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Effects of different dietary ratios of linolenic to linoleic acids or docosahexaenoic to eicosapentaenoic acids on the growth and immune indices in grouper, *Epinephelus coioides*

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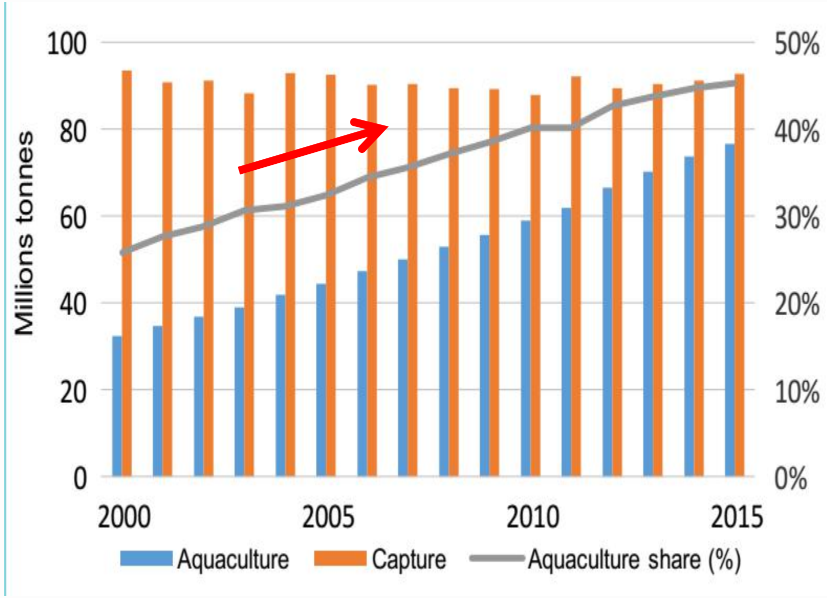
立项依据--研究背景

近年来，随着水产养殖业扩大，鱼油需求量增加，鱼油市场价格升高，用植物油替代鱼油已成为水产养殖业发展的一个趋势。



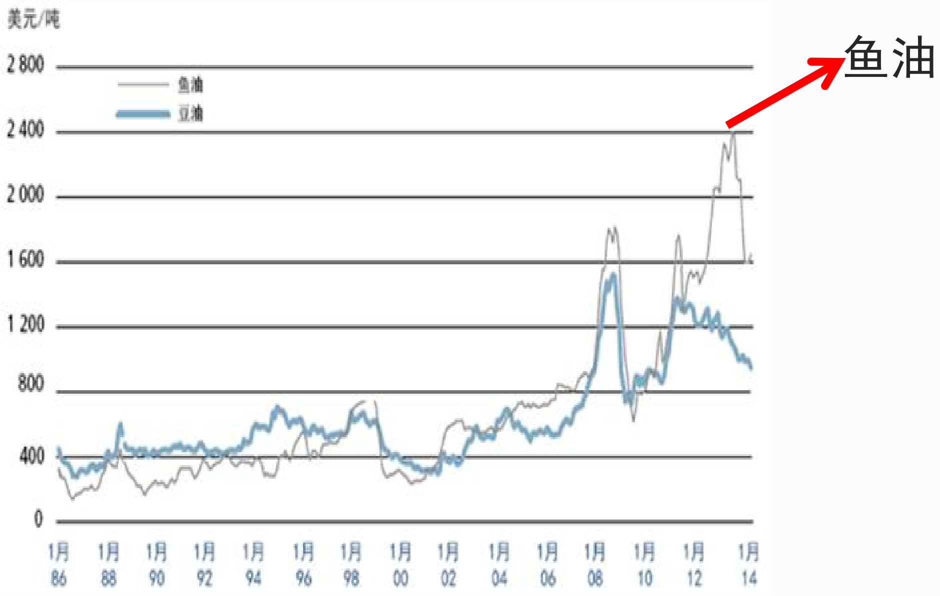


图2： 水产养殖与捕捞鱼类（2000-2015）　　图3： 鱼油豆油价格趋势（1986-2014）

An Overview of Recently Published Global Aquaculture Statistics.Food and Agriculture Organtion of the United Nations.FAO.2017

背景-选材鱼类

- 斜带石斑鱼（*Epinephelus coioides*）俗称“青斑”，是典型的海水肉食性硬骨鱼类，是我国南方沿海养殖的名贵经济鱼种。其脂肪酸去饱和酶和延长酶均已被克隆（李观贵等，2009）。斜带石斑鱼脂肪酸去饱和酶FADS2具有Δ6和Δ8活性，但活性均比较低，暗示其LC-PUFA合成能力可能比较有限 (Li el at,. 2014)。
- 据报道，在斜带石斑鱼中，植物油全部替代鱼油以鱼粉为基础的日粮不会对生长或饲料利用产生任何负面影响。因此，斜带石斑鱼是研究海水肉食性硬骨鱼类LC-PUFA合成关键酶转录调控网络的代表性鱼类。

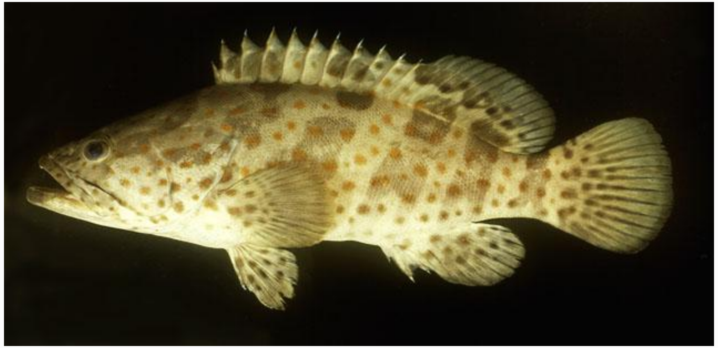


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Table 1
Ingredient and proximate composition of the experimental diets.

	Dietary treatments						
	D0	D1	D2	D3	D4	D5	D6
Ingredient (g/kg of dry weight)							
Casein	400.0	400.0	400.0	400.0	400.0	400.0	400.0
Gelatin	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Corn starch	200.0	200.0	200.0	200.0	200.0	200.0	200.0
Cellulose	24.0	24.0	24.0	24.0	24.0	24.0	24.0
Mineral premixe[a]	80.0	80.0	80.0	80.0	80.0	80.0	80.0
Vitamin premixe[b]	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Sodium carboxymethyl cellulose	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Attractant[c]	45.0	45.0	45.0	45.0	45.0	45.0	45.0
Ascorbic phosphate ester	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Choline chloride	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Antioxidant	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Fish oil[d]	100.0	0.0	0.0	0.0	0.0	0.0	0.0
Perilla oil[e]	0.0	50.9	63.8	86.8	0.0	0.0	0.0
Corn oil[f]	0.0	49.1	36.2	13.2	74.0	74.0	74.0
DHA-enriched oil[g]	0.0	0.0	0.0	0.0	8.7	17.3	20.8
EPA-enriched oil[h]	0.0	0.0	0.0	0.0	17.3	8.7	5.2
Proximate composition (% dry weight)							
Moisture	12.0	10.0	11.0	10.0	9.0	9.0	9.0
Crude protein	55.6	54.7	54.9	55.5	55.7	55.3	54.9
Crude lipid	10.8	10.8	10.7	10.8	10.8	10.7	10.7
Ash	5.6	5.5	5.5	5.5	5.6	5.6	5.5

表1 实验饲料成分及组成

Table 2
Fatty acid composition (% total fatty acids) of the experimental diets for grouper, *Epinphelus coioides*.

Fatty acid	Dietary treatments						
	D0	D1	D2	D3	D4	D5	D6
14:0	3.54	0.94	0.31	0.71	0.38	0.57	0.34
16:0	17.32	20.81	12.95	18.46	12.69	13.21	12.18
18:0	5.96	8.70	5.83	13.09	5.16	4.45	3.86
16:1n-7	3.96	0.59	1.17	0.42	0.21	0.51	0.23
18:1n-9	23.63	28.79	21.54	15.70	24.50	22.37	24.88
18:2n-6 (LA)	21.94	22.44	24.98	13.04	38.21	38.51	37.71
18:3n-6	0.73	nd	nd	nd	nd	nd	nd
20:2n-6	0.59	nd	nd	nd	nd	nd	nd
20:3n-6	0.43	nd	nd	nd	nd	nd	nd
20:4n-6 (ARA)	1.32	nd	nd	nd	nd	nd	nd
18:3n-3 (ALA)	5.35	16.12	33.65	37.13	1.38	1.12	0.82
20:3n-3	0.13	nd	nd	nd	nd	nd	nd
20:5n-3 (EPA)	5.33	nd	nd	nd	7.96	5.42	4.44
22:5n-3 (DPA)	1.54	nd	nd	nd	0.97	0.61	0.60
22:6n-3 (DHA)	7.01	nd	nd	nd	7.97	10.49	12.54
∑ SFA	26.82	30.45	19.09	32.26	18.23	18.23	16.38
∑ MUFA	27.59	29.38	22.71	16.12	24.71	22.88	25.11
∑ n-6 PUFA	25.01	22.44	24.98	13.04	38.21	38.51	37.71
∑ n-3 PUFA	19.36	16.12	33.65	37.13	18.28	17.64	19.22
n-3/n-6 PUFA	0.77	0.72	1.35	2.85	0.49	0.46	0.51
ALA/LA	0.24	0.72	1.35	2.85	0.04	0.03	0.02
DHA/EPA	1.32	/	/	/	1.00	1.93	2.83
∑ n-3 LC-PUFA	13.88	/	/	/	16.90	16.52	17.58

nd: not detected (<0.01).

表2 实验饲料脂肪酸组成

D0（对照组）以鱼油为脂肪源；D1-D3以紫苏油和玉米油为脂肪源，ALA / LA比为1.0,2.0和3.0（分别为0.72,1.35和2.85）； 而D4-D6以玉米油和纯化的富含EPA/DHA的油为脂肪源，其DHA / EPA比率分别为1.0,2.0和3.0（分别为1.00,1.93和2.83）.D4，D5和D6中的n-3 LC -PUFA约为干重的1.83％。

Table 3
Growth performance, feed utilization efficiency and survival rate of juvenile grouper fed different diets for 9 weeks.[1]

	Dietary treatments						
	D0	D1	D2	D3	D4	D5	D6
Initial weight (g)	9.61 ± 0.01	9.61 ± 0.01	9.69 ± 0.05	9.69 ± 0.03	9.73 ± 0.04	9.71 ± 0.06	9.72 ± 0.05
Final weight (g)	23.16 ± 1.72^{ab}	20.33 ± 0.71^{b}	21.12 ± 0.96^{b}	21.01 ± 0.86^{b}	26.64 ± 1.84^{a}	25.91 ± 1.07^{a}	23.10 ± 1.83^{ab}
WG (%)[2]	141.19 ± 17.94^{ab}	111.81 ± 7.43^{b}	119.22 ± 9.87^{b}	117.26 ± 8.3^{b}	174.77 ± 19.95^{a}	167.3 ± 12.62^{a}	137.98 ± 18.11^{ab}
SGR (% day^{-1})[3]	1.40 ± 0.11^{ab}	1.21 ± 0.05^{b}	1.25 ± 0.07^{b}	1.24 ± 0.06^{b}	1.61 ± 0.11^{a}	1.56 ± 0.07^{a}	1.38 ± 0.13^{ab}
FCR[4]	1.67 ± 0.18^{ab}	2.13 ± 0.25^{a}	1.97 ± 0.19^{ab}	1.99 ± 0.12^{ab}	1.58 ± 0.15^{b}	1.62 ± 0.08^{ab}	1.71 ± 0.01^{ab}
SR (%)[5]	86.67 ± 5.81	76.00 ± 10.07	88.00 ± 4.00	82.67 ± 5.33	85.33 ± 1.33	86.67 ± 2.67	80.00 ± 8.33

[1] Values are means ± SE from three treatments of fish (n = 3). Different superscripts in the same rows indicate significant difference at $P < 0.05$.
[2] Weight gain (WG, %) = 100 × (final weight − initial weight) × (initial weight)$^{-1}$.
[3] Specific growth rate (SGR, % day^{-1}) = 100 × [Ln (final weight) − Ln (initial weight)] × (days of feeding trial)$^{-1}$.
[4] Feed conversion rate (FCR) = (total dry weight of feed fed) × (final weight − initial weight)$^{-1}$.
[5] Survival rate (SR, %) = 100 × (final fish number) × (initial fish number)$^{-1}$.

WG-增重率
SGR-特定生长率
FCR-饲料系数
SR-存活率

表3 石斑鱼幼鱼饲喂不同日粮的生长性能，饲料利用率和成活率

1. 饲喂D1，D2和D3的鱼的WG和SGR显着低于饲喂D4和D5日粮的鱼，但与D0和D6组相比，没有显着差异。
2. D4组饲料的FCR最低，显着低于饲喂D1饲料的鱼。
3. 随着DHA / EPA比例的增加，WG和SGR略有下降，FCR上升。

Table 4
Proximate composition of whole body fish fed different diets for 9 weeks.[1]

	Dietary treatments						
	D0	D1	D2	D3	D4	D5	D6
Moisture (%)	72.79 ± 1.68	73.56 ± 0.76	73.22 ± 0.25	72.48 ± 1.09	71.03 ± 0.55	73.45 ± 1.32	73.75 ± 1.25
Protein (%)	18.98 ± 0.45	18.09 ± 0.81	18.29 ± 0.59	18.41 ± 0.24	18.78 ± 0.41	18.63 ± 0.15	18.39 ± 0.34
Lipid (%)	4.85 ± 0.17	4.69 ± 0.25	4.70 ± 0.51	4.67 ± 0.36	4.76 ± 0.21	4.71 ± 0.43	4.74 ± 0.32
Ash (%)	5.62 ± 0.12	5.51 ± 0.14	5.57 ± 0.09	5.54 ± 0.11	5.63 ± 0.15	5.60 ± 0.13	5.58 ± 0.12

[1] Values are means ± SE from three treatments of fish (n = 3) with free fish per treatment. Different superscripts in the same rows indicate significant difference at $P < 0.05$.

表4 饲喂不同处理组的全鱼组分分析

表5 不同处理组石斑鱼幼鱼肝脏脂肪酸组成分析

Table 5

Liver fatty acid composition of juvenile grouper fed different diets for 9 weeks.[1]

Fatty acid	Initial fish	Dietary treatments						
		D0	D1	D2	D3	D4	D5	D6
14:0	2.36	2.23 ± 0.13	2.05 ± 0.42	1.74 ± 0.43	1.58 ± 0.39	2.59 ± 0.71	1.88 ± 0.30	1.05 ± 0.06
16:0	34.48	25.86 ± 1.15	23.12 ± 3.59	21.08 ± 1.96	21.58 ± 1.72	28.91 ± 1.54	29.13 ± 1.60	20.08 ± 0.06
18:0	10.51	12.96 ± 0.89	7.77 ± 0.42	8.67 ± 1.17	10.10 ± 3.04	10.11 ± 0.85	10.61 ± 1.33	11.63 ± 0.38
∑SFA	47.35	41.06 ± 0.73	32.94 ± 4.29	31.50 ± 1.85	33.27 ± 2.77	41.62 ± 3.83	41.63 ± 0.84	32.76 ± 0.42
16:1n-7	5.36	3.74 ± 0.43^{ab}	1.65 ± 0.33^{bc}	1.31 ± 0.34^{c}	1.67 ± 0.20^{bc}	4.01 ± 0.79^{a}	2.97 ± 0.47^{abc}	1.02 ± 0.13^{c}
18:1n-9	21.73	21.43 ± 0.89^{a}	23.65 ± 1.97^{a}	19.29 ± 0.43^{ab}	15.55 ± 1.14^{b}	22.69 ± 1.32^{a}	21.02 ± 1.55^{ab}	18.74 ± 0.13^{ab}
20:1n-9	0.41	0.75 ± 0.18	0.28 ± 0.11	0.42 ± 0.03	0.41 ± 0.25	0.31 ± 0.10	0.45 ± 0.10	0.86 ± 0.04^{b}
∑MUFA	27.64	25.92 ± 1.31^{a}	25.58 ± 1.80^{a}	21.01 ± 0.77^{ab}	17.62 ± 1.08^{b}	27.01 ± 1.99^{a}	24.30 ± 1.86^{ab}	20.21 ± 0.31^{ab}
18:2n-6 (LA)	2.04	12.28 ± 0.87^{c}	22.41 ± 2.89^{ab}	21.18 ± 1.15^{ab}	15.63 ± 1.12^{c}	14.92 ± 2.43^{bc}	16.60 ± 1.26^{bc}	23.75 ± 0.76^{abc}
18:3n-6	0.32	0.46 ± 0.04	0.42 ± 0.06	0.42 ± 0.02	0.42 ± 0.01	0.41 ± 0.05	0.46 ± 0.05	0.39 ± 0.02
20:2n-6	0.43	0.74 ± 0.18	0.35 ± 0.07	0.41 ± 0.03	0.41 ± 0.12	0.31 ± 0.11	0.30 ± 0.09	0.35 ± 0.04
20:3n-6	0.06	0.01 ± 0.01	nd	nd	nd	nd	nd	nd
20:4n-6 (ARA)	2.03	1.21 ± 0.20^{ab}	0.71 ± 0.23^{b}	1.68 ± 0.47^{a}	1.36 ± 0.32^{ab}	0.74 ± 0.17^{b}	0.67 ± 0.10^{b}	1.12 ± 0.26^{ab}
∑n-6 PUFA	4.88	14.60 ± 0.69^{c}	23.79 ± 2.88^{ab}	23.50 ± 1.20^{ab}	17.63 ± 0.81^{bc}	16.46 ± 2.69^{bc}	18.23 ± 1.38^{abc}	25.17 ± 0.78^{a}
∑n-6 LC-PUFA	2.84	1.86 ± 0.21	0.97 ± 0.14	1.90 ± 0.49	1.58 ± 0.36	1.13 ± 0.23	1.16 ± 0.17	1.02 ± 0.16
18:3n-3 (ALA)	2.10	2.73 ± 0.30^{b}	13.09 ± 1.99^{a}	17.96 ± 0.84^{a}	21.99 ± 2.84^{a}	1.96 ± 0.41^{b}	1.44 ± 0.16^{b}	1.53 ± 0.16^{b}
20:3n-3	0.17	0.36 ± 0.03^{a}	0.24 ± 0.02^{ab}	0.27 ± 0.02^{ab}	0.17 ± 0.02^{b}	0.25 ± 0.02^{ab}	0.26 ± 0.01^{ab}	0.20 ± 0.08^{ab}
20:5n-3 (EPA)	4.47	4.05 ± 0.12^{a}	0.37 ± 0.18^{b}	0.96 ± 0.54^{b}	1.36 ± 0.68^{b}	3.97 ± 0.67^{a}	3.34 ± 0.40^{a}	4.17 ± 0.02^{a}
22:5n-3 (DPA)	1.96	1.28 ± 0.08^{a}	0.24 ± 0.11^{b}	0.43 ± 0.09^{b}	0.47 ± 0.16^{b}	1.30 ± 0.31^{a}	1.30 ± 0.31^{a}	1.66 ± 0.14^{a}
22:6n-3 (DHA)	8.74	8.46 ± 0.53^{b}	1.32 ± 0.70^{c}	2.59 ± 0.51^{c}	2.82 ± 1.09^{c}	6.46 ± 1.42^{b}	8.49 ± 0.98^{b}	12.65 ± 0.26^{a}
∑n-3 PUFA	17.44	16.88 ± 0.90^{bcd}	15.26 ± 2.14^{cd}	22.20 ± 1.15^{b}	28.60 ± 2.24^{a}	13.93 ± 2.78^{d}	14.83 ± 1.34^{cd}	20.22 ± 0.40^{bc}
∑n-3 LC-PUFA	15.34	14.15 ± 0.64^{b}	2.18 ± 1.01^{c}	4.24 ± 1.15^{c}	4.81 ± 1.91^{c}	11.98 ± 2.42^{b}	13.39 ± 1.42^{b}	18.68 ± 0.25^{a}
∑PUFA	22.32	31.49 ± 1.59^{b}	39.06 ± 5.02^{ab}	45.70 ± 2.33^{a}	46.52 ± 2.70^{a}	30.40 ± 5.45^{b}	33.05 ± 2.67^{b}	45.38 ± 0.52^{ab}
∑LC-PUFA	18.18	16.01 ± 0.53^{ab}	3.14 ± 0.87^{c}	6.14 ± 1.64^{c}	6.41 ± 1.95^{c}	13.11 ± 2.65^{b}	14.56 ± 1.57^{b}	19.70 ± 0.33^{a}
∑DHA + EPA	13.21	12.51 ± 0.63^{b}	1.69 ± 0.88^{c}	3.54 ± 1.04^{c}	4.17 ± 1.76^{c}	10.43 ± 2.09^{b}	11.83 ± 1.36^{b}	16.83 ± 0.26^{a}

nd: not detected.

[1] Values are means ± SE from three treatments of fish (n = 3) with four fish per treatment. Different superscripts in the same rows indicate significant difference at $P < 0.05$.

Table 6

Muscle fatty acid composition of juvenile grouper fed different diets for 9 weeks.

表6 不同处理组石斑鱼幼鱼肌肉脂肪酸组成分析

Fatty acid	Initial fish	Dietary treatments						
		D0	D1	D2	D3	D4	D5	D6
14:0	2.52	2.43 ± 0.20^{a}	1.06 ± 0.09^{b}	1.34 ± 0.37^{b}	1.44 ± 0.30^{b}	1.15 ± 0.11^{b}	1.17 ± 0.09^{b}	1.15 ± 0.06^{b}
16:0	25.95	21.52 ± 0.65^{a}	17.36 ± 0.56^{b}	17.66 ± 0.56^{b}	17.25 ± 1.01^{b}	18.64 ± 0.53^{ab}	18.67 ± 0.25^{ab}	17.22 ± 0.64^{b}
18:0	10.26	8.13 ± 0.48	8.82 ± 0.67	8.10 ± 1.17	8.03 ± 0.71	7.06 ± 1.13	5.93 ± 0.33	5.62 ± 0.18
∑SFA	38.73	32.07 ± 0.98^{a}	27.24 ± 1.11^{ab}	27.09 ± 0.77^{ab}	26.71 ± 2.00^{ab}	26.84 ± 1.36^{ab}	25.77 ± 0.21^{b}	23.98 ± 0.88^{b}
16:1n-7	6.67	4.43 ± 0.12^{a}	1.83 ± 0.06^{b}	2.04 ± 0.28^{b}	2.74 ± 0.62^{b}	2.12 ± 0.08^{b}	2.08 ± 0.13^{b}	1.95 ± 0.21^{b}
18:1n-9	14.14	25.21 ± 0.08^{a}	18.41 ± 0.81^{cd}	19.65 ± 0.71^{bcd}	16.74 ± 0.74^{d}	22.85 ± 1.75^{abc}	24.41 ± 1.27^{ab}	25.25 ± 1.12^{a}
20:1n-9	0.15	0.47 ± 0.02	0.56 ± 0.05	0.51 ± 0.15	0.36 ± 0.09	0.45 ± 0.19	0.33 ± 0.06	0.16 ± 0.06
∑MUFA	20.96	30.10 ± 0.06^{a}	20.79 ± 0.81^{de}	22.20 ± 0.85^{cde}	19.84 ± 0.34^{e}	25.42 ± 1.55^{bcd}	26.82 ± 1.34^{abc}	27.36 ± 0.91^{ab}
18:2n-6 (LA)	2.30	16.42 ± 0.73^{de}	21.88 ± 0.98^{bc}	20.98 ± 0.47^{cd}	13.42 ± 1.94^{e}	25.34 ± 1.32^{abc}	27.88 ± 0.88^{a}	26.99 ± 0.55^{ab}
18:3n-6	0.53	0.52 ± 0.03^{a}	0.47 ± 0.04^{ab}	0.45 ± 0.03^{ab}	0.45 ± 0.02^{ab}	0.39 ± 0.01^{b}	0.40 ± 0.01^{b}	0.38 ± 0.02^{b}
20:2n-6	0.51	0.38 ± 0.03^{a}	0.29 ± 0.03^{b}	0.26 ± 0.02^{b}	0.25 ± 0.02^{b}	0.24 ± 0.02^{b}	0.25 ± 0.01^{b}	0.24 ± 0.01^{b}
20:3n-6	0.96	0.06 ± 0.01^{b}	nd	nd	nd	0.05 ± 0.01^{b}	0.06 ± 0.01^{b}	0.08 ± 0.03^{b}
20:4n-6 (ARA)	2.66	1.55 ± 0.35	1.97 ± 0.27	1.80 ± 0.57	1.77 ± 0.22	1.37 ± 0.41	0.93 ± 0.10	1.08 ± 0.17
∑n-6 PUFA	6.69	18.94 ± 0.57^{d}	24.62 ± 0.93^{bc}	23.49 ± 0.22^{c}	15.89 ± 2.06^{d}	[illegible].38 ± 0.91^{ab}	29.51 ± 0.98^{a}	28.77 ± 0.36^{a}
∑n-6 LC-PUFA	4.13	1.99 ± 0.35	2.27 ± 0.30	2.06 ± 0.59	2.02 ± 0.21	1.65 ± 0.43	1.24 ± 0.11	1.40 ± 0.20
18:3n-3 (ALA)	1.31	4.78 ± 0.53^{c}	15.83 ± 1.50^{b}	17.59 ± 1.58^{b}	23.76 ± 3.06^{a}	2.21 ± 0.22^{c}	1.22 ± 0.10^{c}	2.53 ± 0.15^{c}
20:3n-3	0.44	0.55 ± 0.03^{ab}	0.28 ± 0.08^{ab}	0.23 ± 0.07^{b}	0.78 ± 0.37^{a}	0.50 ± 0.07^{ab}	0.55 ± 0.01^{ab}	0.50 ± 0.06^{ab}
20:5n-3 (EPA)	7.65	3.65 ± 0.15^{ab}	2.15 ± 0.45^{cd}	1.56 ± 0.17^{d}	2.54 ± 1.00^{bcd}	5.57 ± 0.19^{a}	4.01 ± 0.04^{ab}	3.10 ± 0.10^{abc}
22:5n-3 (DPA)	2.69	1.44 ± 0.06^{ab}	0.93 ± 0.11^{b}	0.86 ± 0.13^{b}	1.25 ± 0.44^{ab}	1.67 ± 0.06^{a}	1.68 ± 0.04^{a}	1.72 ± 0.08^{a}
22:6n-3 (DHA)	18.15	7.45 ± 0.23^{bc}	6.19 ± 0.77^{c}	5.40 ± 1.06^{c}	6.42 ± 1.04^{c}	9.38 ± 0.87^{ab}	9.42 ± 0.38^{ab}	10.47 ± 0.27^{a}
∑n-3 PUFA	30.24	17.86 ± 0.48^{c}	25.39 ± 1.33^{b}	25.63 ± 0.22^{b}	34.74 ± 0.67^{a}	19.34 ± 1.03^{c}	16.87 ± 0.49^{c}	18.31 ± 0.46^{c}
∑n-3 LC-PUFA	28.93	13.08 ± 0.08^{ab}	9.56 ± 1.21^{bc}	8.05 ± 1.43^{c}	10.98 ± 2.80^{bc}	17.12 ± 0.82^{a}	15.65 ± 0.42^{ab}	15.79 ± 0.35^{ab}
∑PUFA	36.93	36.79 ± 0.97^{d}	50.35 ± 0.71^{ab}	49.37 ± 0.11^{abc}	50.97 ± 2.54^{a}	46.71 ± 0.14^{bc}	46.38 ± 1.41^{c}	47.08 ± 0.10^{abc}
∑LC-PUFA	33.06	15.07 ± 0.42^{abc}	11.83 ± 1.47^{cd}	10.11 ± 2.00^{d}	13.00 ± 2.64^{bcd}	18.78 ± 1.25^{a}	16.90 ± 0.53^{ab}	17.19 ± 0.54^{ab}
∑DHA + EPA	25.80	11.09 ± 0.08^{bc}	8.34 ± 1.10^{cd}	6.96 ± 1.23^{d}	8.95 ± 2.04^{cd}	14.95 ± 0.71^{a}	13.42 ± 0.40^{ab}	13.57 ± 0.35^{ab}

nd: not detected.

[1] Values are means ± SE from three treatments of fish (n = 3) with four fish per treatment. Different superscripts in the same rows indicate significant difference at $P < 0.05$.

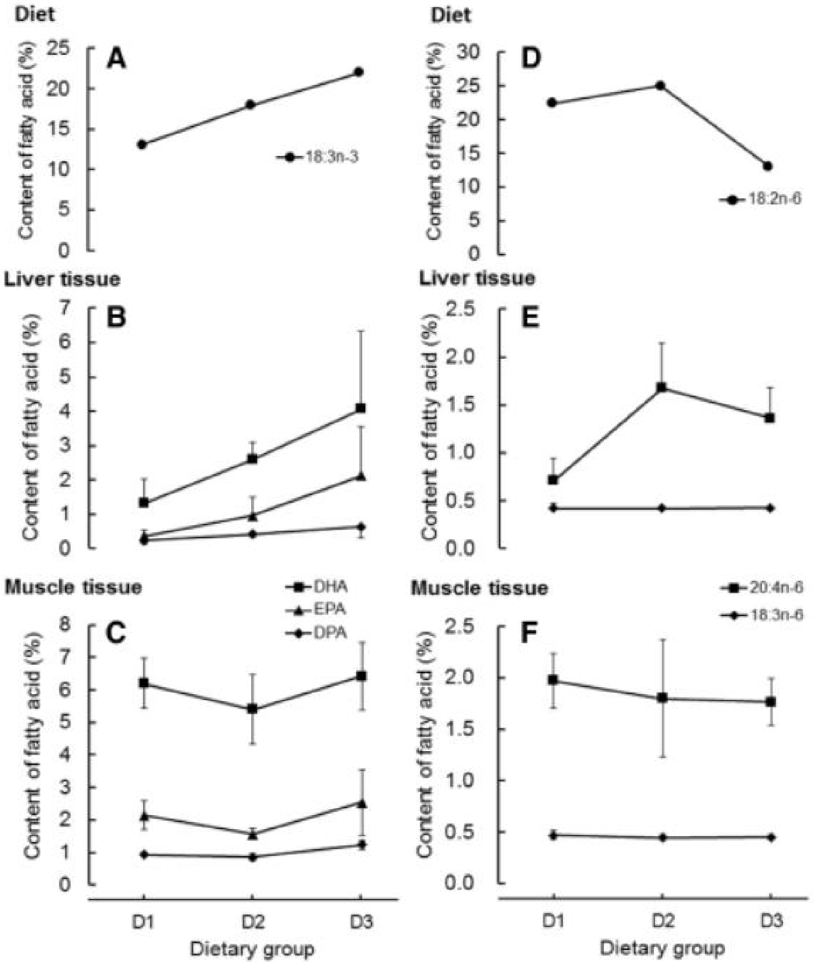

Fig. 1. The integrated results of Tables 2, 5 and 6, which showed that the hepatic contents of n-3 PUFA (B) and n-6 PUFA (E) in fish fed D1–D3 displayed parallel change pattern with the respective dietary levels of 18:3n-3 (A) and 18:2n-6 (D). While the muscle contents of n-3 PUFA (C) and n-6 PUFA (F) displayed unapparent change trend with the respective dietary levels of 18:3n-3 (A) and 18:2n-6 (D) in fish fed D1–D3. Values in B–C and E–F are mean ± SE of 9 samples from 3 replicate groups.

Table 7

Albumin, immunoglobulin M (IgM), lysozyme (LZM) activity, alkaline/acid phosphatase (AKP/ACP) activity in serum of juvenile grouper fed different diets for 9 weeks.[1]

Immune parameters	Dietary treatments						
	D0	D1	D2	D3	D4	D5	D6
Albumin ($g\ l^{-1}$)	10.21 ± 0.62^{a}	6.91 ± 0.31^{c}	7.52 ± 0.34^{c}	7.29 ± 0.38^{c}	10.36 ± 0.51^{a}	8.06 ± 0.49^{bc}	9.14 ± 0.40^{ab}
IgM ($mg\ l^{-1}$)	18.04 ± 0.82^{ab}	12.71 ± 2.01^{c}	15.37 ± 0.49^{bc}	14.38 ± 0.71^{bc}	17.91 ± 0.59^{ab}	18.22 ± 0.68^{a}	16.54 ± 1.32^{ab}
LZM activity ($U\ ml^{-1}$)	297.27 ± 29.08^{a}	204.16 ± 4.77^{ab}	220.66 ± 28.55^{ab}	176.67 ± 16.25^{b}	218.20 ± 24.06^{ab}	239.87 ± 21.68^{ab}	197.83 ± 8.43^{ab}
AKP activity (U/100 ml)	20.68 ± 0.71^{ab}	16.61 ± 3.35^{b}	21.27 ± 1.23^{ab}	21.83 ± 0.30^{ab}	27.87 ± 5.38^{a}	21.87 ± 3.09^{ab}	24.24 ± 1.82^{ab}
ACP activity (U/100 ml)	2.83 ± 0.06	2.65 ± 0.22	3.13 ± 0.61	2.63 ± 0.16	3.17 ± 0.07	3.52 ± 0.51	2.95 ± 0.49

[1] Values are means ± SE from three treatments of fish (n = 3) with four fish per treatment. Different superscripts in the same row indicate significant difference at $P < 0.05$.

表7 不同处理组石斑鱼幼鱼血清各种酶活性

Albumin-血清白蛋白
IgM-免疫球蛋白M
LZM-溶菌酶
AKP-碱性磷酸酶
ACP-酸性磷酸酶

1. D4组鱼血清白蛋白浓度最高，其次为对照组鱼体，均显着高于D1-D3和D5组；
2. D5组IgM浓度最高，显着高于D1-D3组，但与D0，D4和D6组相比无显着差异；
3. 对照组LZM活性最高，显着高于D3组；
4. D4组鱼类AKP活性最高，D1组最低。

4/讨论

讨论

- 石斑鱼具有将LA和ALA转化为LC-PUFA的能力，但能力有限。
- 添加EPA和DHA可显著增强其免疫指数，在某种程度上反映了鱼类的健康状况。
- 其生长最适当的DHA / EPA比率为是1.0或2.0。

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