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Growth rate, maturation level and flesh quality of three strains of large rainbow trout (*Oncorhynchus mykiss*) reared in Estonia

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Abstract. Three all-female strains of large rainbow trout imported to Estonia (Danish, Finnish and Donaldson strain) were evaluated in a communal rearing experiment in tanks. The fish had been reared on different fish farms before the experiment started and they had an initial weight of 400–500 g. There were no significant genetic differences between the investigated strains on the basis of three allozyme loci. The total weight gain of the strains during the trial was similar but differences were revealed between seasons. The growth rate of the Finnish trout was high during the first autumn but decreased during the second summer of the trial, probably due to infestation by eye fluke *Diplostomum* sp. The strains differed in the percentage of immature fish and in the level of gonad development at the age of 2.5–3 years. The Donaldson strain had the highest number of immature fish of the studied strains. Mature females of the Finnish strain had the smallest gonads but also the lowest percentage of immature fish. The level of maturation was the main factor determining the quality – slaughter yield and flesh color.

Key words: Dressing percentage, Growth rate, Maturation, *Oncorhynchus mykiss*, Quality, Rainbow trout, Strains

Introduction

Large (2–3 kg) all-female rainbow trout is the main item produced on North European fish farms. As a marketing product it is similar to salmon. Fast growth rate is the most important production trait of this trout from the point of view of fish farmers. The main demands of the processing industry and consumers to the quality of large trout are the bright red color of the flesh and high slaughter yield (Gjedrem, 1997; Willoughby, 1999). Maturation decreases the quality of large farmed trout, as it does in salmon (Aksnes et al., 1986, Shearer, 1994), and the late maturing fish are preferred unless the caviar production is an additional aim of the trout cultivation. Significant differences between trout strains have been revealed in growth rate (Reinitz et al., 1978;

Linder et al., 1983; Morkramer et al., 1985; Sylvén and Elvingson, 1992) and also in maturation rate or dressing percentage (Sylven and Elvingson, 1992). Selection of the most suitable strain of trout is of vital importance to trout farmers. Fish farms, buying eggs or young fish from different suppliers usually rely on the production parameters of the fish advertised by the company. Estonia is one of the North European countries whose aquaculture totally depends on the import of eggs or fingerlings of rainbow trout from neighboring countries (Denmark, Finland, Sweden). The aim of the current study was to compare the genetic composition (allozyme variability), growth rate, maturation rate and slaughter yield of three imported trout strains, which were reared under identical conditions on an average Estonian trout farm.

Material and methods

Three all-female trout strains were evaluated during a rearing experiment on the fish farm Rutikvere (Central Estonia). Fish of the Donaldson strain were hatched in Estonia on fish farm Roosna-Alliku from the eggs of local broodstock, which originates from the fish imported into Estonia in 1982. The Danish strain was imported into Estonia from a commercial fish hatchery in central Denmark (Brande) as eyed eggs and hatched on fish farm Aravuse. The Finnish strain was imported at the age of 1 year from a fish farm near Joutsa (central Finland) to fish farm Härjanurme. The Estonian strain, used for background data in genetic analysis, was reared on local fish farms after its initial introduction in the 1950s. Subsequently, the Estonian strain was mixed up with several later introductions from different countries and is now extinct.

Fish of relatively similar weight (around 400–500 g) were tagged by clipping off adipose or the ventral fin and co-stocked into two 60 m^2 concrete tanks. The initial density of fish in tanks was 2 and 3 kg per m^3, respectively, and the final density 11 and 16 kg per m^3, respectively. The fish were fed with commercial trout feed Aller Aqua GEP 576 (crude lipid content 29%, protein content 44%) according to the standard feeding table. Food conversion ratio was 1.0 during the summer months and 1.2 during the colder season. The fish were not graded during the experiment. The trial lasted from August 2000 to December 2001, when the fish weighed over 2 kg. During the trial all the fish from the Tank 1 were individually weighed and counted six times. In the second tank only a sample consisting of 15–30% (but not less than 25 specimens) of fish of every group was individually weighed at the same time as fish of tank 1 to estimate the average weight. For weighing and counting the fish were anesthetized with quinaldine. The quality analysis was carried out in early 2002, when the fish were slaughtered. Total weight, slaughter yield (dressing percentage) and maturation level (gonadosomatic index, GSI) were determined. Fillet-yield and fillet color (according to Roche Color Card for Salmonids, scale 11–18) were analyzed in a sample of filleted fish. In a sample of 18 fish from every strain, the dry matter content of flesh was determined. Infestation rate by eye fluke *Diplostomum* sp. was measured by counting the number of metacercari in both eyes of each fish under the microscope.

Liver and muscle samples of 30–46 fish per strain were taken for genetic analysis. Genetic differences between the strains were estimated by analysis of allozyme variability at three loci (*SOD*-1*, *EST*-1*, *PGM*-2*) by means of polyacrylamide gel electrophoresis. Allozyme data were processed with GENEPOP 3.3 (Raymond and Rousset, 1995)

The weight data and slaughter traits (dressing percentage, GSI) were analyzed with a classical two-way ANOVA model with interaction:

$$Y_{ijk} = \mu + S_i + T_j + ST_{ij} + \mathrm{e}_{ijk},$$

where Y_{ijk} is the measurement of the corresponding trait of the kth fish from strain i in tank j, μ is the general mean, S_i is the fixed effect of strain i, T_j is the fixed effect of tank j, ST_{ij} is the interaction and e_{ijk} is the random residual error. Daily weight gains were analyzed with a two-way ANOVA model with main effects only:

$$Y_{ijk} = \mu + S_i + T_j + \mathrm{e}_{ijk}.$$

The Tukey HSD test for unequal sample sizes was applied to estimate the significance of differences in multiple comparisons of the averages of the performance traits. Significance of differences in means of quality traits (dressing percentage, fillet yield, GSI, fillet color) between mature and immature fish was determined by the t-test. Frequency data (mortality and the percentage of immature fish) were analyzed with the following log-linear model:

$$\ln f_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \alpha\beta_{ij} + \alpha\gamma_{ik} + \beta\gamma_{jk} + \alpha\beta\gamma_{ijk},$$

where f_{ijk} is the expected frequency in a cell of the three-way contingency table, μ is the mean of the logarithms of the expected frequencies, α_i, β_j and γ_k are the effects of categories i, j and k of factors A (mortality or maturity status), B (strain) and C (tank), respectively, and the $\alpha\beta_{ij}$, $\alpha\gamma_{ik}$, $\beta\gamma_{jk}$, and $\alpha\beta\gamma_{ijk}$ are the interaction terms that express the dependence between factors. The best model was revealed by testing hierarchically the significance of the interaction terms being left out of the initial most complex model. If the significant interaction terms were present, separate two-way χ-square tests of independence within each level of one of the factors were performed. Differences in infestation rate with *Diplostomum* between the rainbow trout strains were tested by the Kruskal–Wallis ANOVA and the multisample median test, because the distribution of numbers of metacercari per individual did not meet normality assumption within the studied samples. All statistical analyses were done using Statistica version 6.0 software (StatSoft, Inc. 2001).

Results

Genetic and morphological differences

The differences in allele frequencies of polymorphic enzymes between the strains were small. Only the Danish trout had significantly lower frequency of allele *PGM*-2 × 100 than the other strains (Table 1). However, all three imported strains differed from the local Estonian strain in variability of SOD and EST. The third, slow allele of *SOD*-1* was missing from the gene pool of the imported strains, but present in the Estonian strain and the frequency of the common allele *EST*-1 × 100 was higher in the imported strains. The differences between the strains in body shape and coloration could be detected visually, but were hardly measurable. Most of the fish of the Finnish strain looked more compact and had darker, bronze colored and more densely spotted skin.

Growth rate and survival of different strains

The average initial body weight of different strains was similar but not equal (Table 2), because the fish had been reared in different conditions before the starting point of the trial. The fish of the Donaldson strain were the largest, the Danish fish had intermediate weight and the Finnish fish were the smallest. The results of ANOVA indicated that the effect of strain on body weight was significant throughout the trial period and there was no significant interaction between the strain and the rearing tanks. During the first autumn the Finnish trout had the highest daily weight gain and by the end of November 2000 they reached the same weight as fish of the Danish strain (Table 2). In the winter at temperatures near 0°C the growth was negligible. During the second summer the growth rate of the Finnish strain became retarded and the mean weight was significantly lower than that of the Danish and Donaldson strains by the end of the trial (Table 2). In spring 2001, infestation of the fish with eye fluke *Diplostomum* sp. was discovered and was

Table 1. Allele frequencies of three polymorphic allozyme loci in four strains of rainbow trout

Strain	*N*	Loci and alleles						
		SOD-1*			*EST*-1*		*PGM*-2*	
		130	100	60	100	90	100	90
Danish	44	0.14	0.86	0.00	0.94	0.06	0.78	0.28
Finnish	36	0.18	0.82	0.00	0.99	0.01	0.99	0.01
Donaldson	30	0.15	0.85	0.00	0.95	0.05	0.91	0.09
Local Estonian (7 samples)	410	0.12–0.15	0.80–0.85	0.04–0.08	0.64–0.82	0.36–0.18	0.90–0.95	0.10–0.05

Table 2. Growth performance of all-female rainbow trout strains during the experiment across two rearing tanks (least square means ± SE, n = number of individuals). Average daily weight gains apply for the periods starting with the previous test weighing

Strain	Initial body weight* (30 August 2000)	Test weighing 1 (12 October 2000)	Test weighing 2 (29 November 2000)	Test weighing 3 (8 May 2001)	Test weighing 4 (4 September 2001)	Final body weight (31 October 2001)
Body weight (g)						
Danish	458.8 ± 5.7^{b}	608.0 ± 8.5^{b}	725.5 ± 12.4^{b}	865.2 ± 7.7^{b}	1981.5 ± 29.8^{a}	2439.8 ± 29.1^{a}
	($n = 150$)	($n = 200$)	($n = 184$)	($n = 457$)	($n = 179$)	($n = 206$)
Finnish	405.8 ± 5.7^{c}	574.2 ± 8.5^{c}	728.9 ± 12.3^{b}	866.4 ± 8.2^{b}	1824.2 ± 89.8^{b}	2288.6 ± 30.0^{b}
	($n = 150$)	($n = 200$)	($n = 185$)	($n = 366$)	($n = 180$)	($n = 202$)
Donaldson	496.0 ± 5.7^{a}	663.8 ± 10.0^{a}	779.8 ± 17.7^{a}	898.4 ± 9.9^{a}	1978.6 ± 40.5^{a}	2425.4 ± 41.0^{a}
	($n = 150$)	($n = 183$)	($n = 165$)	($n = 246$)	($n = 148$)	($n = 158$)
Daily weight gain (g)						
Danish		3.53 ± 0.05^{b}	2.45 ± 0.19^{a}	0.88 ± 0.09^{a}	9.39 ± 0.33^{a}	8.04 ± 1.25^{a}
Finnish		4.32 ± 0.05^{a}	3.23 ± 0.19^{a}	0.86 ± 0.09^{a}	8.05 ± 0.33^{a}	8.15 ± 1.25^{a}
Donaldson		4.17 ± 0.05^{a}	2.42 ± 0.19^{a}	0.75 ± 0.09^{a}	9.08 ± 0.33^{a}	7.84 ± 1.25^{a}

*Individual measurements of initial body weight were obtained only in Tank 1; the average starting weight for the Danish, Finnish and Donaldson strains in Tank 2 was 454.5, 371.3 and 471.7 g, respectively (estimated by dividing the total weight by the no. of individuals).

[a,b,c]Least square means followed by different letters in superscript are significantly different ($p < 0.05$).

Table 3. Average performance of all-female rainbow strains across the two rearing tanks at the end of the experiment (LSM = least square mean; SE = standard error; n = number of studied fish)

Trait	Strain		
	Danish	Finnish	Donaldson
Infestation rate by *Diplostomum*			
Median	1^{b}	23	2^{b}
Range	0–4	1–65	0–6
n	18	18	18
Mortality (%)			
Tank 1: mean ± SE	1.3 ± 0.9^{b}	0.7 ± 0.7^{b}	11.3 ± 2.6^{a}
n	150	150	150
Tank 2: mean ± SE	2.2 ± 0.8^{a}	0.9 ± 0.6^{a}	0.9 ± 0.9^{a}
n	324	232	109
Proportion of immature fish (%)			
mean ± SE	20.4 ± 3.4^{a}	4.8 ± 1.9^{b}	22.9 ± 3.6^{a}
n	142	125	140
Dressing percentage (%)*			
LSM ± SE	76.03 ± 0.41^{b}	78.46 ± 0.34^{a}	75.96 ± 0.55^{b}
n	96	102	69
GSI (%)*			
LSM ± SE	17.02 ± 0.33^{a}	13.67 ± 0.31^{c}	15.80 ± 0.29^{b}
n	104	95	101

*Immature fish excluded.
[a,b,c]Means followed by different letters in superscript are significantly different ($p < 0.05$).

significantly higher ($p < 0.001$) in the Finnish strain (Table 3). The Finnish trouts were probably infected on the fish farm, where they were kept after import from Finland and before stocking to the experimental tanks. The overall mortality was generally low in both experimental tanks but the log-linear analysis indicated the presence of significant three-factor interaction (mortality × strain × tank), implying that the degree of association between mortality and strain depended on the rearing tank. Tests of independence between mortality and strain within each tank revealed that the differences between strains were not significant in Tank 2 ($\chi^2 = 1.841$, $p > 0.05$) but highly significant in Tank 1 ($\chi^2 = 25.22$, $p < 0.001$). After excluding the Donaldson strain from the analysis, the association between mortality and strain in this tank be-

Table 4. Quality of filleted mature and immature rainbow trouts in spring 2002 (average ± SE)

Trait	Mature	Immature
No of fish	108	67
Total weight (g)	2230 ± 37	2058 ± 44
Dressing percentage (%)	76.8 ± 0.2[a]	87.3 ± 0.6[b]
Fillet-yield (%)	59.1 ± 0.4[a]	68.4 ± 0.3[b]
GSI (%)	15.0 ± 0.4	<0.30
Fillet color (by Roche Card)	14 ± 0.2[a]	17 ± 0.2[b]

[a,b]Different letters in superscript mark statistically significant differences ($p < 0.05$).

came insignificant ($\chi^2 = 0.3367$, $p > 0.05$), indicating that the mortality of the Donaldson strain was significantly higher than the two other strains (Table 3).

The log-linear analysis of maturity revealed no joint association between the three factors (maturity status, strain and tank). However, the association between maturity and strain was significant ($\chi^2 = 18.51$, $p < 0.05$) and further analysis indicated that the proportion of immature fish in the Finnish strain was significantly lower than in the Donaldson and Danish strains (Table 3).

When pooled over all strains, the immature fish had a significantly higher slaughter yield and brighter red fillet color than the mature fish (Table 4). To avoid the bias caused by a different proportion of immature fish of different strains all the immature fish were excluded from the further analysis. In the pooled sample of mature fish the slaughter yield (dressing percentage and fillet-yield) was not dependent on fish size but was strongly correlated with the level of maturity expressed as GSI (Figure 1). GSI did not depend on the fish size. The results of ANOVA indicated a highly significant ($p < 0.001$) effect of the strain on both dressing percentage and GSI of mature fish, whereas there was no interaction of the strain with the rearing tank. The Finnish trout had on an average the lowest GSI and the highest dressing percentage (Table 3). There were no significant differences between the strains in fillet color or the dry matter content (33.8–35.6% of raw weight) of flesh of mature trout. Dry matter content is strongly correlated with the lipid content (Weatherley and Gill, 1983) and we can assume that the fat content of flesh in the investigated strains was similar.

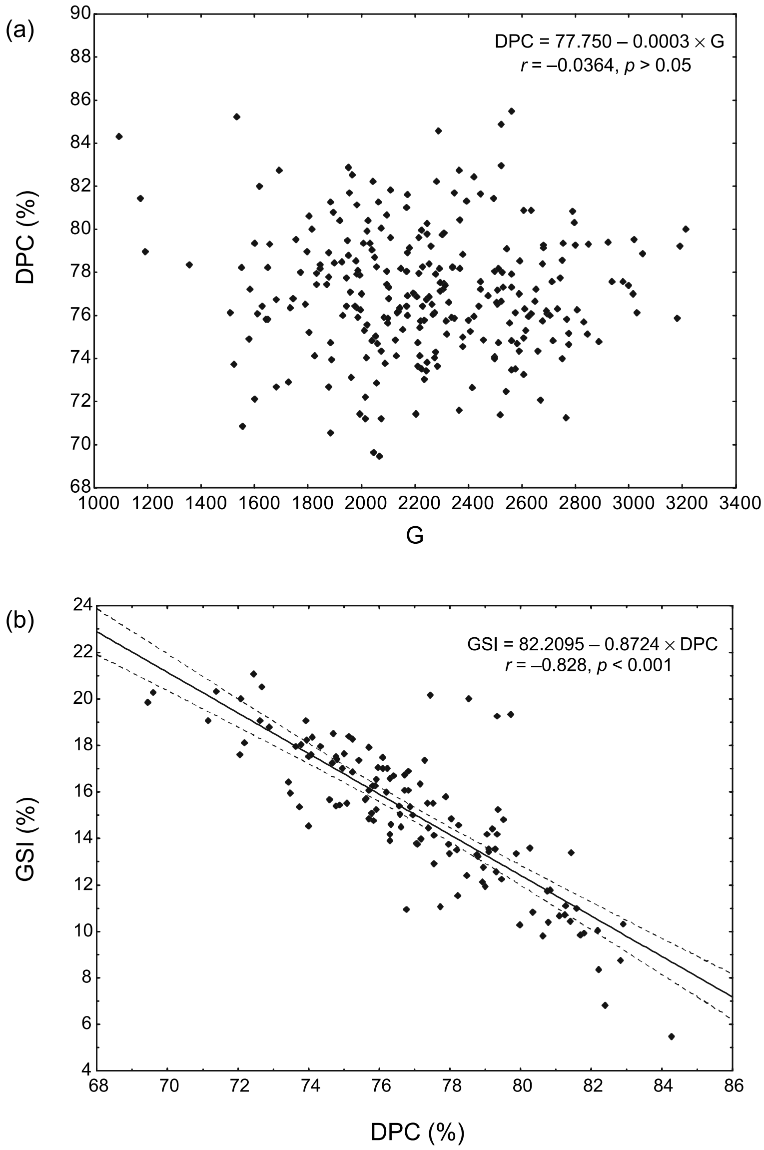

Figure 1. Regression of dressing percentage (DPC) on total weight (a) and GSI (b) among all-female mature rainbow trout.

Discussion

Compared to the common level of genetic variation among the strains or local stocks of rainbow trout in the whole of Europe (Guyomard, 1981; Thompson, 1985; Koljonen, 1986) or even in small Estonia (Paaver, 1988), the differences between the three investigated strains were insignificant. Thus, the differences in growth rate and maturity between the strains were not caused by the origin of the strains from different ancestral forms but were most probably the result of selective breeding. The Estonian strain was a mixture of several introductions and a little higher variability is not surprising. It can be also concluded that allozymes are not suitable markers to be used as genetic tags for distinguishing the imported trout strains.

Significant growth rate differences between the trout strains have been revealed by many authors (Linder et al., 1983; Morkramer et al., 1985; Sylven and Elvingson, 1992; Sumpter, 1992). Sylvén and Elvingson (1992) found that the differences of average weight between the trout strains are 500 and 700 g at the age of three summers. However, all these studies have included fish of both sexes and it is known that the growth and maturation rate of males and females is different. Also, most of these studies were carried out with small (pan-size) trout weighing less than 500 g or during short time intervals. Our experiment was started at the fattening stage of the fish (weight about 400–500 g) and continued through two growth periods and one wintering period until the fish reached a weight of 2.0–2.5 kg. The total weight gain was similar in all the strains and the differences between the strains were smaller than described in the literature. The first reason of this could be that only all-female strains were tested, while the other authors analyzed the stocks consisting of both sexes. The second possibility is that the commercially reared trout stocks are now more uniform than in the 1980s and early 1990s due to selective breeding during several generations.

However, if we analyze the growth rate of fish during the periods of the trial, significant differences between the strains could be revealed. The strains had different weight gain during different seasons, that is, at different temperatures. It has been suggested that the trout selected for rearing in northern countries could grow better at low temperatures than the trout from countries with mild climate (Sumpter, 1992). One could expect the Donaldson and Danish strain to have better growth during summer and the Finnish strain during autumn and spring. Indeed, the Finnish fish grew better in the first autumn, but this was not repeated in the second year, when the Danish fish had the best growth. The results of the trial could be biased by eye fluke infection. Damage of eyes might affect the growth rate of heavily infested Finnish fish in the second year. They were not blind, but the large number of parasites in the eyes could decrease their ability to compete for food. However, the density of the fish in the tanks was lower than by usual commercial rearing and the competition should not be strong. The Donaldson trout did not performed the best in earlier growth trials (Linder et al., 1983; Sylven and Elvingson, 1992). In our experiment it had good growth and quality parameters. The only disadvantage of the Donaldson trout was the high mortality in the tank where all the fish were counted regularly. The fish of both tanks were anesthetized before counting. Still, in the tank, where all the fish were counted, exposure to handling stress during catching and during recovery from the anesthesia was much longer than in the other one, where only a sample was analyzed. This could seriously affect Donaldson trout and cause higher mortality among fish of this strain, which according to fish farmers is relatively stress sensitive.

The main factor determining the slaughter yield of the mature fish was maturation level (GSI). The dressing percentage of immature salmonids depends the most on the amount of visceral depot fat (Rasmussen, 2001). When the female salmonids develop gonads, their slaughter yield and flesh color decreases (Aksnes et al., 1986). Different opinions about the influence of fish size on the dressing percentage have been expressed (Rasmussen, 2001; Kause et al., 2002). Our results confirm the view that the slaughter yield of adult trout does not depend on the fish size (Johanson and Jobling, 1998; Weatherup and McCracken, 1999). The quality differences between the strains result therefore only from the proportion of the immature fish among the strains and the maturation level of the fish in every strain. The faster growing fish tend to mature earlier (Siitonen, 1986; Quinton et al., 2002) and this could lead to the higher percentage of mature fish among Finnish trouts, which had the highest growth rate in the first year. However, the opposite may also be true – the growth rate of Finnish trout could decrease because of maturation.

We cannot prefer any of the studied strains unambiguously. The evaluation of the strains depends on the production profile of the fish farm. For the fillet production the highest proportion of immature fish is desirable and the Donaldson strain could be the best option but its high mortality can be a problem. However, when a fish farmer also produces caviar, the Finnish trout could be a better choice. They had high growth potential and high maturation rate but retained high dressing percentage.

Conclusions

1. On the background of allozyme variability among the European rainbow trout stocks there were no significant genetic differences between the three investigated strains.
2. The growth rate of the Finnish trout was high during the first autumn, but during the second summer of the trial the growth of Finnish fish decreased, probably due to infestation by eye fluke.
3. The most important differences between the strains were in the percentage of immature fish with high quality flesh at the age of 2.5–3 years and in

the different GSI of mature fish. The level of maturation was the main factor determining the quality – slaughter yield and flesh color.

4. No unambiguous ranking of the strains was revealed. Every strain had its positive and negative characters. The mature Finnish fish had the lowest GSI but this strain also had the lowest percentage of immature fish.

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