (g)) + 0.656. In order to reach fast growth and simultaneously avoid feed waste, rainbow trout at high ration (RT-H) were fed 90% of this maximum ration, i.e., RT-H feed intake (g) = 0.9((0.0130 $\cdot$ ww (g)) + 0.656). RT-L were fed half of the RT-H ration (i.e., RT-L feed intake (g) = 0.5 $\cdot$ 0.90 $\cdot$ ((0.0130 $\cdot$ ww (g)) + 0.656). Fish weight increase was estimated daily on the basis of a feed conversion ratio value of 0.800 and feeding was corrected according to this value. The temperature fluctuations were small (maximum span in whole study: 2.8°C) and were consequently ignored in the calculation of feed amount.

Feed tables were adjusted according to actual values every third week following weighing of the fish. Farmed brook trout are considered slower growing than rainbow trout and their maximum ration was therefore estimated to be 75% of the maximum amount for rainbow trout, i.e., BT-H feed intake (g) = 0.75 $\cdot$ ((0.0130 ww (g)) + 0.656). BT-L were fed half of the BT-H ration, i.e., BT-L feed intake (g) = 0.5 $\cdot$ 0.75 $\cdot$ ((0.0130

$\cdot$ ww (g)) + 0.656). This value for BT-H appeared to be an adequate estimate for near satiety since periodic feed waste was observed in BT-H tanks. Feed was supplied automatically by a band feeder within 6–8 h. Feeding was carried out from 0800–1600, 7 days a week.

2.3. Laboratory practise

Initial groups of fish (total number of fish sampled, $N = 12$; number of each species, $n = 6$) were sampled for analysis of whole body composition. Chemical proximate composition was also carried out after homogenisation of whole body of three fish per tank ($N = 35$ (fish in total), $n = 8$–9 (fish per experimental group)) at group termination, with the exception of one BT-H fish that failed in the analytical procedure. Another three to four fish per tank ($N = 43$, $n = 9$–12) were sampled for analyses of percent fillet yield (fillet weight (g) $\cdot$ 100% $\cdot$ (fish weight (g))$^{-1}$) and carcass percentage (eviscerated fish (g) $\cdot$ 100% $\cdot$ (fish weight (g))$^{-1}$). The right fillet of each of these fish was de-skinned and analysed for proximate composition. In each case proximate composition was carried out on two samples per specimen and in accord with the following procedures: protein content was determined by the Kjeldahl method as described by Williams (1984). Lipid was analysed according to Bligh and Dyer (1959) and dry matter was obtained after drying at 105°C for 24 h. Ash was recorded after combustion of organic material at 520°C for 24 h. Protein retention efficiency (PRE) was calculated on basis of whole body proximate values in the initial and final sampled fish. Values were calculated for each sampled fish. The specific, individual protein intake was estimated on background of the individual weight increase, the total amount of feed ingested in the tank, the tank feed conversion ratio and the feed protein content:

$$\begin{aligned}
\text{PRE} &= \text{body protein increase} \cdot \text{protein intake}^{-1} \cdot 100\% \\
&= \Big(\big(\text{g protein} \cdot \text{g tissue}\, t_{\text{final}}^{-1} \cdot \text{bw}\, t_{\text{final}}\big) \\
&\quad - \big(\text{g protein} \cdot \text{g tissue}\, t_{\text{initial}}^{-1} \cdot \text{bw}\, t_{\text{initial}}\big)\Big) \cdot \Big(\big(\text{g protein} \cdot \text{g feed}^{-1}\big) \\
&\quad \cdot \big(\text{g feed intake}_{\text{tank}} \cdot \text{g biomass increase}_{\text{tank}}^{-1}\big) \cdot \big(\text{bw}\, t_{\text{final}} - \text{bw}\, t_{\text{initial}}\big)\Big)^{-1} \\
&\quad \cdot 100\%
\end{aligned}$$

2.4. Statistical analysis

The two-way ANOVA model was applied to reveal effects of either growth rate (H, L) or species (RT, BT). Upon observation of general effects the Student–Newman–Keuls test was carried out in order to signify specific effects. Pearson product moment analyses exposed specific relations among the parameters. Linear regression was applied for detection of linearity. Specifically for body and fillet lipid the impact of fish final weight was evaluated as a covariant to growth rate and species (ANCOVA). Discrimination of values was identified at significance levels $P < 0.05$ or $P < 0.01$.

3. Results

The different feed rations supplied induced growth rate differences as depicted in Table 1. These results showed that the feed conversion ratio was unaffected by growth rate and that FCR was similar for the two species. However, PRE was significantly $(P < 0.01)$ higher for brook trout than for rainbow trout (Table 1). As indicated in Table 2 slaughter quality in terms of carcass percentage was improved by slow growth $(P < 0.01)$ and was highest in rainbow trout $(P < 0.01)$. Fillet yield, on the other hand, was not significantly affected by growth but was highest in rainbow trout $(P < 0.01)$. Neither whole body protein nor fillet protein was influenced by growth rate, but was in both cases significantly higher in brook trout than in rainbow trout $(P < 0.01)$. Body lipid was also higher in brook trout compared to rainbow trout $(P < 0.01)$, but species interacted with growth, while only a trend $(P = 0.052)$ for increased fat was observed in brook trout fillets compared to rainbow trout. Fast growth increased fat in both whole body $(P < 0.01)$ and in fillets $(P < 0.01)$. Dry matter was influenced by interaction between species and growth rate but was higher in whole body of fast-growing fish $(P < 0.01)$ and in brook trout $(P < 0.01)$. Data on fillets showed that dry matter was higher in brook trout $(P < 0.01)$ while fillet moisture was unaffected by growth. Fillet ash was not affected by neither species nor growth rate but body ash was lower in fast growing fish $(P < 0.01)$ and lower in brook trout than in rainbow trout $(P < 0.01)$. Analysis of linear correlations revealed significant relations between some of the parameters investigated. Amongst others it was found, that body lipid increased for both species in a seemingly linear manner $(P < 0.01)$ with growth rate (Fig. 1). Also fillet lipid in rainbow trout increased significantly upon growth enhancement (Fig. 2),

Table 1
Growth and feed exploitation data for each of the four treatment groups (rainbow trout, fed high (RT-H) or low rations (RT-L); brook trout fed high (BT-H) or low rations (BT-L). The average value is presented together with the standard deviation (in parenthesis). The lower block indicates the impact of growth and species and interaction effects on the parameters presented. Statistic significance levels: ns: not significant $(P > 0.05)$, *: $P < 0.05$, **: $P < 0.01$

Treatment group	Growth			Feed utilisation	
	Initial weight (g)	Final weight (g)	Specific growth rate (%/day)	FCR (g feed/g ww increase)	PRE (% protein retained)
RT-H	157 (11)	267 (14)	1.26 (0.14)	0.816 (0.043)	42.0 (1.8)
RT-L	142 (16)	255 (21)	0.56 (0.11)	0.822 (0.036)	43.2 (2.6)
BT-H	129 (13)	241 (13)	1.00 (0.12)	0.818 (0.054)	46.0 (2.4)
BT-L	120 (12)	209 (23)	0.52 (0.10)	0.812 (0.063)	47.7 (5.4)
Two-way ANOVA					
Growth (g)				ns.	ns.
Species (s)				ns.	**
Interaction (g×s)				ns.	ns.

Table 2
Quality data for the four treatment groups (rainbow trout, fed high (RT-H) or low rations (RT-L); brook trout fed high (BT-H) rations or low rations (BT-L)). The average value is presented together with the standard deviation (in parenthesis). The lower block reveals impact of growth, species and interaction effects on the parameters studied. Statistic significance levels: ns.: not significant ($P > 0.05$), *: $P < 0.05$, **: $P < 0.01$

Treatment group	Slaughter data		Whole body composition				Fillet composition			
	Fillet yield (%)	Carcass yield (%)	Protein (%)	Lipid (%)	Dry matter (%)	Ash (%)	Protein (%)	Lipid (%)	Dry matter (%)	Ash (%)
RT-initial			16.9 (0.6)	10.3 (1.10)	30.7 (0.8)	2.70 (0.24)				
RT-H	52.7 (3.1)	89.1 (2.1)	16.8 (0.2)	11.9 (1.2)	31.3 (1.2)	2.28 (0.10)	19.4 (0.5)	5.5 (1.2)	26.6 (1.0)	1.43 (0.08)
RT-L	53.0 (1.6)	91.9 (1.4)	17.1 (0.4)	8.2 (1.1)	27.3 (0.9)	2.30 (0.09)	19.7 (0.3)	4.4 (0.3)	25.7 (0.6)	1.49 (0.02)
BT-initial			17.2 (0.2)	10.6 (1.2)	31.0 (1.2)	2.51 (0.15)				
BT-H	50.0 (2.9)	87.4 (1.3)	17.7 (0.4)	12.3 (0.9)	31.7 (0.4)	2.10 (0.09)	20.4 (0.8)	5.6 (0.6)	27.7 (0.6)	1.48 (0.11)
BT-L	50.5 (2.2)	88.5 (1.5)	17.8 (0.6)	10.2 (0.7)	30.0 (0.6)	2.27 (0.10)	20.6 (0.3)	5.2 (0.6)	27.8 (0.8)	1.51 (0.05)
Two-way ANOVA										
Growth (g)	ns.	**	ns.	**	**	**	ns.	**	ns.	ns.
Species (s)	**	**	**	**	**	**	**	ns.	**	ns.
interaction (g×s)	ns.	ns.	ns.	*	**	*	ns.	ns.	*	ns.

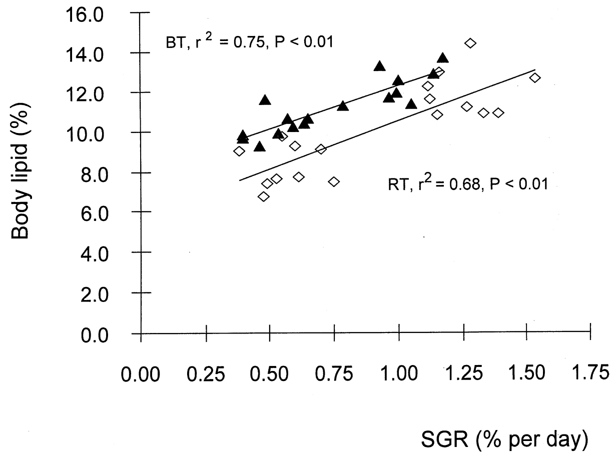

Fig. 1. Whole body lipid versus specific growth rate (% per day). Dark triangles represent values for brook trout (BT, $n = 17$) and white diamonds represent rainbow trout (RT, $n = 18$) values. A linear relationship between the two parameters is indicated for both species.

although this relation was less clear. Adding body weight as a covariant to growth rate and species did not reveal a significant impact of this factor on body lipid nor fillet lipid results ($P > 0.05$).

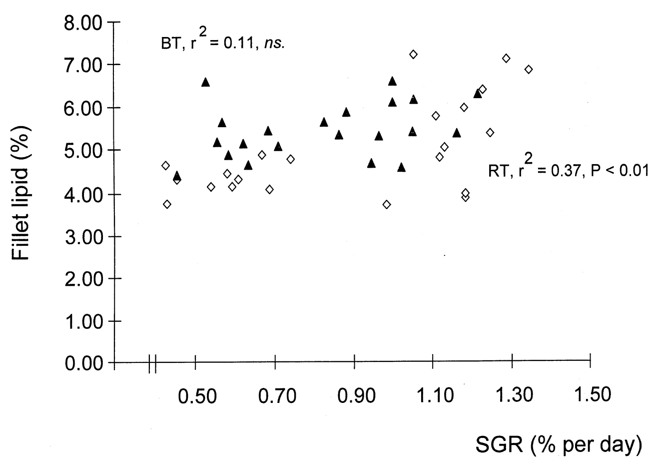

Fig. 2. Correlation between fillet lipid and specific growth rate (% per day). Dark triangles indicate brook trout (BT, $n = 21$) values and white diamonds represent values for rainbow trout (RT, $n = 22$). No statistical significant ($P > 0.05$) relation was obtained for brook trout. In rainbow trout fillet lipid increased significantly ($P < 0.01$) with growth. The r^2-values are based on simple linear relationships.

4. Discussion

In general, the present study indicates that from a quality perspective there are certain disadvantages associated with the rearing of salmonids at fast growth. The FCR, that in the present was similar for both species, and showed no significant relation to growth rate, has been reported to be optimal below maximum feed intake and growth in salmonids (Brett et al., 1969). Data obtained by Zoccarato et al. (1993; 1994); Arzel et al. (1998) and Lanari et al. (1998) support this while the results presented by Storebakken and Austreng (1987) and Azevedo et al. (1998) are less evidential. The present results can however, not exclude that the feed conversion efficiency reaches an optimum below the fastest growth rate since only two growth areas were examined.

The PRE showed no relation to growth rate, indicating that nitrogen discharge cannot be reduced by rearing trout with longer production time. However, in routine (basic) metabolism protein usage is higher at increased feeding levels (Alsop and Wood, 1997). Our results confirm the findings by Beamish and Thomas (1984) and Azevedo et al. (1998). Both these sources report that recovered nitrogen in rainbow trout is similar at different feeding levels. On the other hand, Lanari et al. (1998) fed soybean meal based diets for rainbow trout and found that protein retention tended to decrease with higher rations in fish differing in final weights. Nitrogen retention was also reported to decrease upon feeding large rations to brown trout fry (Arzel et al., 1998). A closer analysis of the results obtained by Grisdale-Helland and Helland (1997) and Arzel et al. (1998) with Atlantic salmon indicates that PRE might be closely related to relative protein intake in a negative manner. The present data suggest that relative protein accretion is stable in salmonids growing at different rates, which is in concurrence with the observations on protein being largely unaffected by, for instance, exercise level in rainbow trout (Lauff and Wood, 1996; Alsop and Wood, 1997). On the contrary, lipid content is much more fluctuating in the fish body than protein. Hence, lipid is the major energy donor during exercise (Lauff and Wood, 1996; Kieffer et al., 1998). The present results reveal that during fast growth at high rations fat build up is prevalent while at slow growth lipid deposition is subtle.

It appears logical that a fraction of the ingested ‘‘excess’’ energy is deposited as lipid, and therefore that increasing feed ration lead to more fat fish (Reinitz, 1983; Storebakken and Austreng, 1987; Storebakken et al., 1991). However, some studies have indicated that this is not necessarily so (Alsted, 1991; Tidwell et al., 1991; Azevedo et al., 1998). According to Shearer et al. (1997) there is a tendency for ration to determine growth and dietary lipid to control body fat. Regardless of the results obtained, a general problem in studies within the field is the lack of awareness of the fact that body lipid increases with size of the fish (e.g., Denton and Yousef, 1976). The present study, however, shows that body lipid is increased by feeding larger feed ration (Fig. 1) even when size effects are minimised. Hereby, the results provide evidence for findings which are derivable from Reinitz (1983).

Dry matter is closely and positively associated with lipid (e.g., Weatherley and Gill, 1983b) and moisture therefore decreases in the fattier, fast growing fish. The lower ash percentage in the body of fast growing fish is probably a result of relative low skeletal growth (negative allometry) compared to other tissues such as visceral fat. According to

Johansson et al. (1995) rainbow trout fed high rations have a higher condition factor (weight · length^{-3}) than size-matching specimens fed lower rations.

The fillet proximate composition is important from a sensory viewpoint and widely reflects that of the whole body. As depicted in Fig. 2, for rainbow trout there was a significant increase in fillet fat upon growth increase ($P < 0.01$). From the present data it is suggested that body fat is more altered by fast growth than fillet fat. Protein content, on the other hand, is not affected by growth when growth is enhanced by more feed. However, a species-specific effect was found since brook trout had a significantly higher protein and dry matter content than rainbow trout measured in both whole body and fillet. Such distinct characteristics of proximate composition induced by either growth or species may be of importance to the edible quality and the slaughter quality of the fish.

The present data suggest that a higher yield both in terms of carcass percentage and fillet fraction can be obtained from rainbow trout than from brook trout. The larger visceral fraction in the fast growing fish is likely to be explained by a higher deposition of excess energy in the viscera (Weatherley and Gill, 1983a) and confirms other studies on rainbow trout (Weatherley and Gill, 1983a; Storebakken et al., 1991). In agreement with the findings by Wathne (1995) in large Atlantic salmon, the present data reveal only a trend and no significant effect of ration level on fillet yield.

The present study shows that brook trout are just as good as rainbow trout in overall utilising the commercial trout feed. This indicates the familiar adherence between the two species since the feed used was developed primarily for rainbow trout. Specifically with respect to protein retention the brook trout show even a propensity to be more efficient than rainbow trout. On the other hand slaughter yield was lower for brook trout than for rainbow trout, and brook trout ingested less feed and grew slower. A general evaluation of the advantages associated with brook trout as a rearing species should therefore consider amongst others a higher protein retention and a lower slaughter yield from this species. A further indication of the present study is that rainbow trout may be more prone to changes in body proximate composition than brook trout. This can be of relevance in aquaculture if it is sought to produce fish of specific end compositions.

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