

Fatty Acid Profile of Sunshine Bass: I. Profile Change is Affected by Initial Composition and Differs Among Tissues

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Abstract Fatty acid (FA) composition of fillet tissue can be tailored by transitioning fish from alternative lipid-based, low long-chain polyunsaturated fatty acid (LC-PUFA) grow-out feeds to high LC-PUFA “finishing” feeds. To address whether grow-out feed composition influences the responsiveness of fillet tissue to finishing, sunshine bass (SB, *Morone chrysops* × *M. saxatilis*) were reared to a submarketable size on grow-out feeds containing fish oil (FO) or a 50:50 blend of FO and coconut (CO), grapeseed (GO), linseed (LO), or poultry (PO) oil. For the final 8 weeks of the trial, fish were either maintained on assigned grow-out feeds or finished with the 100% FO feed. Production performance was unaffected by dietary lipid source, but fillet FA profile generally conformed to nutritional history. Regardless of grow-out regimen, finishing had a significant restorative effect on fillet FA composition; however, complete restoration of control levels of 20:5n-3, 22:6n-3, total LC-PUFA and n-3:n-6 FA ratio was achieved only among fish fed the CO-based grow-out feed. Saturated fatty acids (SFA) appear to be preferential catabolic substrates, whereas medium-chain and long-chain PUFA are selectively deposited in tissues. Provision of SFA in grow-out feeds appears to optimize selective FA metabolism and restoration of beneficial fillet FA profile during finishing.

Keywords Fish oil · Alternative lipid · Finishing feed · Fatty acid turnover/dilution · LC-PUFA · *Morone* spp.

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Abbreviations

ANOVA	Analysis of variance
CO	Coconut oil
DHA	Docosahexaenoic acid, 22:6n-3
EPA	Eicosapentaenoic acid, 20:5n-3
FA	Fatty acid
FCR	Feed conversion ratio
FO	Fish oil
GO	Grapeseed oil
HSI	Hepatosomatic index
IPF	Intraperitoneal fat
IPFR	Intraperitoneal fat ratio
LC-PUFA	Long-chain polyunsaturated fatty acid(s)
LO	Linseed oil
MC-PUFA	Medium-chain polyunsaturated fatty acid(s)
MUFA	Monounsaturated fatty acid(s)
PO	Poultry oil
PUFA	Polyunsaturated fatty acid(s)
SB	Sunshine bass
SFA	Saturated fatty acid(s)

Introduction

Seafood represents an increasingly important food source for the human population, particularly in developing regions—seafood comprises 20% of animal protein intake for more than half of the world population [1]. In addition, seafood is the predominant dietary source of long-chain polyunsaturated fatty acids (carbon atoms ≥ 20 , degree of unsaturation ≥ 3 , LC-PUFA), such as eicosapentaenoic (EPA, 20:5n-3) and docosahexaenoic acids (DHA, 22:6n-3), that are critical to human health [2]. These fatty acids (FA) impart benefits beyond basic nutritive value,

positively influencing neural, cardiac, vascular, immunological, reproductive, and oncogenetic health [3–8]. As a result, both nutritional and medical communities have recommended increasing human consumption of LC-PUFA to improve and maintain health of the American public [9].

With most traditional capture fisheries at sustainable harvest limits or in decline [10], seafood demand is increasingly met by aquaculture products. Currently, 45% of the fish consumed worldwide are cultured [1]. Assuming per capita seafood consumption is maintained, aquaculture production must double by 2030 to keep pace with human population growth over this time period [11]. Attendant to growth in the aquaculture sector is the further expansion of aquafeed manufacturing, an industry which relies on “reduction” fisheries for the production of fish meal and fish oil (FO) [12]. Recent peaks in the price of FO [13] reflect increasing competition for this resource among end-users and the inability of reduction fisheries to sustain further growth. In addition to economic and sustainability considerations, evidence linking FO in aquafeeds to elevated levels of environmental contaminants in cultured seafood [14–16] has motivated the aquaculture industry to identify alternatives to FO.

Fish oil replacement has been evaluated using a variety of plant- and animal-derived, alternative lipids in numerous aquaculture species, often with great success [17–20]. Although growth performance is typically unaffected by dietary lipid source, FA composition of fish tissues mirrors dietary content and is responsive to dietary change. Following a switch in dietary lipid source, fillet composition will change over time to more closely resemble the new dietary FA profile [21–24]. Thus, replacing FO with alternative lipid sources in aquafeeds results in the loss of nutritionally beneficial LC-PUFA within the resultant fillets and may, in turn, limit health benefits of cultured seafood to human consumers [25].

Based on the known plasticity of fillet composition, nutritionists have suggested the use of “finishing” feeds, high in LC-PUFA, to increase and/or restore high levels of these beneficial FA to the fillet prior to harvest. In this strategy, fish are raised on alternative lipid-based “grow-out” feeds for most of the production cycle and then transitioned to the finishing feed prior to harvest. Finishing feeds have been used to enhance fillet LC-PUFA content in a number of aquaculture species [26–34], however, the extent of LC-PUFA augmentation varies and complete restoration of FO-associated profile is infrequently reported [31, 34]. Fatty acid composition of the grow-out feed and pre-finishing fillet profile may contribute to differences in overall finishing success. Previous research suggested medium-chain polyunsaturated fatty acids (18 carbon, MC-PUFA) are resistant to “washout” or “dilution” during finishing [35], whereas saturated FA (SFA) are perhaps

more labile in fish tissues [33]. Most finishing strategies have employed MC-PUFA-rich plant oils during the grow-out phase, but high levels of MC-PUFA may render fillets comparatively unresponsive to finishing and LC-PUFA augmentation. To address this hypothesis, we evaluated alternative lipid sources with distinct FA profiles in sunshine bass (SB, *Morone chrysops* × *M. saxatilis*) grow-out feeds and subsequently assessed the responsiveness of fillet tissue to LC-PUFA augmentation during finishing.

Methods and Materials

Diet Preparation and Analyses

Five feeds were manufactured based on a practical, reduced fish meal feed our group previously developed for SB culture ([36], Table 1). As originally formulated, this feed contained 9.8% FO (dry matter basis; menhaden-derived; Virginia Gold™, Omega Protein, Inc., Houston, TX, USA). In the present work, the original, FO-based formulation served as the control grow-out feed as well as the finishing feed. Four experimental grow-out feeds were derived from the basal formulation, with 50% of the FO replaced with poultry (PO, Tyson Foods, Inc., Robards, KY, USA), linseed (LO, Barlean's Organic Oils, Ferndale, WA, USA), grapeseed (GO, Kusha, Inc, Irvine, CA, USA), or coconut oil (CO, Spectrum Organic Products, Petaluma, CA, USA). These alternative lipids are predominantly comprised of a single FA class (monounsaturates [MUFA], n-3 MC-PUFA, n-6 MC-PUFA, and SFA, respectively) and were strategically chosen to generate distinct feed FA profiles for the purposes of hypothesis testing (Table 2). All feedstuffs were incorporated using a cutter–mixer (Model CM450, Hobart Corporation, Troy, OH, USA), pelleted using a food grinder, dried at room temperature to ~870 g kg⁻¹ dry matter, and stored frozen (–20°C) throughout the duration of the study. Proximate analyses of triplicate diet samples were conducted according to standard methods for analysis of animal feeds [37, 38] to confirm diet composition (Table 1). Reserved crude lipid samples were analyzed for FA composition (Table 2) according to the procedures described by Lane et al. [33].

Experimental Design and Feeding Trial

Nine feeding regimens were developed to address influences of dietary lipid source and FA composition on production performance and subsequent finishing diet success in SB culture (Fig. 1). Eight experimental regimens represented feeding the grow-out feeds described above throughout the feeding trial (CO, LO, GO, and PO regimens) or with an 8-week finishing period (CO + Finish, LO + Finish, GO + Finish, and PO + Finish regimens). The control

Table 1 Formulation and proximate composition of experimental diets adapted from Lewis and Kohler [36]

Ingredient	Fish oil (FO)	Coconut oil (CO)	Grapeseed oil (GO)	Linseed oil (LO)	Poultry oil (PO)
Fish meal ^a	200	200	200	200	200
Fish oil ^a	98	49	49	49	49
Coconut oil ^b	–	49	–	–	–
Grapeseed oil ^c	–	–	49	–	–
Linseed oil ^d	–	–	–	49	–
Poultry oil ^e	–	–	–	–	49
Corn gluten meal ^f	140	140	140	140	140
Wheat middlings	201	201	201	201	201
Soybean meal	300	300	300	300	300
Carboxymethyl cellulose	20	20	20	20	20
Sodium phosphate monobasic	15	15	15	15	15
Calcium phosphate dibasic	15	15	15	15	15
Choline chloride	6	6	6	6	6
Mineral Premix ^g	1.5	1.5	1.5	1.5	1.5
Vitamin Premix ^h	1.5	1.5	1.5	1.5	1.5
Proximate composition					
Dry matter	88.0	87.8	88.3	84.7	85.7
Protein	41.1	41.5	41.0	40.5	39.4
Lipid	14.3	14.5	14.4	14.6	13.2
Ash	10.8	10.2	9.6	11.4	10.6

All proximate composition values are expressed as a mean in g/100g (%), dry matter basis. Formulation composition is expressed in g/kg

^a Derived from menhaden *Brevoortia* spp., Omega Protein, Inc., Houston, TX, USA

^b Spectrum Organic Products, Petaluma, CA, USA

^c Kusha, Inc., Irvine, CA, USA

^d Barlean's Organic Oils, Ferndale, WA, USA

^e Tyson Foods, Inc., Robards, KY, USA

^f Tate and Lyle, Decatur, IL, USA

^g Formulated to contain: 7,000 mg kg⁻¹ copper, 70,000 mg kg⁻¹ iron, 100,000 mg kg⁻¹ manganese, 200,000 mg kg⁻¹ zinc, 0.24% iodine

^h Formulated to contain: 99.8 mg kg⁻¹ selenium, 2,200 mg kg⁻¹ folic acid, 88,000 mg kg⁻¹ niacin, 35,200 mg kg⁻¹ pantothenic acid, 11,000 mg kg⁻¹ vitamin B6, 13,200 mg kg⁻¹ riboflavin, 11,000 mg kg⁻¹ thiamin, 11,000 mg kg⁻¹ vitamin B12, 66,000 mg kg⁻¹ vitamin E, 4,400 mg kg⁻¹ vitamin K, 4,400,000 IU kg⁻¹ vitamin A, 2,200,000 IU kg⁻¹ vitamin D, 100,000 mg kg⁻¹ vitamin C

regimen represented feeding the FO control/finishing feed throughout the duration of the feeding trial (FO Control regimen). Juvenile SB [46 ± 1 g, mean ± SE; age 1 (~ 10 months); Keo Fish Farm, Keo AR] were group-reared on the grow-out feeds described above, then stocked into a recirculation system consisting of 30, 270-l fiberglass tanks with associated mechanical and biological filtration units for the final 12 weeks of the production cycle. Each experimental regimen was randomly assigned to three replicate tanks ($n = 3$), whereas the control regimen was assigned to six replicate tanks ($n = 6$). For all regimens, each replicate tank was stocked with six fish from the appropriate dietary group. Eight weeks prior to harvest, a subsample of one fish per tank was collected to determine baseline tissue FA profile prior to finishing (tissues collected as described in “[Harvest, Sample Collection, and Production Performance](#)”). After baseline sampling, remaining fish were finished with the

100% FO feed for the remaining 8 weeks of the feeding trial (CO + Finish, LO + Finish, GO + Finish, and PO + Finish regimens) or maintained on assigned grow-out feeds (FO Control, CO, LO, GO, and PO regimens). Throughout the 7-month culture period, fish were fed assigned feeds once daily to apparent satiation.

Temperature (YSI Model 55 Oxygen Meter, Yellow Springs, OH, USA) was measured daily, whereas dissolved oxygen (YSI Model 55 Oxygen Meter, Yellow Springs, OH, USA), ammonia-, nitrite-, and nitrate–nitrogen as well as alkalinity were measured periodically throughout the study period (Hach DR/2010 spectrophotometer, Hach Company, Loveland, CO, USA). All water quality parameters were maintained within ranges suitable for SB culture [39]. All culture and husbandry methods, as well as euthanasia and sample collection procedures described below, were conducted under the direction and approval of the Southern

Table 2 Dietary composition with respect to FA and FA classes

Fatty acid(s)	Fish oil (FO)	Coconut oil (CO)	Grapeseed oil (GO)	Linseed oil (LO)	Poultry oil (PO)
8:0	0.00 ± 0.05	1.83 ± 0.05	0.00 ± 0.05	0.00 ± 0.05	0.00 ± 0.05
10:0	0.00 ± 0.02	2.02 ± 0.02	0.00 ± 0.02	0.00 ± 0.02	0.00 ± 0.02
12:0	0.11 ± 0.02	17.59 ± 0.02	0.02 ± 0.02	0.04 ± 0.02	0.06 ± 0.02
14:0	7.65 ± 0.02	11.29 ± 0.02	4.41 ± 0.02	4.42 ± 0.02	4.68 ± 0.02
16:0	18.71 ± 0.02	15.12 ± 0.02	14.47 ± 0.02	13.45 ± 0.02	20.87 ± 0.02
18:0	3.50 ± 0.01	3.28 ± 0.01	3.58 ± 0.01	3.71 ± 0.01	4.48 ± 0.01
Total SFA ^a	31.90 ± 0.06	52.38 ± 0.06	23.90 ± 0.06	22.97 ± 0.06	31.40 ± 0.06
16:1n-7	9.84 ± 0.02	5.65 ± 0.02	5.62 ± 0.02	5.61 ± 0.02	7.85 ± 0.02
18:1n-7	2.90 ± 0.00	1.75 ± 0.00	1.98 ± 0.00	1.92 ± 0.00	2.45 ± 0.00
18:1n-9	7.74 ± 0.02	8.12 ± 0.02	13.62 ± 0.02	11.16 ± 0.02	19.67 ± 0.02
Total MUFA ^b	21.68 ± 0.03	16.20 ± 0.03	21.98 ± 0.03	19.40 ± 0.03	30.76 ± 0.03
18:2n-6	8.42 ± 0.08	8.85 ± 0.08	32.40 ± 0.08	14.68 ± 0.08	15.58 ± 0.08
20:4n-6	0.92 ± 0.01	0.58 ± 0.01	0.58 ± 0.01	0.58 ± 0.01	0.71 ± 0.01
n-6	10.12 ± 0.08	10.21 ± 0.08	33.45 ± 0.08	16.02 ± 0.08	16.92 ± 0.08
18:3n-3	2.14 ± 0.01	2.04 ± 0.01	1.59 ± 0.01	22.56 ± 0.01	1.82 ± 0.01
18:4n-3	3.49 ± 0.01	1.86 ± 0.01	1.86 ± 0.01	1.87 ± 0.01	1.82 ± 0.01
20:4n-3	1.49 ± 0.01	0.81 ± 0.01	0.84 ± 0.01	0.81 ± 0.01	0.81 ± 0.01
20:5n-3	11.46 ± 0.02	6.60 ± 0.02	6.53 ± 0.02	6.53 ± 0.02	6.52 ± 0.02
22:5n-3	2.11 ± 0.02	1.22 ± 0.02	1.28 ± 0.02	1.22 ± 0.02	1.21 ± 0.02
22:6n-3	12.73 ± 0.03	6.96 ± 0.03	6.86 ± 0.03	6.89 ± 0.03	7.04 ± 0.03
n-3	33.64 ± 0.05	19.60 ± 0.05	19.08 ± 0.05	40.02 ± 0.05	19.34 ± 0.05
Total PUFA ^c	46.42 ± 0.07	31.42 ± 0.07	54.12 ± 0.07	57.63 ± 0.07	37.84 ± 0.07
Total LC-PUFA ^d	29.13 ± 0.05	16.40 ± 0.05	16.33 ± 0.05	16.30 ± 0.05	16.59 ± 0.05
Total MC-PUFA ^e	14.72 ± 0.08	13.16 ± 0.08	36.26 ± 0.08	39.53 ± 0.08	19.69 ± 0.08
n-3:n-6	3.32 ± 0.02	1.92 ± 0.02	0.57 ± 0.02	2.50 ± 0.02	1.14 ± 0.02

Values represent least-square means ± SE of triplicate samples

^a Saturated fatty acids—sum of all FA without double bonds

^b Monounsaturated fatty acids—sum of all FA with a single double bond

^c Polyunsaturated fatty acids—sum of all FA with ≥2 double bonds

^d Long-chain PUFA—sum of all FA with chain length ≥ 20 carbon atoms and double bonds ≥ 3

^e Medium-chain—sum of all PUFA with chain length of 18 carbon atoms; includes 18:3n-4 in addition to individually reported MC-PUFA

Illinois University Institutional Animal Care and Use Committee, protocol #07-008.

Harvest, Sample Collection, and Production Performance

After completion of the feeding trial, feed was withheld for 48 h prior to harvest. Fish within individual tanks were harvested and immediately anesthetized in an ice-water bath. Each anesthetized fish was individually weighed and euthanized by single cranial pithing prior to tissue sample collection. Boneless, skinless, J-cut (without belly flap) fillets were harvested by experienced filleters to calculate % dress-out [(weight of fillets/whole body weight) × 100]. Fillet subsamples were collected from a standardized dorso-anterior landmark (to isolate white muscle tissue),

packaged in sterile, polyethylene bags (Whirl-pak[®], Nasco, Fort Atkinson, WI, USA), and stored frozen (−80°C) prior to proximate and FA analyses. Additional fillet subsamples were packaged similarly and held refrigerated for analysis of oxidative stability. Livers and intraperitoneal fat (IPF) masses were dissected from the viscera to calculate hepatosomatic index [HSI; (liver weight/whole body weight) × 100] and intraperitoneal fat ratio [IPFR; (IPF weight/whole body weight) × 100] indices. Subsamples of hepatic and IPF tissue were packaged and stored in the same manner as fillet tissue for FA analysis. Survival, percent weight gain [(average individual weight_{final} − average individual weight_{initial})/average individual weight_{initial} × 100], and food conversion ratio (FCR; average individual dry matter consumption/average individual gain) were calculated for each tank.

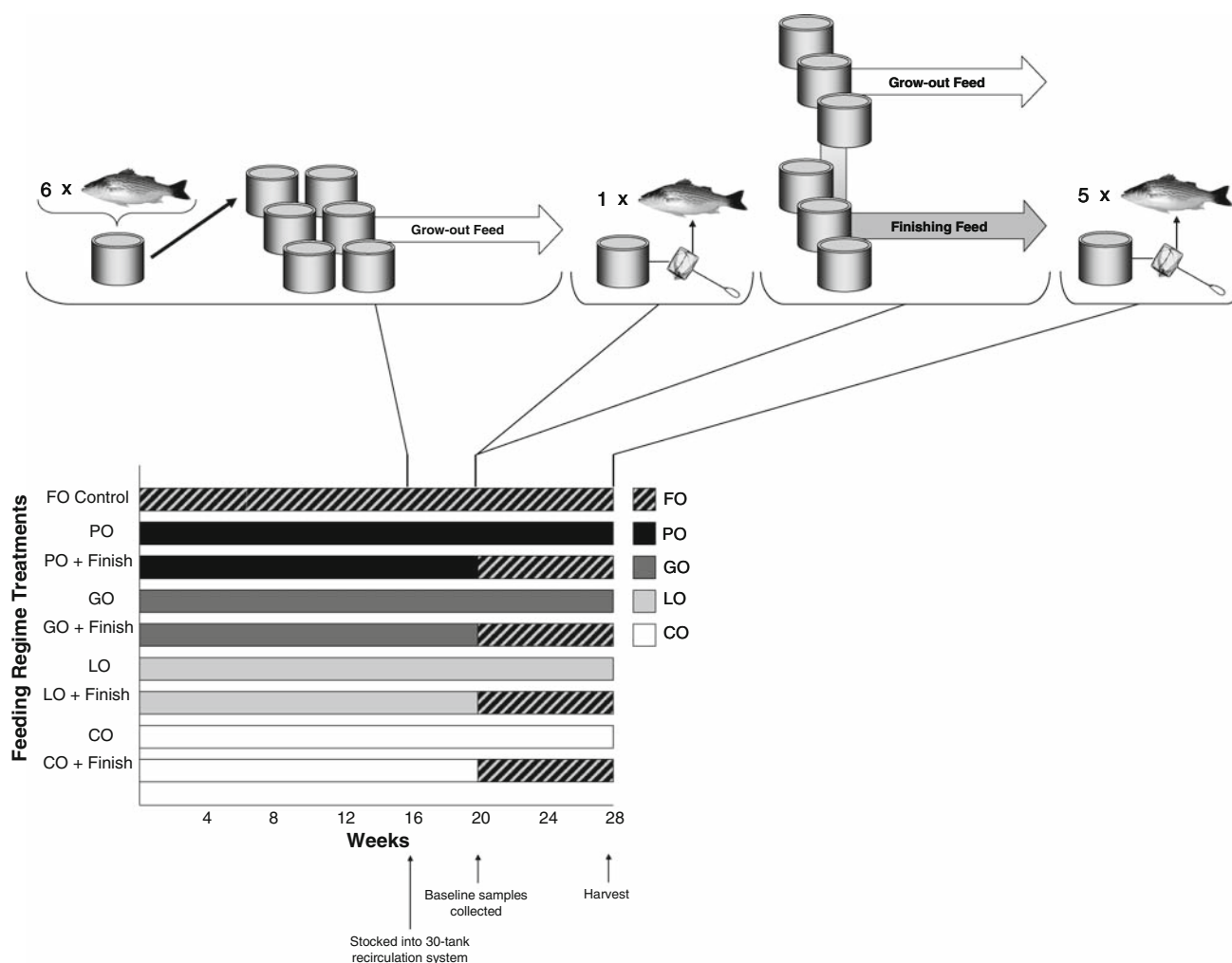


Fig. 1 Schematic of experimental design and feeding trial. Groups of sunshine bass were group-reared on one of five grow-out feeds and then stocked into a recirculation system. Each grow-out group was assigned to six replicate tanks, each originally housing six fish. After 20 weeks of culture, baseline tissue samples were collected (1 fish per tank). Three replicate tanks within each grow-out group were transitioned to the FO-based finishing feed for the last 8 weeks of

the trial, whereas the other tanks were maintained on assigned grow-out feeds. At harvest, production performance was assessed and tissue samples were collected from all remaining fish (5 fish per tank). FO, 100% fish oil feed; PO, 50:50 poultry/fish oil feed; GO, 50:50 grapeseed/fish oil feed; LO, 50:50 linseed/fish oil feed; CO, 50:50 coconut/fish oil feed

Tissue Composition

Fillet samples were analyzed according to standard methods [37, 38] for meat products to determine percent moisture, crude protein, crude lipid, and ash. All tissue samples were analyzed for FA composition in the same manner as diet samples (see “Diet Preparation and Analyses”).

Peroxidative Stability

Short-term fillet oxidative stability was assessed at 24 h post-harvest by analyzing refrigerated fillet samples for the presence of peroxides and aldehydes using the Peroxy-safe™ and Aldesafe™ colorimetric assay kits (Saftest Incorporated, Tempe, AZ, USA).

Statistical Analyses

Although multiple individual fish were sampled from each tank, replicate tanks served as the experimental units for all statistical analyses ($n = 3$ for experimental regimens, $n = 6$ for control regimen). All data were analyzed by one-way analysis of variance (ANOVA) within the General Linear Model framework of the Statistical Analysis System, version 9.1 (SAS Institute, Cary, NC, USA) to determine significance of differences among feeding regimens. Tissue FA data was further analyzed by two-way ANOVA within the Mixed Model framework of the Statistical Analysis System to test for independent and interactive effects of feeding regimen and tissue type. In all cases, differences were considered significant at $P < 0.05$.

Results

Lipid source and FA profile of the grow-out feeds strongly influenced fillet FA profile and subsequent finishing success in SB culture. Feeding diets with different dietary lipid sources during the first 5 months of the feeding trial resulted in dramatic alterations of fillet FA composition, with baseline fillet profile (Table 3) generally mirroring dietary FA composition (Table 2). Expectedly, baseline fillet samples of fish fed the LO, GO, and PO feeds contained high levels of 18:3n-3, 18:2n-6, and total MUFA, respectively, whereas fillets of FO-fed fish were higher in LC-PUFA, particularly 20:5n-3 and 22:6n-3. However, baseline fillet samples of CO-fed fish did not reflect dietary prevalence of SFA or reduced LC-PUFA content, and prior to finishing, were largely equivalent to samples from the FO Control regimen.

Continued use of the alternative lipid-based grow-out feeds through harvest resulted in similar, though more pronounced deviations from the FO Control profile (Table 4). Nonetheless, in each of these unfinished regimens, fillet levels of LC-PUFA were exaggerated in comparison to dietary profile (Fig. 2). Finishing had a significant restorative effect on fillet FA profile, augmenting fillet levels of FO-associated FA, regardless of grow-out regimen (Table 4). However, complete restoration of FO Control levels of 20:5n-3, 22:6n-3, and LC-PUFA and n-3:n-6 FA ratio was achieved only in the CO + Finish group.

Liver and IPF FA composition were also significantly influenced by feeding regimen; however, comparison among fillet, liver, and IPF profiles revealed significant differences in how dietary FA were partitioned among the tissue types (Fig. 3). Saturated FA and MUFA were most abundant within the IPF, particularly when abundant in the feed. Conversely, levels of LC-PUFA, but not MC-PUFA, were consistently lower within the IPF compared to liver and fillet tissue ($P_{\text{tissue type effect}} < 0.01$). Liver FA profile largely mirrored fillet composition, in that both tissue types typically contained lower levels of MUFA and higher levels of LC-PUFA compared to IPF tissue ($P_{\text{tissue type effect}} < 0.01$). When tissue composition of the unfinished groups was standardized to dietary composition (Fig. 4), these distinctions were particularly apparent, indicating concentration of LC-PUFA within the liver and fillet tissues and concentration of MUFA within the IPF.

Fillet proximate composition did not vary, with the exception of fillet moisture content (Table 5), which showed slight, though significant, reductions for GO Control and PO + Finish treatments. Consumption, weight gain, FCR, HSI, and dress-out were unaffected by feeding regimen and acceptable in terms of production performance typically observed for SB (Table 6). LSI values

were significantly lower among fish fed the CO- and GO feeds (Table 6). LSI tended to be higher among finished groups relative to their unfinished counterparts, though significant differences were only observed within the GO-fed groups. No mortalities occurred during the course of the feeding trial. Peroxide and aldehyde concentrations were below detection limits for all samples analyzed (data not shown).

Discussion

Although production performance and fillet crude lipid content were unaffected, feeding diets with different dietary lipid sources resulted in dramatic alterations of fillet total lipid FA composition. These findings are in agreement with previous investigations of CO [40], PO [41, 42], and LO [43], as well as the well-established paradigm of compositional plasticity of fish tissues with respect to FA profile. Finishing augments fillet nutritional quality among fishes raised on feeds containing FO alternatives [26–34]; however, complete restoration of FO-associated FA profile, specifically LC-PUFA content, is rarely observed [31–34]. For example, in Atlantic salmon *Salmo salar* fed linseed, palm, and/or rapeseed oil-based grow-out feeds, complete profile restoration was not observed after 20–24 weeks of finishing [27, 30, 32]. Similarly, 8–16 weeks of finishing were insufficient to completely restore the profile of Murray cod *Maccullochella peelii peelii* previously fed diets containing blends of linseed, olive, palm, sunflower, or rapeseed oils [34, 35]. Prior attempts to restore fillet LC-PUFA content of SB fed a corn-oil based, n-6 MC-PUFA-rich grow-out feed were unsuccessful after 12 weeks of finishing [33]. In the present work, restoration was incomplete among fish fed diets high in MC-PUFA. Fillet 20:5n-3, 22:6n-3, and LC-PUFA levels were considerably improved by finishing in the LO- and GO-fed fish, however, the magnitude of restoration was moderate compared to the CO- and PO-fed groups. Arguably, fillet profile could have been completely restored among the LO- and GO-fed fish, however, a longer finishing period would have been necessary to achieve complete FA profile restoration. Conversely, fish fed the CO feed needed little alteration to achieve the FO-associated composition, and fillet FA profile was successfully restored to control levels of LC-PUFA within 8 weeks of finishing.

Pre-finishing fillet FA profile influenced finishing success, and the inclusion of oils high in 18-carbon FA in grow-out feeds limited the effects of finishing feeds on SB fillet FA composition. Others have noted MC-PUFA, such as 18:2n-6 and 18:3n-3, deposited in the fillet are resistant to dietary modification and may be problematic in the context of LC-PUFA restoration during finishing. For

Table 3 Total lipid composition of baseline fillet samples with respect to predominant (>1% fatty acid methyl esters, FAME) fatty acid (FA) and FA classes

Fatty acid(s)	Fish (FO)		Coconut (CO)		Grapeseed (GO)		Linseed (LO)		Poultry (PO)	
	FO control	CO	CO + Finish	GO	GO + Finish	LO	LO + Finish	PO	PO + Finish	
12:0	1.3 ± 0.4b	3.6 ± 0.5a	4.0 ± 0.6a	0.1 ± 0.5b	0.1 ± 0.5b	0.0 ± 0.5b	0.0 ± 0.5b	0.1 ± 0.5b	0.1 ± 0.5b	
14:0	5.6 ± 0.3a	6.1 ± 0.4a	6.0 ± 0.5a	3.1 ± 0.4b	3.2 ± 0.4b	3.3 ± 0.4b	3.0 ± 0.4b	3.2 ± 0.4b	3.3 ± 0.4b	
16:0	19.8 ± 0.5a	20.3 ± 0.7a	20.0 ± 0.9a	17.5 ± 0.7b	17.5 ± 0.7b	17.0 ± 0.7b	16.7 ± 0.7b	20.3 ± 0.7a	20.4 ± 0.7a	
18:0	3.5 ± 0.3	4.8 ± 0.5	5.0 ± 0.6	3.9 ± 0.5	3.7 ± 0.5	4.2 ± 0.5	4.0 ± 0.5	4.2 ± 0.5	4.0 ± 0.5	
Total SFA ^a	31.3 ± 0.5b	35.6 ± 0.7a	35.9 ± 0.9a	25.4 ± 0.7d	25.3 ± 0.7d	25.2 ± 0.7d	24.6 ± 0.7d	28.7 ± 0.7c	28.6 ± 0.7c	
16:1n-7	8.7 ± 0.4a	5.9 ± 0.6bc	5.2 ± 0.7c	5.1 ± 0.6c	5.3 ± 0.5c	5.5 ± 0.6c	5.5 ± 0.6c	7.2 ± 0.6b	7.5 ± 0.6ab	
18:1n-7	3.1 ± 0.0a	2.5 ± 0.1b	2.4 ± 0.1bc	2.2 ± 0.1c	2.2 ± 0.1c	2.3 ± 0.1bc	2.3 ± 0.1bc	2.7 ± 0.1b	2.7 ± 0.1b	
18:1n-9	11.7 ± 0.6bc	10.5 ± 0.9c	10.3 ± 1.0c	13.3 ± 0.9b	13.8 ± 0.9b	13.2 ± 0.9b	13.6 ± 0.9b	18.8 ± 0.9a	19.3 ± 0.9a	
Total MUFA ^b	24.2 ± 1.0b	19.5 ± 1.4c	18.5 ± 1.7c	21.1 ± 1.4bc	22.0 ± 1.4bc	21.7 ± 1.4bc	22.0 ± 1.4bc	29.5 ± 1.4a	30.3 ± 1.4a	
18:2n-6	8.4 ± 0.4c	8.1 ± 0.6c	8.1 ± 0.7c	25.5 ± 0.6a	25.5 ± 0.6a	13.1 ± 0.6b	12.7 ± 0.6b	13.1 ± 0.6b	13.1 ± 0.6b	
20:4n-6	1.2 ± 0.1ab	1.4 ± 0.1a	1.4 ± 0.1a	1.0 ± 0.1b	0.9 ± 0.1b	0.9 ± 0.1b	1.1 ± 0.1b	1.3 ± 0.1ab	1.2 ± 0.1ab	
n-6 ^c	10.4 ± 0.4c	10.4 ± 0.5c	10.5 ± 0.7c	27.7 ± 0.5a	27.8 ± 0.5a	14.9 ± 0.5b	14.7 ± 0.5b	15.4 ± 0.5b	15.3 ± 0.5b	
18:3n-3	1.6 ± 0.3b	1.5 ± 0.5b	1.4 ± 0.6b	1.2 ± 0.5b	1.3 ± 0.5b	15.5 ± 0.5a	14.5 ± 0.5a	1.5 ± 0.5b	1.4 ± 0.5b	
18:4n-3	1.8 ± 0.1a	1.1 ± 0.1b	0.9 ± 0.2b	0.9 ± 0.1b	0.9 ± 0.1b	1.0 ± 0.1b	0.9 ± 0.1b	1.0 ± 0.1b	1.0 ± 0.1b	
20:5n-3	9.5 ± 0.3a	9.9 ± 0.5a	10.3 ± 0.6a	6.8 ± 0.5b	6.6 ± 0.5b	6.6 ± 0.5b	6.9 ± 0.5b	7.4 ± 0.5b	6.9 ± 0.5b	
22:5n-3	2.4 ± 0.0a	2.2 ± 0.1a	2.2 ± 0.1a	1.7 ± 0.1bc	1.7 ± 0.1bc	1.6 ± 0.1c	1.9 ± 0.1b	1.8 ± 0.1bc	1.8 ± 0.1b	
22:6n-3	17.2 ± 1.0ab	18.5 ± 1.4a	18.8 ± 1.6a	14.0 ± 1.4bc	13.2 ± 1.4c	12.3 ± 1.4c	13.3 ± 1.4c	13.6 ± 1.4c	13.6 ± 1.4c	
n-3 ^d	33.7 ± 1.1b	34.2 ± 1.6ab	34.8 ± 1.9ab	25.5 ± 1.6c	24.6 ± 1.6c	37.9 ± 1.6a	38.5 ± 1.6a	26.1 ± 1.6c	25.6 ± 1.6c	
Total PUFA ^e	44.5 ± 0.8b	44.9 ± 1.2b	45.6 ± 1.4b	53.5 ± 1.2a	52.7 ± 1.2a	53.1 ± 1.2a	53.4 ± 1.2a	41.8 ± 1.2bc	41.1 ± 1.2c	
Total LC-PUFA ^f	31.7 ± 1.3a	33.2 ± 1.8a	34.0 ± 2.2a	24.4 ± 1.8b	23.5 ± 1.2b	22.5 ± 1.8b	24.2 ± 1.8b	25.1 ± 1.8b	24.6 ± 1.8b	
Total MC-PUFA ^g	12.1 ± 0.7c	11.0 ± 0.9c	10.8 ± 1.1c	27.9 ± 0.9a	28.0 ± 0.9a	29.8 ± 0.9a	28.4 ± 0.9a	15.9 ± 0.9b	15.7 ± 0.9b	
n-3:n-6	3.3 ± 0.2a	3.3 ± 0.2a	3.4 ± 0.3a	0.9 ± 0.2d	0.9 ± 0.2d	2.5 ± 0.2b	2.6 ± 0.2ab	1.7 ± 0.2c	1.7 ± 0.2c	

Values represent least-square means (relative area % of FAME) ± SE of a single individual sample from all tanks. Means within fatty acid(s) with common letter are not significantly different. Absence of letters indicates lack of statistical significance

^a Saturated fatty acids—sum of all FA without double bonds; includes 15:0 and 17:0 in addition to individually reported SFA

^b Monounsaturated fatty acids—sum of all FA with single double bond; includes 20:1n-9 in addition to individually reported MUFA

^c Includes 20:2n-6 and 20:3n-6 in addition to individually reported n-6 FA

^d Includes 20:3n-3 in addition to individually reported n-3 FA

^e Polyunsaturated fatty acids—sum of all FA with double bonds ≥ 2; includes 18:3n-4, 20:3n-3, 20:4n-3, 20:2n-6, and 20:3n-6 in addition to individually reported PUFA

^f Long-chain PUFA—sum of all PUFA with chain length ≥ 20 carbon atoms, double bonds ≥ 3; includes 20:3n-3, 20:4n-3, and 20:3n-6 in addition to individually reported LC-PUFA

^g Medium-chain PUFA—sum of all PUFA with chain length of 18 carbon atoms; includes 18:3n-4 in addition to individually reported MC-PUFA

Table 4 Total lipid composition of harvest fillet samples with respect to predominant (>1% FAME) FA and FA classes

Fatty acid(s)	Fish oil (FO)		Coconut oil (CO)		Grapeseed oil (GO)		Linseed oil (LO)		Poultry oil (PO)	
	FO control	CO	CO + Finish	GO	GO + Finish	LO	LO + Finish	PO	PO + Finish	
12:0	0.8 ± 0.1c	6.6 ± 0.1a	2.8 ± 0.1b	0.2 ± 0.1d	0.1 ± 0.1d	0.1 ± 0.1d	0.1 ± 0.1d	0.1 ± 0.1d	0.1 ± 0.1d	
14:0	5.5 ± 0.1c	8.1 ± 0.1a	6.2 ± 0.1b	3.2 ± 0.1e	4.1 ± 0.1d	3.2 ± 0.1e	4.2 ± 0.1d	3.4 ± 0.2e	4.0 ± 0.1d	
16:0	19.6 ± 0.1b	18.4 ± 0.2d	19.2 ± 0.2bc	17.2 ± 0.2f	18.7 ± 0.2cd	16.3 ± 0.2g	17.8 ± 0.2e	20.3 ± 0.2a	19.8 ± 0.2ab	
18:0	3.7 ± 0.1	3.8 ± 0.1	3.6 ± 0.1	4.0 ± 0.1	3.8 ± 0.1	3.8 ± 0.1	3.7 ± 0.1	3.9 ± 0.1	4.0 ± 0.1	
Total SFA	30.7 ± 0.2c	37.7 ± 0.2a	32.8 ± 0.2b	25.3 ± 0.2g	27.6 ± 0.2e	24.2 ± 0.2h	26.6 ± 0.2f	28.5 ± 0.3d	28.8 ± 0.3d	
16:1n-7	8.9 ± 0.1a	6.8 ± 0.2d	8.0 ± 0.2b	5.4 ± 0.2e	7.1 ± 0.2d	5.6 ± 0.2e	7.3 ± 0.2cd	7.8 ± 0.2bc	8.0 ± 0.2b	
18:1n-7	3.0 ± 0.0a	2.3 ± 0.0e	2.7 ± 0.0bc	2.2 ± 0.0f	2.6 ± 0.0cd	2.2 ± 0.0f	2.6 ± 0.0d	2.6 ± 0.0d	2.8 ± 0.0b	
18:1n-9	10.7 ± 0.2g	11.4 ± 0.2ef	11.0 ± 0.2fg	13.9 ± 0.2b	12.1 ± 0.2d	13.0 ± 0.2c	11.8 ± 0.2de	19.7 ± 0.3a	14.6 ± 0.2b	
Total MUFA	23.4 ± 0.3c	21.3 ± 0.4e	22.4 ± 0.4cde	22.2 ± 0.4de	22.6 ± 0.4cd	21.4 ± 0.4de	22.3 ± 0.4cde	30.9 ± 0.5a	26.1 ± 0.5b	
18:2n-6	7.9 ± 0.1f	8.4 ± 0.2e	8.0 ± 0.2ef	25.2 ± 0.2a	16.3 ± 0.2b	12.8 ± 0.2c	10.4 ± 0.2d	13.2 ± 0.2c	10.2 ± 0.2d	
20:4n-6	1.5 ± 0.0ab	1.4 ± 0.0c	1.6 ± 0.0a	1.2 ± 0.0d	1.4 ± 0.0bc	1.2 ± 0.0d	1.4 ± 0.0bc	1.4 ± 0.0abc	1.5 ± 0.0abc	
n-6	10.2 ± 0.1e	10.6 ± 0.2e	10.4 ± 0.2e	27.8 ± 0.2a	18.7 ± 0.2b	14.9 ± 0.2c	12.6 ± 0.2d	15.5 ± 0.2c	12.5 ± 0.2d	
18:3n-3	1.5 ± 0.1c	1.4 ± 0.2c	1.4 ± 0.2c	1.2 ± 0.2c	1.2 ± 0.2c	15.8 ± 0.2a	8.5 ± 0.2b	1.6 ± 0.2c	1.4 ± 0.2c	
18:4n-3	1.5 ± 0.0a	1.1 ± 0.0d	1.3 ± 0.0b	0.8 ± 0.0f	1.1 ± 0.0cd	0.9 ± 0.0e	1.2 ± 0.0bc	0.9 ± 0.0ef	1.1 ± 0.0cd	
20:5n-3	10.6 ± 0.1a	9.1 ± 0.2c	10.4 ± 0.2a	6.6 ± 0.2d	9.4 ± 0.2bc	6.9 ± 0.2d	9.3 ± 0.2bc	7.0 ± 0.2d	9.7 ± 0.2b	
22:5n-3	2.7 ± 0.0a	2.4 ± 0.0c	2.6 ± 0.0b	2.0 ± 0.0d	2.3 ± 0.0c	2.0 ± 0.0d	2.5 ± 0.0bc	1.9 ± 0.1d	2.0 ± 0.0bc	
22:6n-3	17.8 ± 0.4a	15.2 ± 0.5b	17.3 ± 0.5a	13.2 ± 0.6c	15.7 ± 0.5b	12.6 ± 0.5c	15.5 ± 0.5b	12.7 ± 0.6c	16.7 ± 0.6ab	
n-3	35.3 ± 0.4b	30.1 ± 0.5d	34.1 ± 0.5b	24.5 ± 0.6e	30.8 ± 0.6cd	39.2 ± 0.6a	38.1 ± 0.5a	24.9 ± 0.7e	32.3 ± 0.6c	
Total PUFA	45.9 ± 0.3d	41.0 ± 0.4e	44.8 ± 0.4d	52.5 ± 0.5b	49.8 ± 0.5c	54.3 ± 0.5a	51.0 ± 0.4c	40.7 ± 0.5e	45.1 ± 0.5d	
Total LC-PUFA	34.0 ± 0.5a	29.2 ± 0.6d	33.1 ± 0.6ab	23.8 ± 0.7e	30.0 ± 0.7cd	23.8 ± 0.7e	30.0 ± 0.6cd	24.1 ± 0.8e	31.5 ± 0.7bc	
Total MC-PUFA	11.3 ± 0.2g	11.2 ± 0.3g	11.0 ± 0.3g	27.5 ± 0.3b	19.0 ± 0.3d	29.8 ± 0.3a	20.4 ± 0.3c	15.9 ± 0.4e	13.0 ± 0.4f	
n-3:n-6	3.5 ± 0.0a	2.8 ± 0.1c	3.3 ± 0.1a	0.9 ± 0.1f	1.6 ± 0.1e	2.6 ± 0.1cd	3.0 ± 0.1b	1.6 ± 0.1e	2.6 ± 0.1d	

Values represent least-square means (relative area % of FAME) ± SE of multiple individuals (≥3) from all tanks. Means within fatty acid(s) with common letter are not significantly different. Absence of indicates lack of statistical significance

All abbreviations and other notations are as reported in Table 3

Fig. 2 Fatty acid (FA) composition of fillet total lipid expressed as a fraction of dietary FA composition for unfinished feeding regimes. Values were calculated from relative fatty acid methyl ester composition (%FAME) as $\%FAME_{\text{fillet}} \times FAME_{\text{feed}}^{-1}$. Based on this calculation, a value of 1 represents equality between fillet and dietary composition. All FA abbreviations are as reported in Table 3. Other abbreviations: FO, 100% fish oil feed; PO, 50:50 poultry/fish oil feed; GO, 50:50 grapeseed/fish oil feed; LO, 50:50 linseed/fish oil feed; CO, 50:50 coconut/fish oil feed

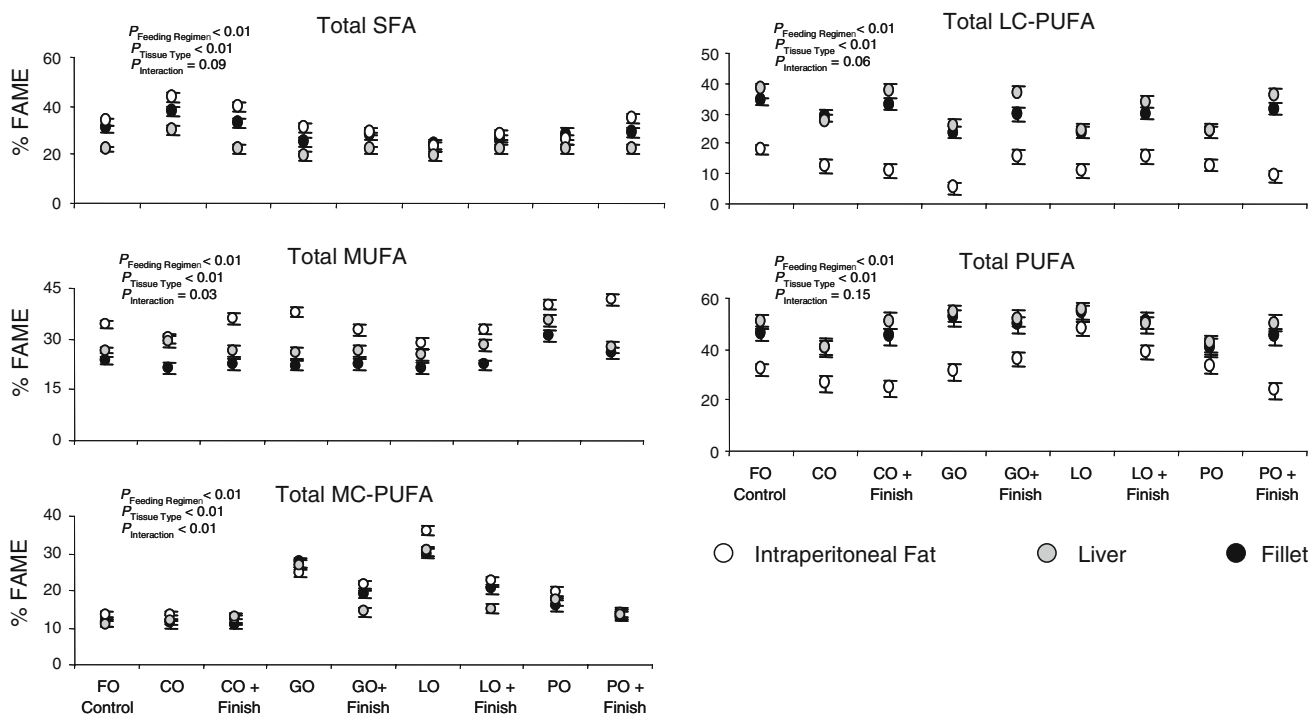
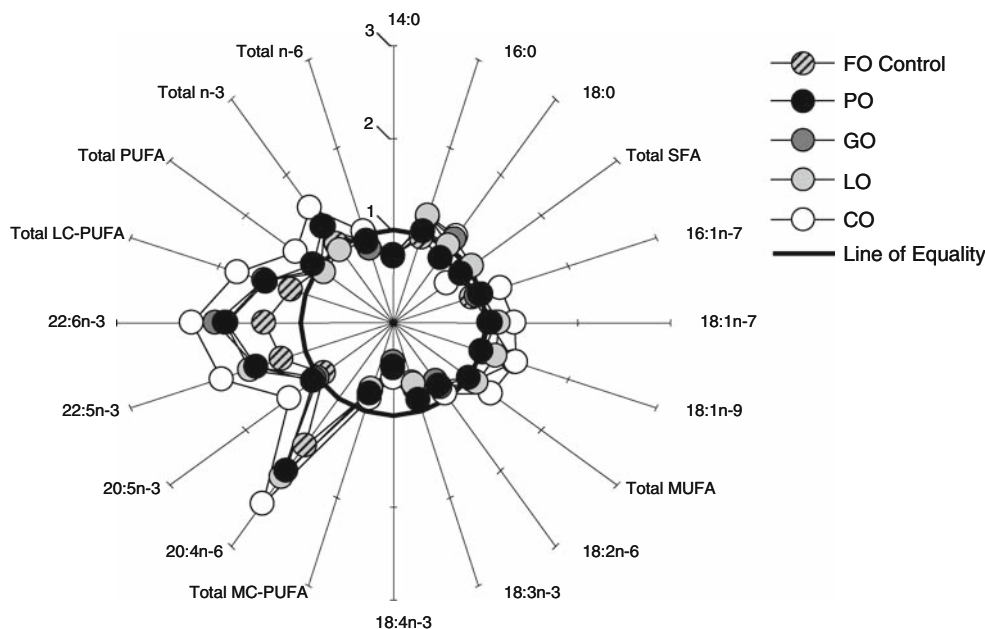


Fig. 3 Fatty acid composition of fillet, liver, and intraperitoneal fat tissue total lipid by feeding regimen. Error bars represent \pm SE. All FA abbreviations are as reported in Table 3. Other abbreviations: FO,

100% fish oil feed; PO, 50:50 poultry/fish oil feed; GO, 50:50 grapeseed/fish oil feed; LO, 50:50 linseed/fish oil feed; CO, 50:50 coconut/fish oil feed

example, after finishing Murray cod raised on vegetable oil-based grow-out feeds, the most rapid and extensive restorative effects were observed in fish fed a low MC-PUFA grow-out feed compared to those fed a high MC-PUFA feed [35]. Menoyo et al. [43] indirectly evaluated the unresponsiveness of 18-carbon FA in Atlantic salmon

tissues by using sunflower oil to spare either FO or LO, and noted ability of dietary sunflower oil to alter fillet composition was attenuated in the LO-fed groups. These authors attributed the differential response to reduced digestibility of the FO-based diets relative to the LO feeds; however, based on our findings, we suspect selective

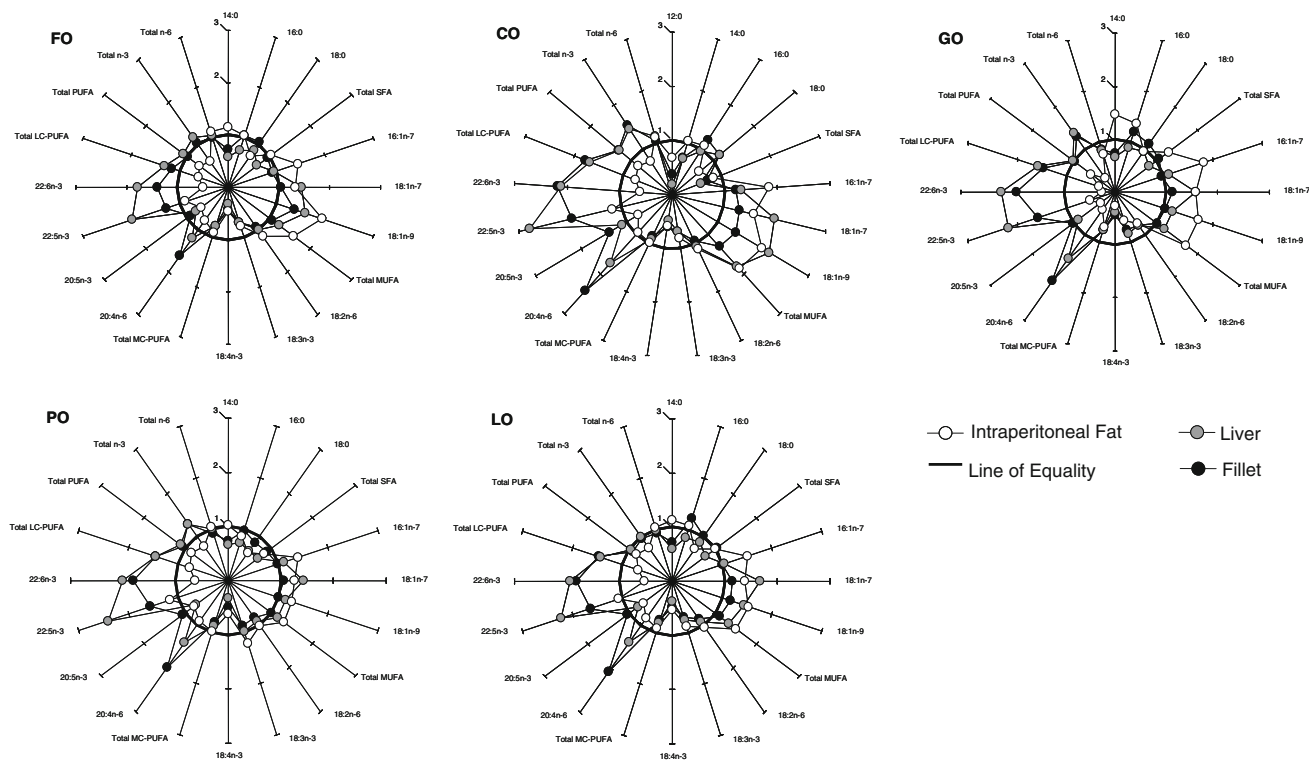


Fig. 4 Fatty acid composition of tissue total lipid expressed as a fraction of dietary FA composition for unfinished feeding regimes. Values were calculated from relative fatty acid methyl ester composition (%FAME) as $\%FAME_{\text{tissue}} \times FAME_{\text{feed}}^{-1}$. Based on this calculation, a value of 1 represents equality between fillet and

dietary composition. All FA abbreviations are as reported in Table 3. Other abbreviations: FO, 100% fish oil feed; PO, 50:50 poultry/fish oil feed; GO, 50:50 grapeseed/fish oil feed; LO, 50:50 linseed/fish oil feed; CO, 50:50 coconut/fish oil feed

metabolism of certain FA may have been a contributing factor.

The process of FA profile change in fish tissues following a change in dietary lipid composition, often described as FA “dilution” or “washout”, is relatively well-described by an asymptotic, simple dilution curve [21–23]. The simple dilution curve predicts temporal changes in tissue FA profile based on the relative disparity between dietary and tissue FA composition and the change in overall body mass or adiposity over time. By its definition, the dilution model assumes no selective processes of FA metabolism. Therefore, deviations from the dilution model are often interpreted as indicative of selective partitioning of specific FA, or FA classes, or catabolism via β -oxidation. Our group previously tested the dilution model by comparing the model’s predictions to observed fillet FA profile of SB reared on corn-oil based feed after finishing [33]. This comparison revealed apparent selective retention of total n-3 FA, MC-PUFA, LC-PUFA, and n-3 LC-PUFA within fillet tissue. Conversely, total fillet SFA were significantly lower than the model’s predictions, suggesting selective catabolism or storage of these FA in other lipid depots. The present work demonstrates dietary SFA are not

proportionally reflected within fillet, liver, or IPF lipid of SB. Plausibly, consumed SFA may be elongated and/or desaturated to MUFA, for example, which are strongly partitioned into IPF lipid (Fig. 4). If this were the case, one would expect increased consumption of dietary SFA to result in increasing levels of MUFA within the tissues. However, given the lack of increasing levels of MUFA within any lipid depot of CO-fed fish (Fig. 3), and the generally poor ability of SB to biotransform FA in appreciable amounts [44], this scenario seems unlikely. Rather, levels of SFA were routinely lower than expected in all tissues analyzed, suggesting catabolism of these FA, not selective partitioning into storage lipid.

Evidence of selective FA metabolism has also been noted for Atlantic salmon [27, 45, 46], however, Bell and colleagues observed the FA composition of the dietary lipid seemed to influence the selective processes. Specifically, 22:6n-3 was selectively retained within fillet lipid in all three studies, illustrating the necessity of this FA for physiological function. Monounsaturated FA were selected against, indicating these FA are comparatively expendable, however, the strength of selective catabolism (magnitude of deviation from line of equality in tissue vs. dietary

Table 5 Fillet compositional characteristics at harvest by dietary/finishing treatment group

Parameter	Fish oil (FO)		Coconut oil (CO)		Grapeseed oil (GO)		Linseed oil (LO)		Poultry oil (PO)	
	FO control	CO	CO + Finish	GO	GO + Finish	LO	LO + Finish	PO	PO + Finish	
Moisture (%)	76.0 ± 0.2ab	75.6 ± 0.3bc	76.0 ± 0.3ab	74.9 ± 0.3cd	76.2 ± 0.3ab	76.6 ± 0.3a	76.1 ± 0.3ab	75.3 ± 0.3bcd	74.6 ± 0.3d	
Crude Protein ^a (%)	86.9 ± 1.0	84.5 ± 1.4	88.7 ± 1.4	84.2 ± 1.4	87.6 ± 1.4	87.2 ± 1.6	89.5 ± 1.4	83.5 ± 1.4	84.9 ± 1.5	
Crude Lipid ^a (%)	8.1 ± 0.4	7.5 ± 0.6	6.9 ± 0.6	7.2 ± 0.6	7.3 ± 0.6	8.8 ± 0.6	8.4 ± 0.6	8.0 ± 0.6	6.8 ± 0.6	
Ash ^a (%)	4.8 ± 0.3	4.60 ± 0.4	4.8 ± 0.4	5.4 ± 0.5	5.7 ± 0.5	6.0 ± 0.4	6.4 ± 0.4	4.6 ± 0.4	5.8 ± 0.4	

Values represent least-square means ± SE of multiple individuals (≥3) within tanks. Means within parameters with common letter are not significantly different. Absence of letters indicates lack of statistical significance

^a Dry matter basis

Table 6 Production performance by dietary/finishing treatment group

Production variable	Fish oil (FO)		Coconut oil (CO)		Grapeseed oil (GO)		Linseed oil (LO)		Poultry oil (PO)	
	FO control	CO	CO + Finish	GO	GO + Finish	LO	LO + Finish	PO	PO + Finish	
Initial Weight ^a (g)	231 ± 7	209 ± 11	239 ± 11	206 ± 11	227 ± 11	221 ± 11	221 ± 11	206 ± 11	231 ± 11	
Final Weight ^a (g)	548 ± 22	504 ± 32	551 ± 32	453 ± 32	531 ± 32	514 ± 32	512 ± 32	500 ± 32	538 ± 32	
Weight Gain ^b (%)	137 ± 7	141 ± 10	131 ± 10	120 ± 10	134 ± 10	132 ± 10	132 ± 10	143 ± 10	133 ± 10	
Consumption ^b (dry matter, g)	632 ± 20	707 ± 29	679 ± 29	656 ± 29	632 ± 29	581 ± 29	582 ± 29	632 ± 29	614 ± 29	
Dress-out ^a (%)	30.5 ± 0.4	31.0 ± 0.7	30.1 ± 0.6	29.9 ± 0.6	30.0 ± 0.6	28.5 ± 0.6	29.0 ± 0.6	31.4 ± 0.7	30.4 ± 0.7	
FCR ^{b,c}	2.0 ± 0.1	2.4 ± 0.2	2.2 ± 0.2	2.7 ± 0.2	2.1 ± 0.2	2.0 ± 0.2	2.1 ± 0.2	2.2 ± 0.2	2.1 ± 0.2	
HSI ^{a,d}	1.1 ± 0.0	1.2 ± 0.1	1.1 ± 0.1	1.2 ± 0.1	1.1 ± 0.1	1.2 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	1.1 ± 0.1	
IPFR ^{a,e}	3.2 ± 0.1ab	2.5 ± 0.2c	2.8 ± 0.2bc	2.9 ± 0.2bc	3.4 ± 0.2a	3.1 ± 0.2ab	3.2 ± 0.2ab	3.3 ± 0.2ab	3.4 ± 0.2ab	

Means within a production variable with common letter are not significantly different. Absence of letters indicates lack of statistical significance

^a Values represent least-square means ± SE of multiple individuals (≥3) within tanks, tanks serving as experimental units

^b Values represent least-square means ± SE of average individual performance criteria within tanks, tanks serving as experimental units

^c Feed conversion ratio (consumption/weight gain)

^d Hepatosomatic index [(liver mass/whole body mass) × 100]

^e Intraperitoneal fat ratio [(intraperitoneal fat mass/whole body mass) × 100]

regressions) decreased with increasing availability of SFA. When SFA were abundant, these FA were more strongly selected for catabolism, and MUFA, given a “catabolic reprieve”, were deposited to a greater extent in fillet tissue. Observations of selective FA metabolism in fish tissues are further supported by the preferential shunting of shorter chain FA into β -oxidation [47–50]. Oxidation of longer-chain and unsaturated FA appears to be a function of their relative abundance [51], and in the case of LC-PUFA, only substantial in vertebrates with a profusion of LC-PUFA stored in tissue [52].

Based on the various estimates of selective metabolism of FA in fishes, SFA appear to be the preferential catabolic substrate, whereas MC-PUFA and LC-PUFA are selectively deposited in tissues. Hence, attempts to spare LC-PUFA and optimize profile restoration during finishing may be enhanced by providing a largely saturated diet, with few MC-PUFA to compete with LC-PUFA for fillet deposition. Our work confirms this hypothesis in the context of SB culture. We demonstrated SB fillets with equivalent LC-PUFA content and associated nutritional value can be produced using a reduced FO grow-out feed followed by an 8-week finishing period. Using CO in the grow-out feed, the negative effects of FO replacement on SB fillet LC-PUFA content were rapidly reversed during finishing. The comprehensive profile restoration we observed among the CO-fed fish is unprecedented in SB culture. Low MC-PUFA feeds could be implemented in SB culture throughout a majority of grow-out, followed by implementation of an 8-week FO finishing period prior to harvest. Assuming the CO + Finish regimen and a conservative FCR (consumption/weight gain) of 2, fillets of equivalent LC-PUFA content and nutritional value could be produced with a 35% reduction in FO use over the course of the production cycle. This strategy offers a substantial reduction in marine-derived inputs to SB feeds and, potentially, a significant savings in feed cost. Furthermore, by restricting use of FO-rich feeds to the weeks immediately preceding harvest, cumulative dietary exposure of the livestock to FO-associated contaminants is reduced. We hypothesize other saturated lipids could be used to similar effect in SB and other cultured fishes. Compared to MC-PUFA-rich lipids, improved finishing success has been observed in Murray cod fed a blend of palm and olive oils, but after 16 weeks, LC-PUFA restoration was still incomplete [35]. Lack of comprehensive profile restoration may reflect a difference between Murray cod and SB as culture taxa (pure species vs. hybrid, marine vs. freshwater-reared euryhaline, medium-fat fleshed vs. lean-fleshed, etc.) or a difference between CO and palm and olive oils as lipid sources (mostly short-chain vs. medium-chain SFA and MUFA). Additional research will be necessary to resolve discrepancies in finishing success, and to identify

appropriate strategies for all species. Regardless, use of a saturated grow-out feed coupled with finishing is an effective strategy to produce high quality cultured SB fillets and represents a considerable step forward in judicious use of limited marine resources in aquaculture.

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