CHAPTER VIII

COMPOSITIONAL ANALYSES AND NUTRITIVE PROPERTIES OF MARKET-SIZE WILD, FARMED AND GENETICALLY MODIFIED COHO SALMON (*Oncorhynchus kisutch*)[1]

[1]To be submitted to Aquaculture

Abstract

Comparisons were made of various quality and sensorial characteristics of market-sized wild, cultured, and genetically modified coho salmon. Each group (n = 5) was filleted and each fillet divided into six discrete sections. Irrespective of animal source, a general proximal to distal gradient was observed in lipid distribution, with highest lipid levels being recorded in the front cuts and lowest in the tail. A dorsal to ventral increase in fillet lipid was also observed. Fillet moisture and ash did not vary between groups. Of the three groups, wild coho salmon expressed lower lipid content ($p \leq 0.05$). Tail cuts were always firmer ($p \leq 0.05$) but wild coho salmon exhibited greater fillet firmness ($p \leq 0.05$) than either cultured or modified fish. L*, a* and b* measurements were similar for modified and wild fish. Fillet mineral and amino acid profiles were similar across all groups. Differences were detected in appearance and odor between farmed and modified fish with panelists preferring cultured animals over modified coho ($p < 0.05$). No difference was detected in overall flavor characteristics when wild and cultured fish were compared.

*Keywords: Salmo*fan™, colorimetry, quality, amino acid, lipid, fillet, transgenic.

1. Introduction

It has been almost a quarter century since the first reports (Palmiter et al., 1982) of vivid growth enhancements in transgenic animals. Since that time, transgenic technology has presented animal science with powerful tools by which numerous fundamental problems have be tackled and solved. From the applied perspective however, it is growth, and its profitable manipulation, that has drawn greatest attention, especially in context to aquaculture. Commencing in the early 1980s, products from recombinant DNA technology, and especially recombinant bovine growth hormone (GH), were employed by several groups as a means to accelerate and optimize performance characteristics, particularly of salmonids (review McLean and Donaldson, 1993). This was rapidly followed by the production of transgenic fish, a research area which has received extensive review (Donaldson and Devlin, 1996; Dunham and Devlin, 1999; McLean and Devlin, 2000; Hew and Fletcher, 2001). The primary motivation for producing transgenic fish was economic - significant financial, biological and environmental gains can accrue with the commercial application of transgenic technology (Mayer and McLean, 1995). A secondary, but nonetheless important consideration was the potential that transgenic technologies present as a means of alleviating pressure on commercial fisheries through enhanced production of fish protein. This same value (i.e., increased production of fish protein) has also been viewed as a means of maintaining current global protein intake in light of the world's ever-increasing population (McLean and Craig, 2003). The potential for widespread application of transgenic technology by aquaculture has led to more serious questions that revolve around safety (food and environmental) issues and research in this area has increased with emphasis upon the maintenance of environmental integrity (Maclean and Laight, 2000; Fletcher et al., 2001; Muir and Howard, 2002). With comparatively few exceptions however, the number of studies that have analyzed the effects of GH transgenesis upon food safety and quality are sparse.

Studies with exogenous hormones suggest that transgenic delivery of GH will result in changes in overall composition, due to the impact of GH upon nutrient repartitioning (review: McLean and Devlin, 2000). Indeed, exogenous GH administration to salmonids has been associated with deterioration in color perception, odor and flavor (Rasmussen et al., 2001; Rønsholdt and McLean, 2004), while reductions in fillet fattiness is known to impact sensorial score of Atlantic salmon (Einen and Skrede, 1998). Clearly, consumer acceptance of transgenic fishes will rely

upon establishment of total safety and quality of the final product. For salmonids, Sylvia et al. (1995) suggest that taste and texture traits are the most consequential factors in determining consumer preference. The emergence of a more health-conscious and sophisticated consumer however, would imply that color and lipid status are also of no lesser importance (Sigurgisladottir et al., 1999). The potential introduction of genetically modified fish into the human food chain must be preceded by careful food safety evaluations (Guillén et al., 1999).

The present investigation was thus undertaken in an attempt to rectify the lack of information upon quality issues and transgenic salmon. Ideally, cultured animals should present the consumer with a product that is indistinguishable from, or superior to, their wild counterparts. Accordingly, transgenic salmon were compared against both cultured and wild fish.

2. Materials and methods

2.1 Animals

F_4 triploid transgenic coho salmon were derived from a founder generation of transgenic coho salmon produced from a Chehalis River strain (Devlin et al., 1995a). Animals were produced using the OnMTGH1 gene construct comprised of 320 bp of sockeye salmon metallothionein-B promoter fused to the 5′-UTR region of the full-length type-I growth hormone gene and terminator from the same species (Devlin et al., 2004). The strains developed from founder animals were produced by backcrossing transgenic fish to non-transgenic coho salmon from the Chehalis River, BC, Canada to produce backcross progeny generations. Triploid animals were produced by pressure shocking (10,000 psi for 5 min) eggs which had been incubated at 10 ºC for 30 min post-fertilization (Devlin et al., 2004). All fish were reared in a biosecure facility designed to prevent escape of transgenic animals to the natural environment. Fish were cultured in fresh well water (10 ± 1º C) until signs of smoltification were apparent (silvering and loss of parr marks), after which groups were transferred to sea water (8-14 ºC). Oxygen levels were maintained at greater than 80% saturation by means of an automated O_2 monitoring/injection system. Densities of fish were kept to below 10 kg m^{-3} at all times. During grow out, animals were fed to satiation three times daily (Pacific Apollo, 6 mm; 30 ppm astaxanthin and 30 ppm cantaxanthin; Skretting, Vancouver, BC, Canada). Transgenic fish were 20 months old at sampling. Frozen fillets and whole fish were vacuum packaged and frozen at -15º C until analyses (5 months).

Farmed coho salmon were obtained from Target Marine Products (Madeira Park, BC, Canada). Fish, which were raised from eggs, were grown in cages, being fed to satiation three times daily (Ewos Pacific, 5 mm; 50-60 ppm astaxanthin; EWOS Canada Ltd., Surrey, BC, Canada;). Farmed fish were 2 years old at sampling. Fish were vacuum packaged and frozen at -15º C until analyses (3 months).

Wild coho salmon were obtained from Albion Fisheries Ltd. (Vancouver, BC, Canada). Fish were troll caught around the Queen Charlotte Islands, BC, Canada in the summer 2003. Cultured and wild whole fish and fillets were handled and stored as described above. Fish were kept frozen until analyses (7 months).

2.2 Sample preparation

Whole fish from each treatment (head on, gutted) were filleted and percent frame yield recorded. Fish fillets from wild, farmed and transgenic coho salmon (n=5) were divided into 6 discrete cuts (Fig. 1) *viz.* 1 = front dorsal; 2 = front ventral; 3 = Scottish dorsal; 4 = Scottish ventral; 5 = dorsal tail, and 6 = ventral tail. Right fillets from each sample were employed for proximate and fatty acid analyses while left fillets were used for textural and color analyses.

2.3 Compositional analyses and firmness

Fish sections (6 sections per fish; n = 5 per treatment) were analyzed for total lipid (Folch et al. 1957), crude protein, moisture and ash following standard methods (AOAC 1990). All data were reported in dry weight basis.

Firmness was analyzed by measurement of total force and maximum force using an Instron Universal Testing Machine (model 3365, Instron Corp., Canton, MA, USA). Samples from each cut (6 sections; n = 5 per treatment) were thawed and placed on ice prior to testing. Each section was weighed and placed in a 10-blade Lee-Kramer cell. Fish samples were similar in thickeness. Crosshead speed was set as 100 mm/min and total force was recorded until blades had passed through the whole sample. Data were reported as total force (N g^{-1}) and maximum force (N/g).

2.4 Color

Color was measured in each section (n = 6) of raw fish fillets from each treatment (n = 5) using a Minolta (CR-2000, Japan) colorimeter to determine L***** (lightness), a* (green to red), and b* (blue to yellow) values. Visual coloration of each cut was also undertaken using a *Salmo*Fan ™ (Hoffmann, La-Roche, Basel, Switzerland).

2.5 Amino acid profiles

Whole fish fillets (n = 3 per treatment) were freeze dried and shipped to USDA/ARS/PWA Hagerman Fish Culture Experiment Station, Idaho, USA, for amino acid determinations. Both essential and non-essential amino acids were quantified by high-performance liquid chromatography (HP 1100; Agilent Technologies, Wilmington, DE, USA), following acid hydrolysis using pre-column *o*-phtaldehyde derivatization (Gaylord et al., 2004).

2.6 Minerals

Whole fish fillets (n = 3 per treatment) were digested by wet ashing for flame emission (AOAC, 1990). Approximately 4 g of each sample were dried for 2.5 h at 110 ºC, digested in concentrated nitric acid and further diluted with hot water to 100 mL. Digestions of each sample

and 1 L of the matrix solution were analyzed by the Soil Testing Laboratory at Virginia Tech for mineral composition (Al, Fe, Cu, Mn, Zn, Cr, As, Se, Sn, Pb, Hg, S, Na, Mg, P, K, Ca,) using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP; Spectro Flame Modula Tabletop ICP with autosampler; Fitchburg, MA, USA). Samples were stored at 3 ºC prior to testing. Minerals were reported as ppm in solution.

2.7 Sensory analyses

A triangle test (Meilgaard et al., 1999) was used to determine an overall difference in flavor between wild and farmed coho salmon fillets. Fillets were minced separately and baked in aluminum foil at 177° C for 10 min. Approximately 28 g of fish were placed in 28 g cups with lids and served to panelists (n = 23). Test sensitivity parameters were set up to be: $\beta = 0.20$; $\alpha = 0.05$ and $P_d = 40$ % (proportion of distinguishers) (Meilgaard et al., 1999). Each panelist received 3 triangle test or 9 samples, identified by a three digit code that was randomly chosen and assigned to each sample. A balanced design was used to randomly present the samples to the panelists. A red light was used to avoid bias and panelists were seated in individual booths. Panelists were chosen from students, faculty and staff from the Food Science and Technology Department at Virginia Tech. Farmed and GMO coho salmon were compared to determine if there was an overall difference in smell and appearance. The same parameters described above were used for this test, with the only variation that samples were not to be tested.

A preference and acceptance test were also assessed between farmed and GMO coho salmon. A tray with a farmed fillet and a GMO fillet covered with transparent plastic film was displayed on a table, where each panelist observed the same samples (n = 50) and answered the ballots. The ballots included a demographic questionnaire (sex, age, salmon average consumption) and a preference question (“Which sample would you buy”).

2.8 Statistical analysis

All data were subjected to One-way Analysis of Variance (ANOVA) using Jump the Statistical Analysis System (SAS Institute, Cary, NC). Sensory analysis was analyzed according to number of correct responses based on Meilgaard et al. (1999).

3. Results

3.1 Fillet yields and proximate composition

Frame yields from experimental groups are summarized in Table 1. Yields varied between 59.25 and 70.93%, with wild and farmed fish returning significantly ($p \leq 0.05$) higher yields than modified animals. Results relating to fillet proximate composition of wild, cultured, and modified coho salmon are summarized in Fig. 1. A discrete proximal to distal arrangement in lipid distribution was observed along the body for all groups, with lowest lipid content being isolated in tail sections ($p \leq 0.05$; Fig. 1). No differences were recorded between farmed and GMO fish with respect to the concentration of tail lipid which was higher ($p \leq 0.05$) than that observed in wild fish. Maximal lipid presence was recorded in frontal and Scottish cuts, with wild salmon expressing lowest levels ($p \leq 0.05$). Like lipid levels, protein content also varied sectionally with a distal to proximal gradient. Higher protein content was generally associated with lower lipid content such that wild fish expressed increased ($p \leq 0.05$) protein content when compared to farmed and modified animals. In general, fillet moisture and ash contents did not differ between groups or with cut (Fig. 1).

3.2 Texture and color

Data comparing fillet firmness or hardness for different cuts in wild, cultured and modified coho salmon are presented in Fig. 2. Firmness was measured as force at break and maximum force per g of muscle ($N\ g^{-1}$) and provides an indication of the amount of force required to penetrate and break a pre-weighed raw piece of fillet. When compared with other cuts, those of the tail generally expressed greatest firmness, which was particularly evident in wild animals ($p \leq 0.05$). The force at break and maximum force g^{-1} in wild fish was higher ($p \leq 0.05$) in wild fish when compared to cultured and modified groups.

Cuts from wild and modified fish did not express variation ($p > 0.05$; Table 2) in L*, a* or b* values, an observation that was extended to include cultured fish for a* and b*. In farmed fish however, higher L* (lightness) values were obtained in ventral front and Scottish cuts ($p \leq 0.05$ Table 2). A comparison of color using *Salmo*Fan™ ratings revealed no differences along the body for wild or GMO fish although in farmed animals some distinctions were observed in color specifically for the dorsal Scottish cut ($p \leq 0.05$; Table 5). All proximal cuts in wild and

modified salmon expressed higher a* values (red) than the corresponding farmed cuts ($p \leq 0.05$; Table 2). A comparison of b* (yellow) between groups revealed higher distal cut values in wild coho when compared to those obtained for cultured salmon ($p \leq 0.05$; Table 2). L* values (lightness) were higher, particularly in the tail region of modified fish (Table 2; $p \leq 0.05$). *Salmo*Fan™ scores illustrated that wild fish cuts were generally rated higher ($p \leq 0.05$) than farmed or modified salmon cuts.

3.3 Minerals and amino acids

The fillet mineral content of wild, farmed, and modified coho salmon are presented in Table 3. With the exception of copper, which was higher in wild salmon ($p \leq 0.05$), no differences were detected between groups. Results pertaining to measured fillet amino acid concentrations were similar between groups (Table 4) with the exceptions that tyrosine, methionine and leucine were higher ($p \leq 0.05$) in wild when compared to modified fish.

3.4 Sensorial Analyses

Differences ($p \leq 0.05$) were detected in appearance and smell between farmed and modified fillets, with panelists favoring (preference test) farmed samples when asked which they would purchase ($p \leq 0.05$). No difference was detected in overall flavor when wild and farmed coho salmon were tasted ($p > 0.05$).

4. Discussion

The size variation in the coho salmon employed during the present investigations reflects availability. Thus, due to their more rapid growth during a production period, genetically modified salmon were larger than corresponding market-sized cultured animals, whereas wild salmon were larger still. Nevertheless, each individual examined during the present investigations was within wholesale market size limits (Anon, 1997). An examination of frame yields revealed that for all animals, these fell within commercially acceptable levels (Rørå et al., 1998). Noticeable however, was that genetically modified fish returned significantly lower yields per frame than either cultured or wild fish. This apparent anomaly may be partially explained by the differences encountered in bone structure and body conformity of transgenic fish (Ostenfeld et al., 1998; McLean and Devlin, 2000). Nevertheless, the compositional characteristics of coho salmon from this study conform to the general ranges established by others for wild and cultivated fish (Karrick and Thurston, 1964; Chan et al., 2002). Salmonids are known to express significant biological variation in whole body and fillet lipid levels (Refsgaard et al., 1998) and this variation was evident in the present study. Likewise, the recognized leanness of wild fish, when compared to cultured animals (Higgs et al., 1989; Cronin et al., 1991), was also apparent. Reasons for differences in especially lipid concentration between wild and farmed salmon are no doubt extensive but are typically considered to result due to variation in genetic disposition, degree of sexual maturation, dietary lipid level, exercise, animal size and the availability of food (Haard, 1992; Jobling and Johansen, 2003). The present study demonstrated an anterior-posterior decline in fillet fat irrespective of whether animals were wild, cultured or modified. These findings are in general agreement with other research upon feral and cultured salmonids (Karrick and Thurston, 1964; Bell et al., 1998; Katikou et al, 2001), and here are extended to include transgenic coho salmon. In salmonids the belly flap represents a major area of lipid deposition (Polvi and Ackman, 1992) and this trait was in evidence with dorsal cuts being lower in lipid than ventral cuts (Fig. 1). These variations highlight the need for increased care and awareness during sampling for compositional, sensorial and like studies with salmonids and potentially other fish.

The impact of GH transgenesis upon fish fillet compositional traits has been examined only infrequently. Data that is available suggests species-specific responses which may vary from no impact through to reductions in body lipid, moisture and ash and increases in muscle protein

(Chatakondi et al., 1995; Fu et al., 1998; Cook et al., 2000; Dunham et al., 2002). Clearly strain, construct employed, ploidy status, and dietary regime will all potentially impact compositional characteristics of the final product (Fu et al., 2000; Devlin et al., 2004). In the present study, transgenic coho salmon were fed on a higher energy diet than farmed salmon (30% versus 18% lipid, 43 versus 45% protein). Normally, high energy diets increase lipid deposition in salmonids (Jobling, 2001) and coho are no exception to this general rule (Chan et al., 2002). Nevertheless, feeding of high energy diets to GH transgenic triploid coho resulted either in no differences or reductions in cut lipid presence when compared against unmodified farmed fish. A number of explanations have been advanced to account for this effect which is undoubtedly GH/IGF-mediated. These include shifts in metabolic activity and energy demand, increased lipolysis and or reduced lipogenesis, enhanced rates of protein synthesis and amongst others, alterations in protein accretion (McLean and Devlin, 2000).

Evaluation of fillet amino acid profiles revealed only minor differences between wild, cultured, and modified fish. Specifically, of the amino acids examined, wild salmon expressed elevated levels of methionine, leucine and tyrosine. Fu et al. (2000) also concluded that transgenesis had limited effect upon whole body amino profiles of hGH transgenic common carp, whereas Chatakondi et al. (1995) reported wider ranging alterations to amino acid profiles of rtGH transgenic common carp; always favoring the transgenic animals.

Irrespective of status, the fillet mineral content of all fish examined herein was similar and in the reported range for other salmonids (Gordon and Roberts, 1977). Noteworthy however, was the tendency towards increased muscle calcium, potassium, and phosphorus content in transgenic coho, and particularly, fillet copper levels, which were approximately three times greater in wild fish. This enhanced level of copper likely reflects environment-nutrition influences (Kamunde et al., 2002). The importance of copper to physiological processes is well-established (Klevay, 2000) and although clearly nutritionally adequate to support growth in cultured and modified animals, the elevated levels in wild fish might provide one explanation for the increased muscle firmness observed. Copper-based enzymes, including lysyl oxidase, are intimately involved in cross-linking of collagen and elastin and, when combined with a reduction in fillet lipid, as observed in the tail cuts, may lead to increased firmness.

Fillet firmness or hardness represents an important quality variable in fish, and may influence consumer purchasing decisions (Kestin and Warriss, 2001). Texture properties of fish muscle

may be affected by a wide range of factors including, but not limited by: growth rate, muscle type, muscle cellularity, nutrition and nutritional history, exercise, slaughter, post-harvest handling and storage (Haard, 1992; Fauconneau et al., 1997; Johnston, 1999), as well as rearing site and conditions. For all animals examined, tail cuts expressed the highest firmness values, and as suggested by Sjervold et al. (2001) this likely reflected high muscular activity and connective tissue presence in this area. Similar findings with regard to firmness gradients in salmon have been presented by Sigurgisladottir et al. (1999). Modified coho salmon generally exhibited similar force values in the dorsal region to those of wild fish. Salmon growth occurs through fiber recruitment (hyperplasia), which may be influenced by strain, diet, exercise and temperature (Johnston, 1999). Fish that show higher fiber recruitment, have higher fiber density and smaller diameter fibers. Hill et al. (2000) observed that GH-transgenic coho salmon exhibited higher percentages of small white fibers, especially in the dorsolateral area suggesting hyperplastic rather than hypertrophic growth in transgenic fish. The presumed influence of transgenesis upon muscle cellularity would be expected to influence, as noted herein, the texture of specific fillet cuts. Muscle cellularity also affects fillet color visualization, with higher muscle fiber density lowering light scattering ability and permitting deeper light penetration (Johnston et al., 2000).

The orange-reddish flesh of salmon represents a major quality characteristic and originates from carotenoids present in the diets of wild fish, whereas in farmed animals, pigments are added to finishing diets to ensure acceptable flesh coloration (Rønsholdt and McLean, 2000). Modified and farmed fish were both fed diets supplemented with pigment (~ 60 ppm as astaxanthin-canthaxanthin). Interestingly, wild and modified coho salmon each expressed similar a* and b* results. When examined in line with firmness data, results with modified salmon suggest that fiber density (muscle hyperplasia), rather than diet, may have influenced color visualization. The high L* values in modified coho salmon cuts potentially impacted color visualization and lower color ratings obtained when using the *Salmo*Fan™. Comments from sensorial judges indicated that fillets from modified coho were redder than those derived from farmed fish but both were not as bright as wild salmon. The apparent lack of effect of genetic modification upon fillet pigmentation was unexpected since treatments with exogenous GH have been reported to decrease coloration in trout (Rønsholdt and McLean, 2004). The authors speculated that reduced pigmentation resulted due to the more efficient use of feed and accompanying dilution effect,

since less pigment per unit mass would be absorbed. It is noteworthy that fillet tyrosine content was greatest in wild coho>modified>farmed coho. Similar results have been presented with respect to wild and cultivated yellow perch, (González et al., 2003) and the authors suggested that the involvement of this amino acid in enzymatic reactions related with pigmentation might have influenced perch coloration. The involvement in tyrosine in salmonid pigmentation warrants further study. If a discrete relationship exists between this amino acid and pigmentation then it might prove possible to manipulate dietary tyrosine levels within finishing diets to enhance coloration. Noteworthy was that comparisons between wild and cultured coho salmon revealed no differences in flavor. These results are comparable to those that compared wild and cultured Atlantic salmon (Farmer et al., 2000) but differ to those presented by Sylvia et al. (1995) with their evaluations of wild and cultured Chinook salmon.

Overall, the present investigations indicate little in the way of compositional differences between cultured and modified coho salmon. The latter retain identical fillet amino acid, and macro-, and micro-mineral profiles to wild and cultured fish but are closer to wild coho in terms of flesh firmness characteristics. Differences occurred with respect to coloration as assessed by color cards and spectrophotometric analyses. Of interest was the apparent lack of discrete color gradient in modified fish when compared to wild and farmed counterparts. Future studies would benefit with the incorporation of sensorial testing of modified animals into a three-way evaluation.

References

Anonymous, 1997. Aquaculture wholesale market report. Week ending Feb 7th 1997. Maryland Department of Agriculture, Annapolis, MD, USA.

AOAC (Association of Official Analytical Chemists).1990. *Official Methods of Analysis*, 15th edn. Association of Official Analytical Chemists, Washington, D.C, USA.

Bell, J.G., McEvoy, J., Webster, J.L., McGhee, F., Millar, R.M., Sargent, J.R., 1998. Flesh lipid and carotenoid composition of Scottish farmed Atlantic Salmon (*Salmo salar*). Journal of Agriculture and Food Chemistry 46, 119-127.

Chan, J.C.K., Mann, J., Skura, B.J., Rowshandeli, M., Rowshandeli, N., Higgs, D.A., 2002. Effects of feeding diets containing various dietary protein and lipid ratios on the growth performance and pigmentation of post-juvenile coho salmon *Oncorhynchus kisutch* reared in sea water. Aquaculture research 33, 1137-1156.

Chatakondi, N., Lovell, R.T., Duncan, P.L., Hayat, M., Chen, T.T., Powers, D.A., Weete, J.D., Cummins, K., Dunham, R.A., 1995. Body composition of transgenic common carp, *Cyprinus carpio*, containing rainbow trout growth hormone gene. Aquaculture 138, 99-109.

Cook, J.T., NcNiven, M.A., Richardson, G.F., Sutterlin, A.M., 2000. Growth rate, body composition and feed digestibility/conversion of growth-enhanced transgenic Atlantic salmon (*Salmo salar*). Aquaculture 188, 15-32.

Cronin, D.A., Powell, R., Gormley, R., 1991. An examination of the n-3 and n-6 polyunsaturated fatty acid status of wild and farmed atlantic salmon (Salmo salar). Irish Journal of Food Science and Technology 15, 53-62

Devlin, R.H., Yesaki, T.Y., Donaldson, E.M., Du, S.-J., and Hew, C.L. 1995a. Production of germline transgenic Pacific salmonids with dramatically increased growth performance. Canadian Journal of Fisheries and Aquatic Sciences 52, 1376-1384.

Devlin, R.H., Biagi, C.A., Yesaki, T.Y., 2004. Growth, viability and genetic characteristics of GH transgenic coho salmon strains. Aquaculture 236, 607- 632.

Donaldson, E.M., Devlin, R.H., 1996. Uses of biotechnology to enhance production. In: Pennell. W., Barton, B.A. (Eds.), Principles of Salmonid Culture. Elsevier, Amsterdam, The Netherlands, pp. 969-1005.

Dunham, R.A., Devlin, R.H., 1999. Comparison of traditional breeding and transgenesis in farmed fish with implications for growth enhancement and fitness. In: Murray, J.D., Anderson, G.B., Oberbauer, A.M., McGloughlin, M.M. (Eds.), Transgenic Animals in Agriculture. CAB International, Wallingford, UK, pp. 209-230.

Dunham, R.A., Chatakondi, N., Nichols, A.J., Kucuktas, H., Chen, T.T., Powes, D.A., Weete, J.D., Cummins, K., Lovell, R.T., 2002. Effect of rainbow trout growth hormone complementary DNA on body shape, carcass yield, and carcass composition of F_1 and F_2 transgenic common carp (*Cyprinus carpio*). Marine Biotechnology 4, 604-611.

Einen, O., Skrede, G., 1998. Quality characteristics in raw and smoked fillets of Atlantic salmon, *Salmo salar*, fed high-energy diets. Aquaculture Nutrition 4, 99–108.

Farmer, L.J., McConnell, J.M., Kilpatrick, D.J., 2000. Sensory characteristics of farmed and wild Atlantic salmon. Aquaculture 187, 105-125.

Fauconneau, B., Andre, S., Chmaitilly, J., Le Bail, P.-Y., Krieg, F., Kaushik, S.J., 1997. Control of skeletal muscle fibres and adipose cells size in the flesh of rainbow trout. Journal of Fish Biology 50, 296-314.

Fletcher, G.L., Goddard, S.V., Shears, M., Sutterlin, A., Hew, C.L., 2001. Transgenic salmon: potential and hurdles. Science Update 57-65.

Folch, J., Lees, M., Stanley, G.H.S., 1957. A simple method for the isolation and purification of total lipids from animal tissues. Journal of Biological Chemistry 226, 496-509.

Fu, C., Cui, Y., Hung, S.S.O., Zhu, Z., 1998. Growth and feed utilization by F4 human growth hormone transgenic carp fed diets with different protein levels. Journal of Fish Biology 53, 115-129.

Fu, C., Cui, Y., Hung, S.S.O., Zhu, Z., 2000. Whole-body amino acid pattern of F_4 human growth hormone gene-transgenic red common carp (*Cyprinus carpio*) fed diets with different protein levels. Aquaculture 189, 287-292.

Gaylord, T.G., Rawles, S.D., Gatlin III, D.M., 2004. Amino acid availability from animal, blended, and plant feedstuffs for hybrid striped bass *(Morone chrysops × M. saxatilis)*. Aquaculture Nutrition 10, 345-352.

González, S., Flick, G. J., McLean, E., Douglas, L., Smith, S., Craig, S. R., 2003. "Composition and shelf-life of yellow perch (*Perca flavescens*)". Aquaculture America 2003. February 18-21, 2003, Louisville, Kentucky.

Gordon, D.T., Roberts, G.L., 1977. Mineral and proximate composition of Pacific coast fish. Journal of Agriculture and Food Chemistry 25, 1262-1267.

Guillén, I., Berlanga, J., Valenzuela, C.M., Morales, A., Toledo, J., Estrada, M.P., Puentes, P., Hayes, O., de la Fuente, J., 1999. Safety evaluation of transgenic tilapia with accelerated growth. Marine Biotechnology 1, 2-14.

Haard, N.F., 1992. Control of chemical composition and food quality attributes of cultured fish. Food Research International 25, 289-307.

Hew, C.L., Fletcher, G.L., 2001. The role of aquatic biotechnology in aquaculture. Aquaculture. 197, 191-204.

Higgs, D.A., Skura, B.J., Dosanjh, B.S., Yan, D., Powrie, W.D., Donaldson, E.M., 1989. Comparing farmed and wild coho salmon. Canadian Aquaculture 5, 51-53.

Hill, J.A., Kiessling, A., Devlin, R.H., 2000. Coho salmon (*Oncorhynchus kisutch*) transgenic for a growth hormone gene construct exhibit increased rates of muscle hyperplasia and detectable levels of differential gene expression. Canadian Journal of Fisheries and Aquatic Sciences 57, 939-950.

Jobling, M., 2001. Nutrient partitioning and the influence of feed composition on body composition. In: Houlihan, D., Boujard, T., Jobling, M. (Eds.), Food Intake in Fish. Blackwell Scientific, Oxford, UK, pp. 354-375.

Jobling, M., Johansen, J.S., 2003. Fat distribution in Atlantic salmon *Salmo salar* L. in relation to body size and feeding regime. Aquaculture research 34: 311-316.

Jonhston, I.A. 1999. Muscle development and growth: potential implications for flesh quality in fish. Aquaculture 177, 99-115.

Johnston, I.A., Alderson, R., Sandham, C., Dingwall, A., Mitchell, D., Selkirk,C., Nickell, D., Baker, R., Robertson, B., Whyte, D., Springate, J., 2000. Muscle fiber density in relation to the colour and texture of smoked Atalntic salmon (*Salmo salar* L.). Aquaculture 189, 335-349.

Kamunde, C., Grosell, M., Higgs, D., Wood, C.M., 2002. Copper metabolism in actively growing rainbow trout (*Oncorhynchus mykiss*): interactions between dietary and waterborne copper uptake. The Journal of Experimental Biology 205, 279-290.

Karrick, N.L., Thurston, C.E., 1964. Proximate composition of silver salmon. Agricultural and Food Chemistry 12: 282-284.

Katikou, P., Hughes, S.I., Robb, D.H.F., 2001. Lipid distribution within Atlantic salmon (*Salmo salar*) fillets. Aquaculture 202, 89-99.

Kestin, S.C., Warriss, P.D. (Eds.). 2001. Farmed Fish Quality. Blackwell Science, Oxford, UK.

Klevay, L.M., 2000. Cardiovascular disease from copper deficiency – A history. Journal of Nutrition 130, 489S-492S.

Maclean, N., Laight, R.J., 2000. Transgenic fish: an evaluation of benefits and risks. Fish and Fisheries 1, 146-172.

Mayer, I., McLean, E., 1995. Biotechnological and bioengineering strategies for reduced waste aquaculture. Water Science and Technology 31, 85–102.

McLean, E., Devlin, R.H. 2000. Application of biotechnology to enhance growth of salmonids and other fish. In: Fingerman, M., Nagabhushanam, R., Thompson, M.F. (Eds), Recent Advances in Marine Biotechnology. Science Publishers, Inc., Einfeld, NH, USA, pp. 17-55.

McLean, E., Craig, S.R., 2003. Overcoming barriers to the oral delivery of peptide and protein therapeutics to aquacultured organisms. In: Lyons, T.P., Jaques, K.A. (Eds.), Nutritional Biotechnology in the Feed and Food Industries. University of Nottingham Press, UK. pp. 551-565.

McLean, E., Donaldson, E.M., 1993. The role of growth hormone in the growth of poikilotherms. In: Schriebman, M.P., Scanes, C.G., Pang, P.K.T. (Eds.), The Endocrinology of Growth, Development and Metabolism in Vertebrates. Academic Press, New York, USA, pp. 43-71.

Meilgaard, M., Civille, G.V., Carr, B.T. 1999. Overall difference tests. In: Sensory Evaluation Techniques. CRC Press, New York, USA, pp. 60-73.

Muir, W.M., Howard, R.D., 2002. Assessment of possible ecological risks and hazards of transgenic fish with implications for other sexually reproducing organisms. Transgenic Ressearch 11, 101-114.

Ostenfeld, T.H., McLean, E., Devlin, R.H., 1998. Transgenesis changes in body and head shape in Pacific salmon. Journal of Fish Biology 52, 850-854.

Palmiter, R.D., Brinster, R.L., Hammer, R.E., Trumbauer, M.E., Rosenfeld, M.G., Birnberg, N.C., Evans, R.M., 1982. Dramatic growth of mice that develop from eggs microinjected with metallothionein-growth hormone fusion genes. Nature 300, 611-615.

Polvi, S.M., Ackman, R.G., 1992. Atlantic salmon (*Salmo salar*) muscle lipids and their response to alternative dietary fatty acid sources. Journal of Agricultural and Food Chemistry 40, 1001-1007.

Rasmussen, R.S., Røhnoldt, B., Ostenfeld, T.H., McLean, E., and Byatt, J.C., 2001. Growth, feed utilization, carcass composition and sensory characteristics of rainbow trout treated with recombinant bovine placental lactogen and growth hormone. Aquaculture 195, 367-384.

Refsgaard, H.H.F., Brockhoff, P.B., Jensen, B., 1998. Biological variation of lipid constituents and distribution of tocopherols and astaxanthin in farmed Atlantic Salon (*Salmo salar*). Journal of Agriculture and Food Chemistry 46, 808-812.

Rønsholdt, B., McLean, E., 2000. Determination of total carotenoid content in rainbow trout muscle by multivariate calibration of VIS reflectance spectra. Journal of Food Composition and Analysis 14, 345-357.

Rønsholdt, B., McLean, E., 2004. Effect of growth hormone and salbutamol on growth performance, fillet proximate composition and pigmentation of rainbow trout (*Oncorhynchus mykiss*). Aquaculture 229, 225–238.

Rørå, A.M.B., Kvåle, A., Mørkore, T., Rørvik, K-A., Hallbjoørn Steien, Thomassen, M.S., 1999. Process yield, colour and sensory quality of smoked Atlantic salmon (*Salmo salar*) in relation to raw material characteristics. Food Research International 31, 601-609

Sigurgisladottir, S., Hafsteinsson, H., Jonsson, A., Lie, Ø, Nortvedt, R., Thomassen, M., Torrissen, O., 1999. Textural properties of raw salmon fillets as related to sampling method. Journal of Food Science 64, 99-104.

Skjervold, P.O., Fjæra, S.O., Østby, P.B., Isaksson, T., Einen, O., Taylor, R., 2000. Properties of salmon flesh from different locations on pre- and post-rigor fillets. Aquaculture 201, 91-106.

Sylvia, G., Morrissey, M.T., Graham, T., Garcia, S., 1995. Organoleptic qualities of farmed and wild salmon. Journal of Aquatic Food product Technology 4, 51-64.

TABLES

Table 1. Weight (head-on, gilled and gutted animals) and frame yields (%) of wild, farmed, and genetically modified coho salmon (n = 5)

	Whole weight (g)	Yield%
Wild	4024 ± 768.52[a]	70.93 ± 1.87[a]
Farmed	756 ± 45.05[b]	72.79 ± 1.56[b]
Modified	1120 ± 346.77[b]	59.25 ± 5.43[b]

Table 2. Color (L*, b*, a* values) of each section measured as break force and maximum force in wild, farmed and modified coho salmon fillets divided in six body zones: 1= Front dorsal; 2= front ventral; 3= Scottish dorsal; 4= Scottish ventral; 5= tail dorsal; 6= tail ventral (n = 5). Data are presented as means ± SD.

	L*	a*	b*	SalmoFan™
		Wild		
1	$50.12 \pm 4.01_{X}$	$21.20 \pm 1.71_{X}$	$23.06 \pm 1.43_{X}$	$27 \pm 3.54_{X}$
2	54.14 ± 4.05	$21.64 \pm 3.24_{X}$	25.95 ± 2.56	$25 \pm 3.49_{X}$
3	$47.91 \pm 4.70_{X}$	$19.82 \pm 3.61_{X}$	$21.65 \pm 3.44_{X}$	$28 \pm 3.51_{X}$
4	53.87 ± 1.48	$21.26 \pm 2.96_{X}$	$24.79 \pm 1.96_{X}$	$26 \pm 2.12_{X}$
5	$49.18 \pm 3.93_{X}$	$22.37 \pm 2.39_{X}$	$24.72 \pm 2.11_{X}$	$29 \pm 3.08_{X}$
6	$49.93 \pm 3.26_{X}$	$22.53 \pm 3.26_{X}$	$24.87 \pm 2.59_{X}$	$27 \pm 2.70_{X}$
		Farmed		
1	$54.45 \pm 1.40^{ab}{}_{XY}$	$14.19 \pm 2.94_{Y}$	$20.24 \pm 3.82_{X}$	$23 \pm 1.52^{ab}{}_{Y}$
2	57.76 ± 4.42^{a}	$12.92 \pm 2.37_{Y}$	20.68 ± 4.25	$21 \pm 0.84^{a}{}_{Y}$
3	$48.89 \pm 2.69^{b}{}_{X}$	$12.46 \pm 1.27_{Y}$	$16.71 \pm 2.22_{Y}$	$24 \pm 1.30^{b}{}_{XY}$
4	56.85 ± 4.17^{a}	$10.80 \pm 2.37_{Y}$	$18.82 \pm 3.97_{Y}$	$21 \pm 0.84^{a}{}_{Y}$
5	$49.43 \pm 2.0^{b}{}_{X}$	$12.00 \pm 2.34_{Y}$	$16.47 \pm 2.89_{Y}$	$23 \pm 2.07^{ab}{}_{Y}$
6	$50.55 \pm 1.49^{b}{}_{X}$	$12.83 \pm 4.30_{Y}$	$17.49 \pm 4.87_{Y}$	$23 \pm 1.52^{ab}{}_{Y}$
		Modified		
1	$57.23 \pm 2.77_{Y}$	$19.07 \pm 2.51_{X}$	$24.49 \pm 1.22_{Y}$	$23 \pm 1.67_{Y}$
2	57.87 ± 1.96	$18.25 \pm 2.83_{X}$	24.75 ± 3.09	$22 \pm 1.14_{XY}$
3	$56.18 \pm 2.56_{Y}$	$18.98 \pm 3.05_{X}$	$23.64 \pm 1.79_{X}$	$23 \pm 1.95_{Y}$
4	55.39 ± 1.89	$17.83 \pm 3.18_{X}$	$22.45 \pm 2.65_{XY}$	$23 \pm 1.30_{Y}$
5	$56.29 \pm 2.62_{Y}$	$17.70 \pm 2.21_{Y}$	$23.02 \pm 1.85_{X}$	$22 \pm 1.30_{Y}$
6	$55.55 \pm 3.06_{Y}$	$18.72 \pm 2.93_{XY}$	$23.23 \pm 2.57_{XY}$	$23 \pm 1.10_{Y}$

^{abc} superscripts denote differences ($p \leq 0.05$) between body cuts by group.

$_{XYZ}$ superscript denotes differences in each body cut compared across fish groups.

* L = lightness extends from 0 (black) to 100 (white); a* = redness- greenness: extends from – a* (green) to + a* (red); b* = yellow-blue: extends from – b* (blue) to + b* (yellow)

Table 3. Muscle micro- (μg/100g edible muscle) and macromineral (mg/100g edible muscle) content of wild, farmed and modified coho salmon (n = 5). Data are presented as means ± SD Superscripts signify differences ($p < 0.05$) between groups. Bdl = below detection limits (actual detection limit)

	Wild	**Farmed**	**Modified**
		Micro minerals	
Lead (Pb)	109.00 ± 17.40	89.06 ± 5.23	114.90 ± 32.10
Selenium (Se)	Bdl (0.03 ppm)	Bdl	Bdl
Mercury (Hg)	Bdl (0.004 ppm)	Bdl	Bdl
Arsenic (As)	86.49 ± 19.28	70.41 ± 22.87	Bdl
Cupper (Cu)	15.22 ± 0.41^{a}	4.26 ± 2.46^{b}	5.98 ± 3.16^{b}
Manganese (Mn)	8.25 ± 2.00	12.06 ± 7.61	10.65 ± 5.59
Aluminum (Al)	Bdl* (0.06 ppm)	Bdl	Bdl
Chromium (Cr)	0.12 ± 0.02	0.15 ± 0.07	0.12 ± 0.03
Iron (Fe)	0.64 ± 0.11	7.42 ± 0.71	7.33 ± 0.67
Zinc (Zn)	0.51 ± 0.06	0.61 ± 0.08	0.77 ± 0.28
		Macro minerals	
Calcium (Ca)	9.49± 1.28	13.76 ± 5.24	14.08 ± 6.80
Potassium (K)	376.3 ± 52.45	391.6 ± 27.47	446.7 ±13.04
Magnesium (Mg)	28.16 ± 1.47	28.72 ± 1.46	29.83 ± 1.67
Sodium (Na)	47.89 ± 2.25	38.83 ± 3.17	46.10±14.70
Phosphorus (P)	231.5 ± 23.34	238.3 ± 11.92	259.8 ± 12.39
Sulfur (S)	222.8 ±7.75	209.00 ± 12.97	215.8 ± 7.53

Table 4. Essential and non-essential amino acid profiles (g/100g freeze dried muscle) of wild, farmed, and modified coho salmon. Data are presented as Means ± SD (n = 5) with different superscripts in the same row signifying significant difference ($p \leq 0.05$) between groups.

	Wild	**Farmed**	**Modified**
		Essential	
Lysine	8.67 ± 0.36	8.04 ± 0.17	7.27 ± 0.96
Methionine	2.68 ± 0.08[a]	2.24 ± 0.14[b]	1.94 ± 0.18[b]
Threonine	4.71 ± 0.11	4.31 ± 0.21	3.99 ± 0.94
Leucine	7.49 ± 0.14[a]	6.80 ± 0.32[ab]	6.33 ± 0.66[b]
Isoleucine	4.26 ± 0.05	3.80 ± 0.24	3.64 ± 0.39
Phenylalanine	3.74 ± 0.04	3.76 ± 0.11	3.90 ± 0.09
Valine	5.07 ± 0.09	4.69 ± 0.21	4.68 ± 0.49
		Non-essential	
Aspartic Acid	7.44 ± 0.12	7.30 ± 0.14	7.23 ± 0.44
Serine	3.82 ± 0.12	3.40 ± 0.16	3.32 ± 0.38
Glycine	4.57 ± 0.21	4.26 ± 0.38	4.00 ± 0.34
Alanine	2.75 ± 0.10	2.46 ± 0.13	2.40 ± 0.24
Tyrosine	3.20 ± 0.09 [a]	2.77 ± 0.13[ab]	2.60 ± 0.28[b]
Glutamate	11.14 ± 0.18	10.83 ± 0.13	10.62 ± 0.63

FIGURES

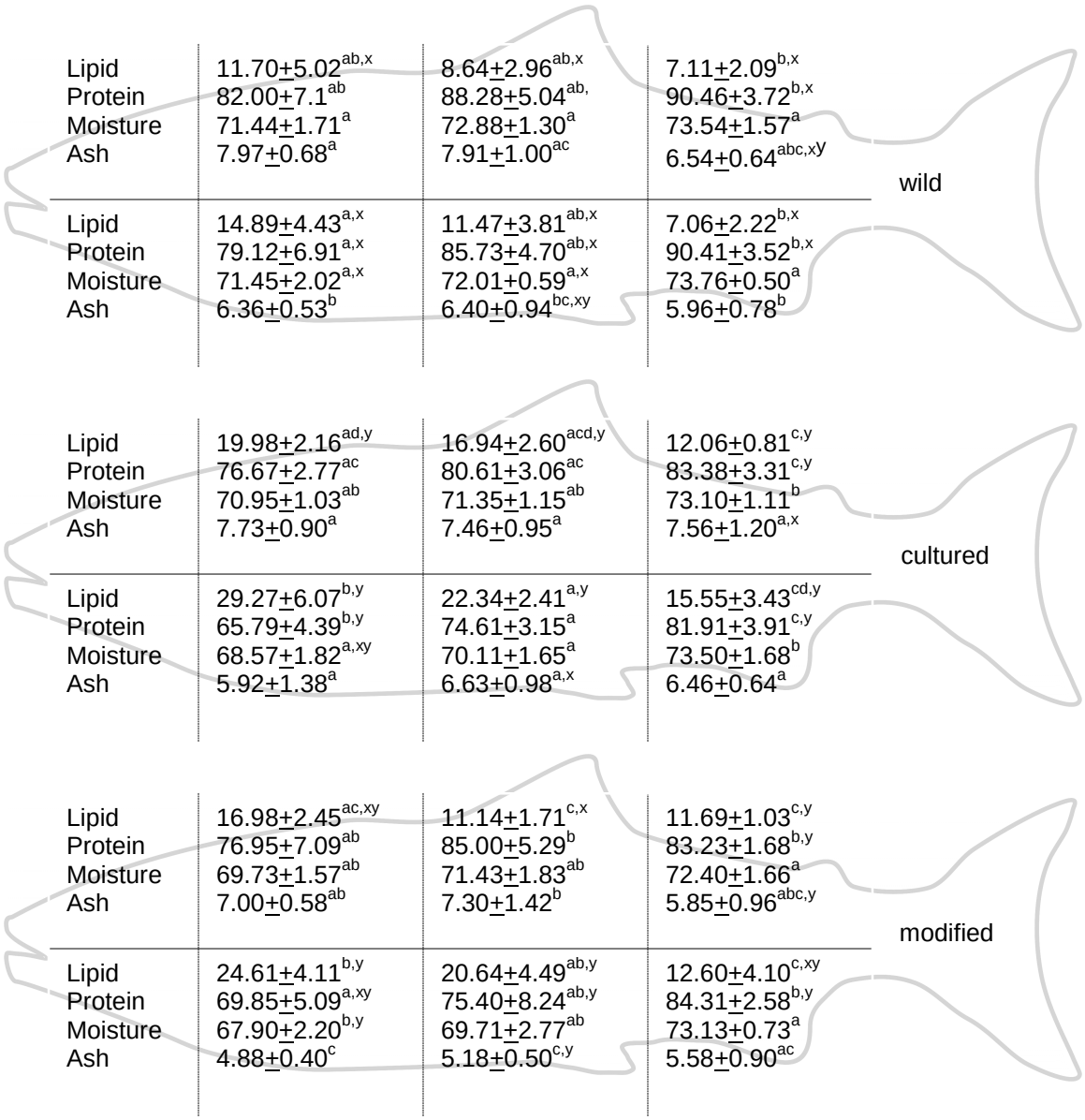

Figure 1. Proximate composition of market-sized wild (upper), farmed (middle) and genetically modified (lower) coho salmon fillets (n = 5). Fillets were divided into front, Scottish and tail cuts, each of which was further divided into dorsal and ventral halves. All data are presented as means±SD. ^{abc} superscripts indicate differences ($p \leq 0.05$) between cuts in the each fish group, whereas ^{xy} signifies differences across groups.

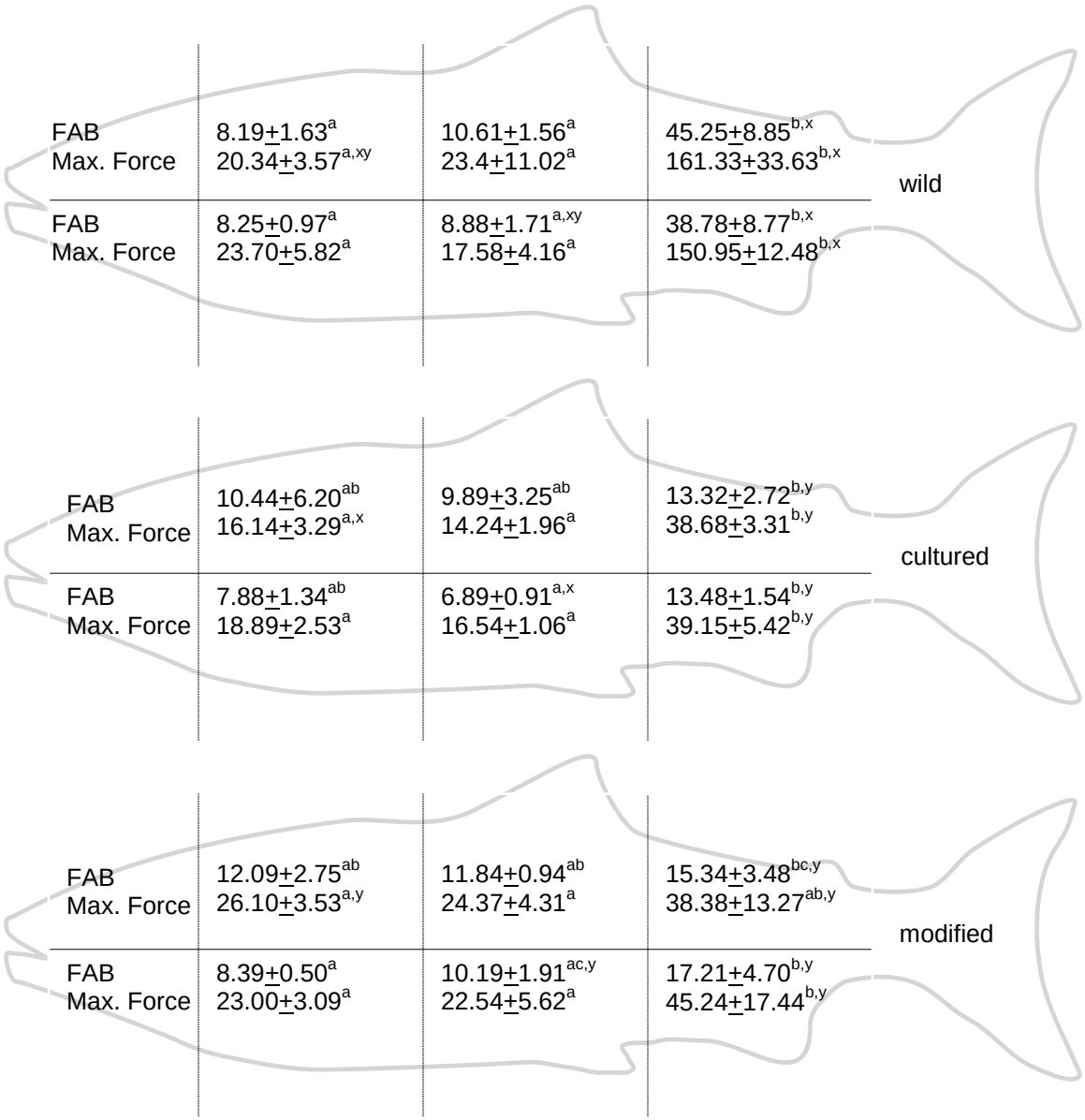

Figure 2. Firmness (hardness) of market-sized wild (upper), farmed (middle) and genetically modified (lower) coho salmon fillets (n = 5). Fillets were divided into front, Scottish and tail cuts, each of which was further divided into dorsal and ventral halves. Firmness was measured as break force/g and maximum force/g. All data are presented as means±SD. ^{abc} superscripts indicate differences ($p \leq 0.05$) between cuts in the each fish group, whereas ^{xy} signifies differences across groups.