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Use of alternative lipids and finishing feeds to improve nutritional value and food safety of hybrid striped bass

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ABSTRACT

The present study assessed the use of saturated fatty acid-rich lipids to replace fish oil in grow-out feeds in conjunction with a fish oil-rich finishing diet to determine if this strategy could produce hybrid striped bass with equal production performance, and equivalent fillet long-chain polyunsaturated fatty acid (LC-PUFA) levels, and reduced fillet persistent organic pollutant (POP) concentrations. Final weight (597.8 ± 11.1 g, mean ± SE, p = 0.29), percent weight gain (2743.1 ± 45.1%, p = 0.11), feed conversion ratio (1.4 ± 0.02, p = 0.28), dress-out (23.5 ± 0.3%, p = 0.46), hepatosomatic index (0.9 ± 0.02, p = 0.54), or liposomatic index (1.5 ± 0.04, p = 0.62) was not adversely affected by any of the feeding regimens. However, fillet composition was altered, with fillets of fish consuming less fish oil having lower LC-PUFA (31.45 ± 0.75 to 16.94 ± 0.78 g/100 g FAME, p < 0.0001) and POP levels (53.93 ± 9.21 to 15.97 ± 9.49 ng/g dry weight, p < 0.0001). Finishing yielded a modest increase in fillet LC-PUFA and POP, but POP accumulated more readily than LC-PUFA with increased fish oil consumption during finishing. Replacing fish oil in aquafeeds produces fish with reduced LC-PUFA and POP in the fillet. Feeding fish oil results in more rapid accumulation of POP than LC-PUFA. Overall, fish consuming the lowest amount of fish oil in the diet yielded fillets with the highest ratio of LC-PUFA to POP, despite lower LC-PUFA content.

1. Introduction

Long-chain polyunsaturated fatty acids (LC-PUFA; $C_{20\text{-}22}$, double bonds ≥3), specifically eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) have important human health benefits (Mozaffarian and Rimm, 2006), leading health organizations to recommend increased consumption of seafood (USDA and USHHS, 2010). Increasing per capita consumption paired with a growing world population will require an increased supply of seafood (FAO, 2012). However, world capture fisheries are at maximum yields, resulting in level annual supply (FAO, 2012). To meet increased demand for seafood, aquaculture must grow (FAO, 2012), but increased production will require increased feed inputs. However, harvest of fish for fish oil production is also at maximum yields (FAO, 2012). Limited fish oil supply (FAO, 2012), lack of cost-effective alternatives of essential fatty acids (Trushenski et al., 2006), and an aquaculture monopoly on the resource (Tacon and Metian, 2008) will constrain growth.

Farm-raised fish may contain higher concentrations of persistent organic pollutants (POP), including polychlorinated biphenyls (PCB), organochlorine pesticides (OCP), and polybrominated diphenyl ethers (PBDE) (Easton et al., 2002; Hites et al., 2004), that present several negative health risks (Longnecker, 2001; USEPA, 2009). When fish oil containing POP is used in aquafeeds, the POP are transferred to the fish (Jacobs et al., 2002), and can create a product higher in POP. However, the risks of eating farmed fish do not outweigh the health benefits of LC-PUFA intake (Mozaffarian and Rimm, 2006), but negative consumer perceptions remain.

Alternative lipids can partially replace dietary fish oil without impacting production performance so long as essential fatty acid requirements are met (Caballero et al., 2002; Trushenski, 2009). Alternative lipids are lower in POP and LC-PUFA than fish oil, and when used to spare dietary fish oil, not only lead to seafood with lower POP (Bell et al., 2005; Friesen et al., 2008), but also reduced LC-PUFA (Caballero et al., 2002; Trushenski, 2009). To counteract this, 'finishing' prior to harvest by feeding a fish oil-rich diet can not only restore LC-PUFA to the fillet (Izquierdo et al., 2004; Trushenski et al., 2008), but this also increases fillet POP via increased dietary exposure (Bell et al., 2005; Nacher-Mestre et al., 2009).

'Pre-finishing' fillet fatty acid composition determines, in part, the success of finishing via 'selective fatty acid metabolism' (Trushenski et al.,

Abbreviations: POP Persistent organic pollutant(s), POP Persistent organic pollutant(s); PCB, polychlorinated biphenyl(s); PBDE, polybrominated diphenyl ether(s); OCP, organochlorine pesticide(s); ICES, International Council for the Exploration of the Seas; HCH, hexachlorocyclohexane; DDT, dichlorodiphenyltrichloroethane; DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; FAME, fatty acid methyl ester(s); SFA, saturated fatty acid(s); MUFA, monounsaturated fatty acid(s); MC-PUFA, medium-chain polyunsaturated fatty acid(s); LC-PUFA, long-chain polyunsaturated fatty acid(s); FO, fish oil; CO, coconut oil; PO, palm oil; EPA, eicosapentaenoic acid; DHA, docosahexaenoic acid.

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2008), wherein saturated (SFA; no double bonds) and monounsaturated fatty acids (MUFA; one double bond) are preferentially catabolized, whereas medium chain polyunsaturated fatty acids (MC-PUFA; C_{18}, double bonds ≥ 2) and LC-PUFA are selectively retained (Bell et al., 2002; Lane et al., 2006; Trushenski et al., 2008). Therefore, to maximize LC-PUFA restoration during finishing, an ideal grow-out diet would be high in SFA and MUFA and low in competing MC-PUFA. This strategy may result in the most efficient use of fish oil to maintain LC-PUFA, while reducing POP accumulation.

The present study investigated the effects of SFA- (coconut oil) and MUFA-rich (palm oil) alternative lipids with or without the use of a 100% fish oil finishing diet on production performance and fillet LC-PUFA content and POP concentrations in hybrid striped bass (*Morone chrysops* × *Morone saxatilis*).

2. Methods

2.1. Feed formulation and preparation

Six isocaloric, isonitrogenous diets were formulated to vary only in the supplemental lipid used (Table 1). The lipid used in the control diet was menhaden fish oil (100% FO). This feed also served as the finishing feed used during the final eight weeks of the feeding trial. Four experimental diets were formulated to contain 50/50 or 25/75 blends of menhaden fish oil and coconut (50% CO and 75% CO) or unrefined, crude red palm oil (50% PO and 75% PO).

A positive control diet for POP accumulation was formulated to contain menhaden fish oil spiked with a PCB, OCP, and PBDE mix (100% FO Spike). The 100% FO control diet contained low concentrations of POP, therefore a spiked oil diet was incorporated to ensure that POP accumulation in fillets would be measureable for the majority of the compounds and congeners analyzed. The stocks used to spike the oil included a PCB stock containing the standards C-CCSEC calibration check solution and a custom S-19160 mixture collectively containing congeners 1, 8, 18, 28, 29, 44, 50, 52, 66, 70, 77, 87, 101, 104, 105, 118, 126, 128, 138, 153, 170, 180, 187, 188, 195, 200, 206, and 209; an OCP stock consisting of neat alpha hexachlorocyclohexane (BHC), beta BHC, gamma BHC, delta BHC, gamma chlordane, alpha chlordane, dichlorodiphenyltrichloroethane (DDT), dichlorodiphenyldichloroethane (DDD), and dichlorodiphenyldichloroethylene (DDE) dissolved in hexane; and a PBDE stock consisting of a BDE-EPA-SET containing congeners 28, 47, 99, 100, 153, 154, 183, and 209 (all from AccuStandard, New Haven, Connecticut, USA). The stocks were added to the oil at a concentration of 200, 300, and 60 ng/g respectively, and left uncapped, in a glass screw-top jar, on a stir plate overnight to ensure homogenous mixing and evaporation of solvent.

Feeds were prepared by combining ingredients in a commercial-grade cutter mixer (Hobart HCM-450 cutter mixer, Troy, Ohio, USA) and pelleted with a commercial-grade meat grinder (Cabelas #32 commercial grade electric grinder, Sidney, Nebraska, USA). Pellets from the grinder were dried in a commercial grade food dehydrator (Commercial Dehydrator Systems Incorporated Harvest saver R-5A, Eugene, Oregon, USA) at 37.8 °C until they reached ~94% dry matter. Dry feed was stored frozen (−20 °C) in plastic bags for the duration of the feeding trial.

2.2. Experimental design and feeding trial

Juvenile hybrid striped bass were stocked in a recirculating aquaculture system comprising 30, 270 L tanks, mechanical and biological filtration units, and a supplemental aeration system (initial individual weight = 21.1 ± 0.2 g, mean ± SE; six fish/tank). During the feeding trial, temperature and dissolved oxygen were monitored daily with a YSI 550A dissolved oxygen meter (Yellow Springs Instruments, Yellow Springs, Ohio, USA) and ammonia, nitrite, nitrate, and alkalinity

Table 1
Formulation and proximate composition of experimental diets. Values expressed as g/kg. Proximate composition listed on a dry matter basis.

Ingredient	100% FO	50% CO	75% CO	50% PO	75% PO	100% FO Spike
Fish meal[a]	200.0	200.0	200.0	200.0	200.0	200.0
Fish oil[a]	98.0	49.0	24.5	49.0	24.5	98.0 (spiked oil) [k]
Coconut oil[b]	0.0	49.0	73.5	0.0	0.0	0.0
Palm oil[b]	0.0	0.0	0.0	49.0	73.5	0.0
Corn gluten meal[c]	140.0	140.0	140.0	140.0	140.0	140.0
Wheat bran[d]	203.8	203.8	203.8	203.8	203.8	203.8
Soybean meal[d]	300.0	300.0	300.0	300.0	300.0	300.0
Carboxy methyl cellulose[e]	20.0	20.0	20.0	20.0	20.0	20.0
Sodium phosphate[f]	15.0	15.0	15.0	15.0	15.0	15.0
Calcium phosphate[f]	15.0	15.0	15.0	15.0	15.0	15.0
Choline chloride[f]	6.0	6.0	6.0	6.0	6.0	6.0
Mineral premix[g, h]	1.0	1.0	1.0	1.0	1.0	1.0
Vitamin premix[g, i]	1.2	1.2	1.2	1.2	1.2	1.2
Stay-C[j]	20.0	20.0	20.0	20.0	20.0	20.0
Proximate composition	Percent dry matter (except dry matter)					
Dry matter (%)	94.9 ± 0.4	94.4 ± 0.3	94.8 ± 0.3	94.9 ± 0.3	94.8 ± 0.3	93.9 ± 0.5
Lipid (%)	14.1 ± 0.3	14.9 ± 0.3	15.6 ± 0.3	15.2 ± 0.3	15.3 ± 0.3	14.6 ± 0.3
Protein (%)	40.9 ± 0.4	41.2 ± 0.4	40.3 ± 0.4	41.3 ± 0.4	42.0 ± 0.4	40.7 ± 0.4
Ash (%)	11.2 ± 0.1	11.5 ± 0.1	11.4 ± 0.1	11.2 ± 0.1	11.0 ± 0.1	10.9 ± 0.1

[a] Omega Protein Inc., Houston, Texas.
[b] Jungle Products, Inc., Bloomfield, New Jersey.
[c] Grain Processing Corporation, Muscatine, Iowa.
[d] Siemer Enterprises Inc., Teutopolis, Illinois.
[e] Acros Organics, Antwerpen, Belgium.
[f] MP Biomedicals LLC., Solon, Ohio.
[g] Purina Test Diet, Richmond, Indiana.
[h] Formulated to contain 24.89% zinc oxide, 14.93% ferrous sulfate, 3.47% manganese oxide, 0.96% cupric carbonate, 0.26% potassium iodide, 0.06% sodium selenate, and 0.03% cobalt carbonate in a cellulose base.
[i] Formulated to contain 25.00% L-ascorbyl-2-polyphosphate, 14.00% RRR-alpha tocopheryl acetate, 13.16% vitamin K, 12.50% inositol, 12.50% nicotinic acid, 7.50% riboflavin, 6.25% calcium pantothenate, 2.50% pyridoxine hydrochloride, 1.25% thiamine mononitrate, 1.00% vitamin A palmitate, 0.50% cyanocobalamin, 0.45% folic acid, 0.12% biotin, and 0.01% cholecalciferol in a cellulose base.
[j] Argent Laboratories, Redmond, Washington.
[k] Contents explained in the Methods section.