河南师范大学
NENAN NORMAL UNIVERSITY

鱼类脂代谢及其营养调控

报告人：谢帝芝

厚德博学·止于至善

1、脂及其代谢

1）脂质基本概念

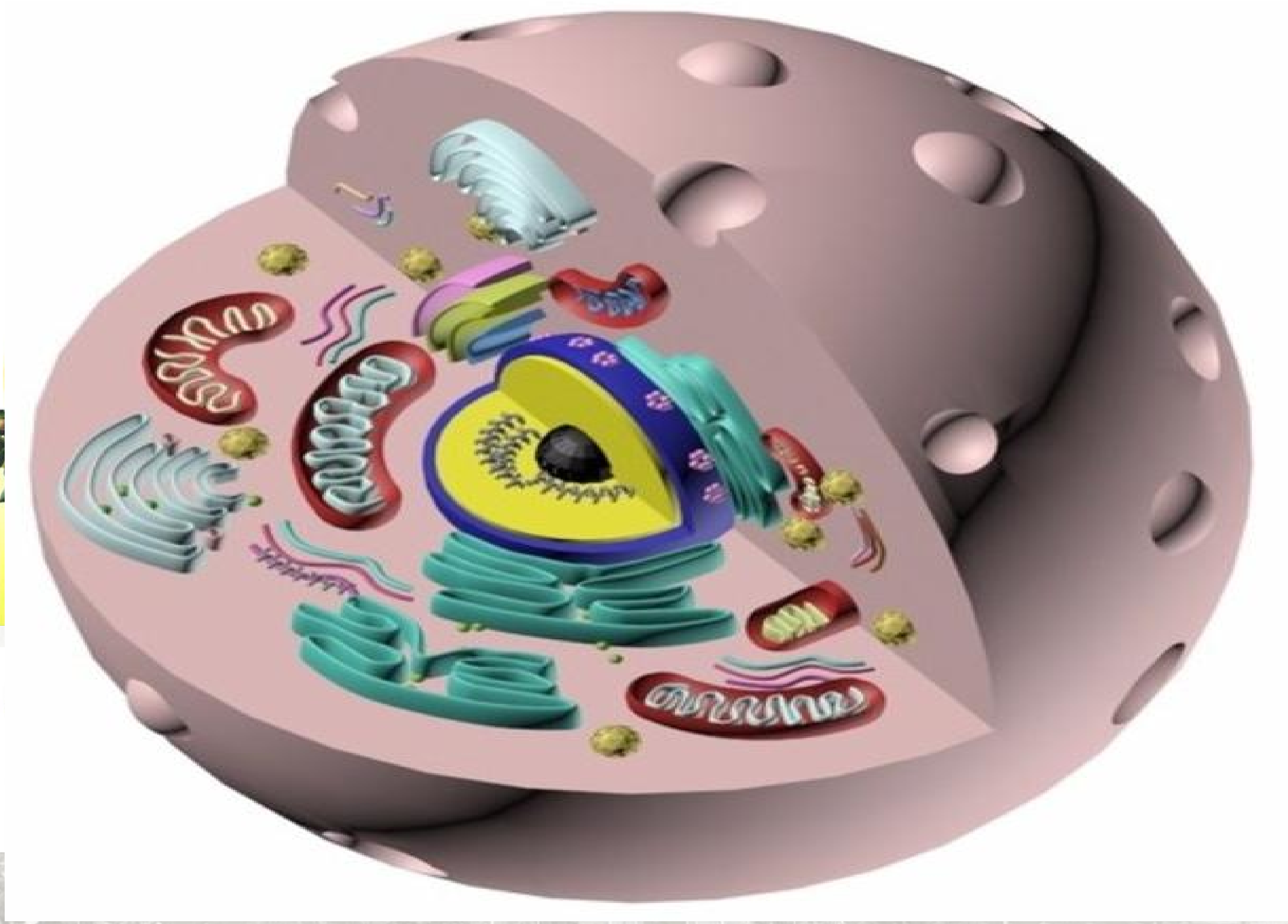
2）脂质代谢

3）脂质感应

1. 脂质及其代谢

植物源

动物源



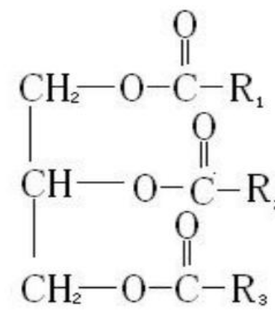
脂 Fats

1.1 脂质基本概念

脂质（Lipid）是一类由**脂肪酸**和**醇**作用生成的酯及其衍生物，且不溶于水而易溶于有机溶剂。

1. 脂质分类：

脂质
- 简单脂：甘油三酯或三酰甘油酯、生物蜡；
- 复合脂：磷脂、糖脂；
- 衍生脂质：类固醇、萜、脂肪酸



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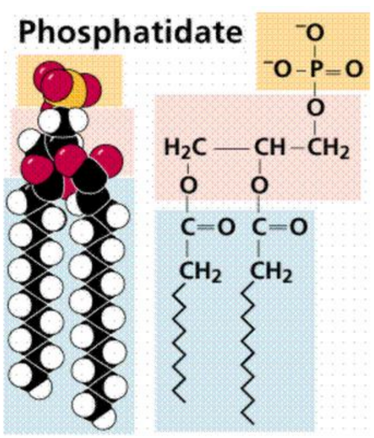

1.2 脂质代谢

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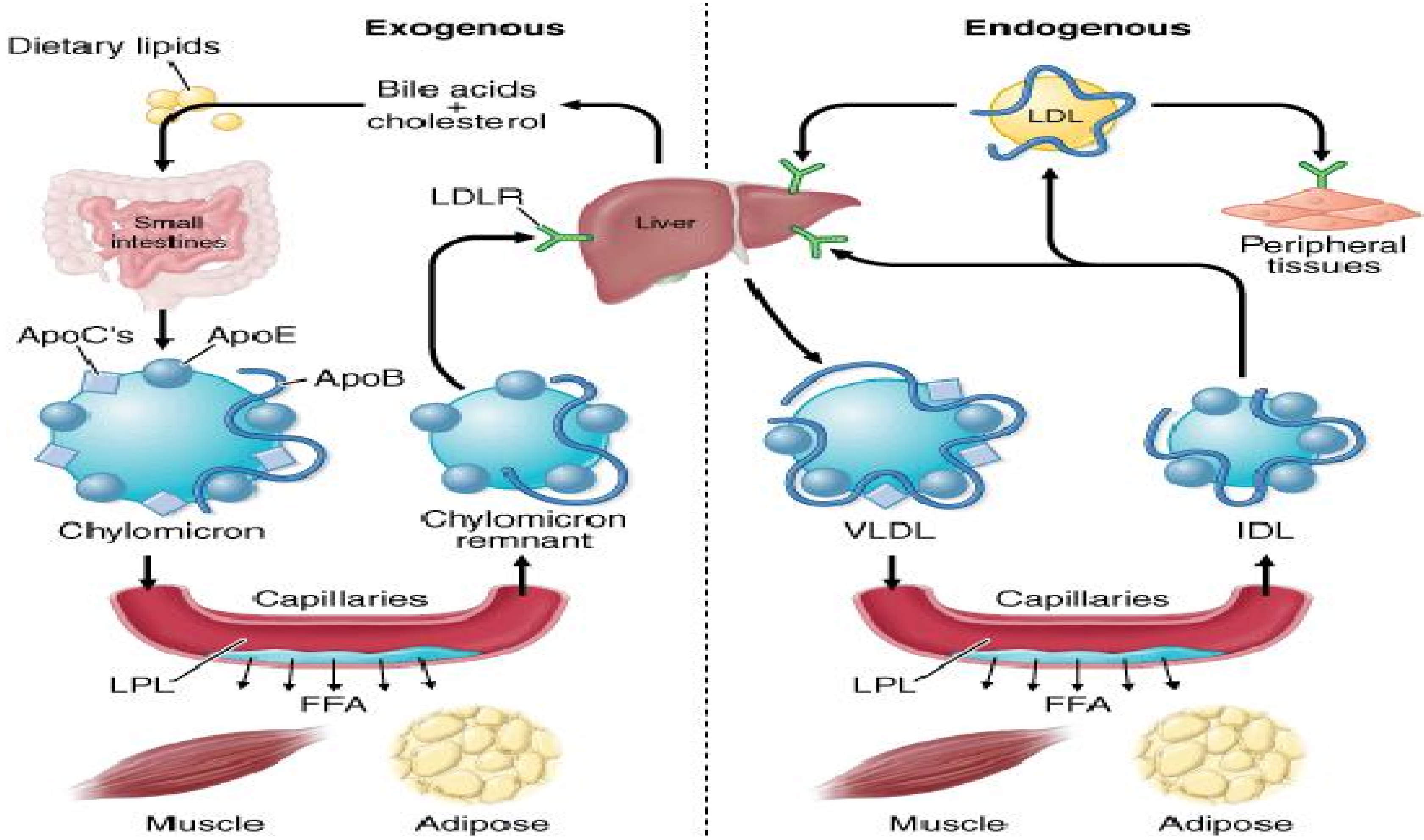
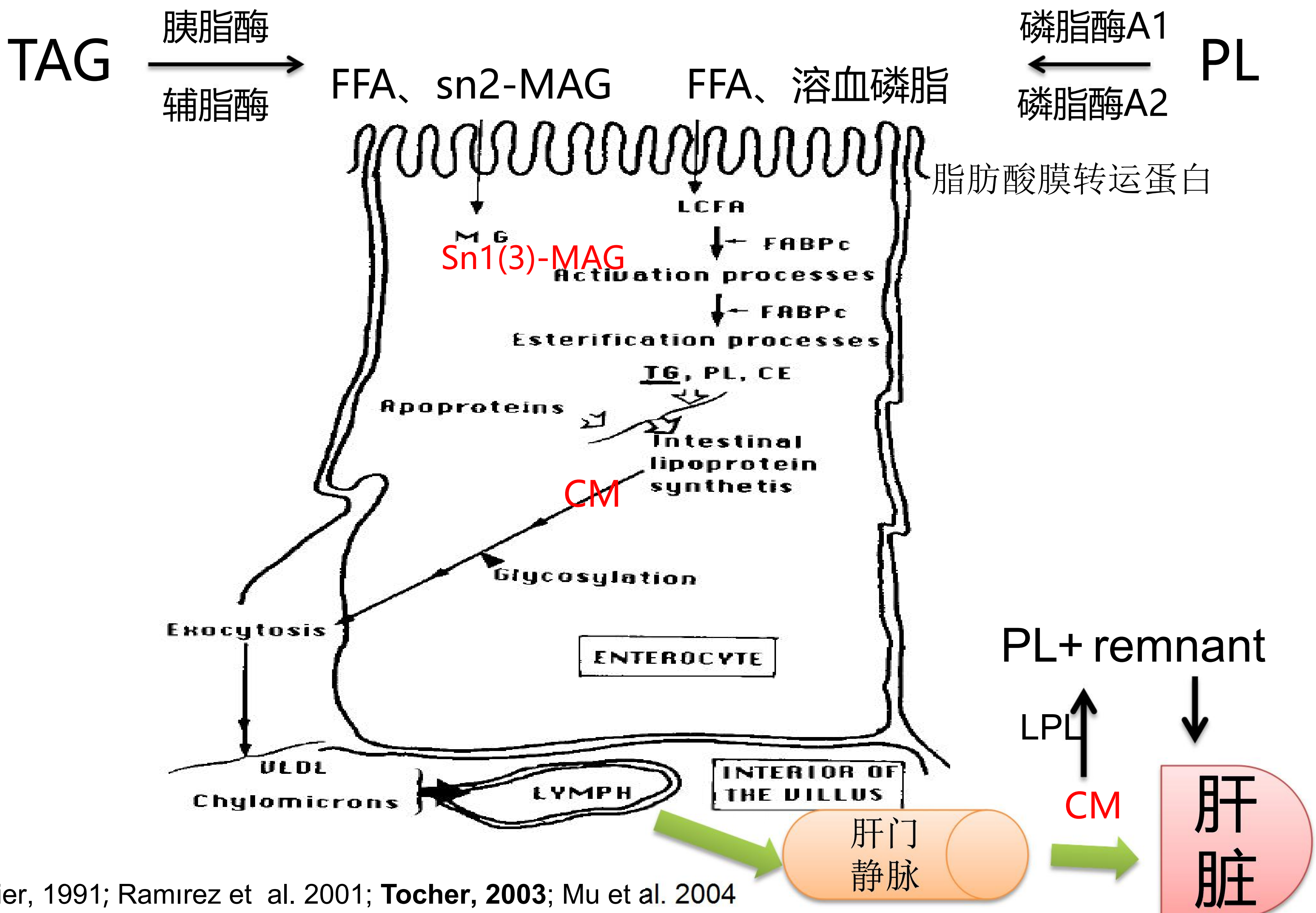
脂代谢途径图

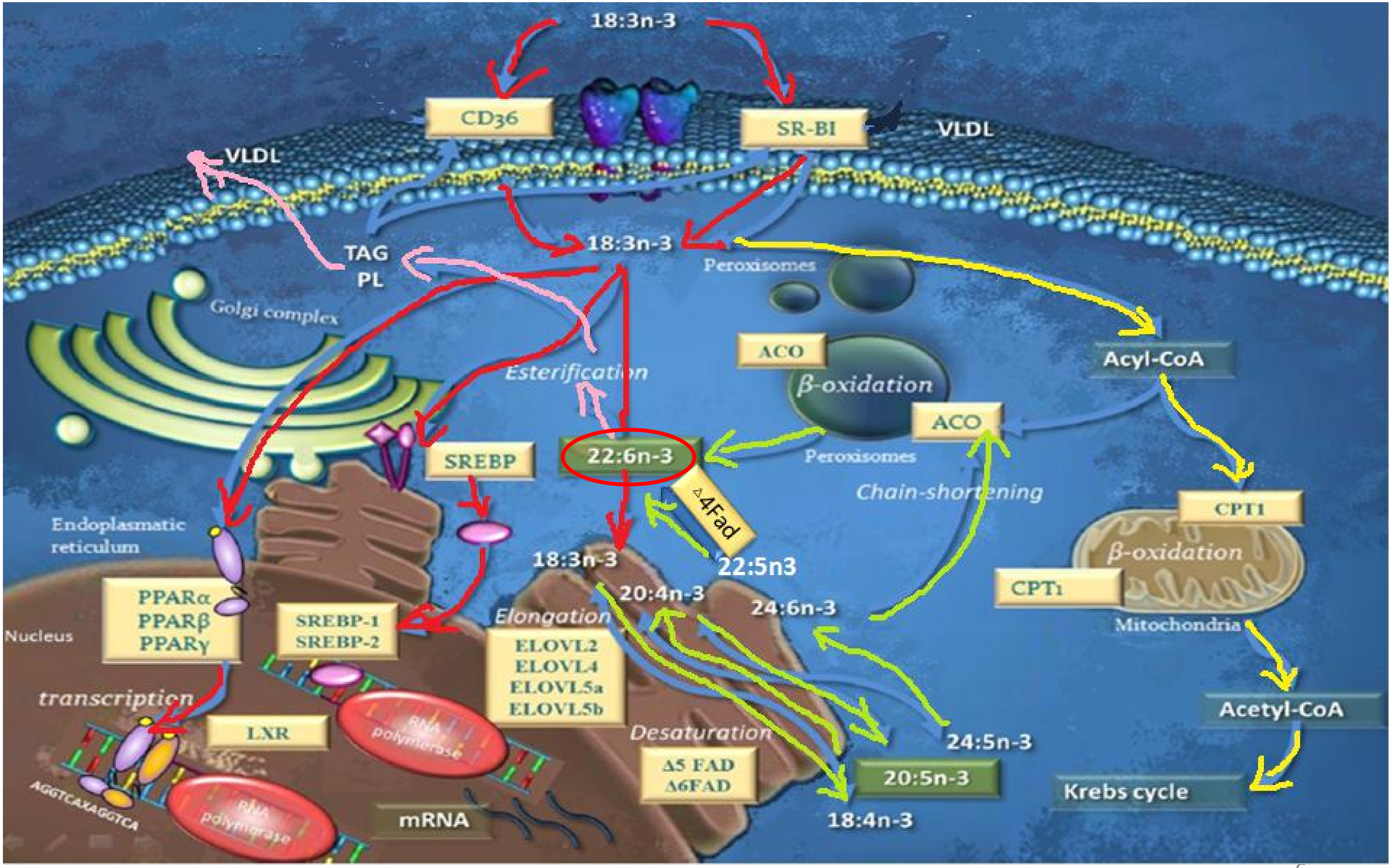


1）外源脂质代谢



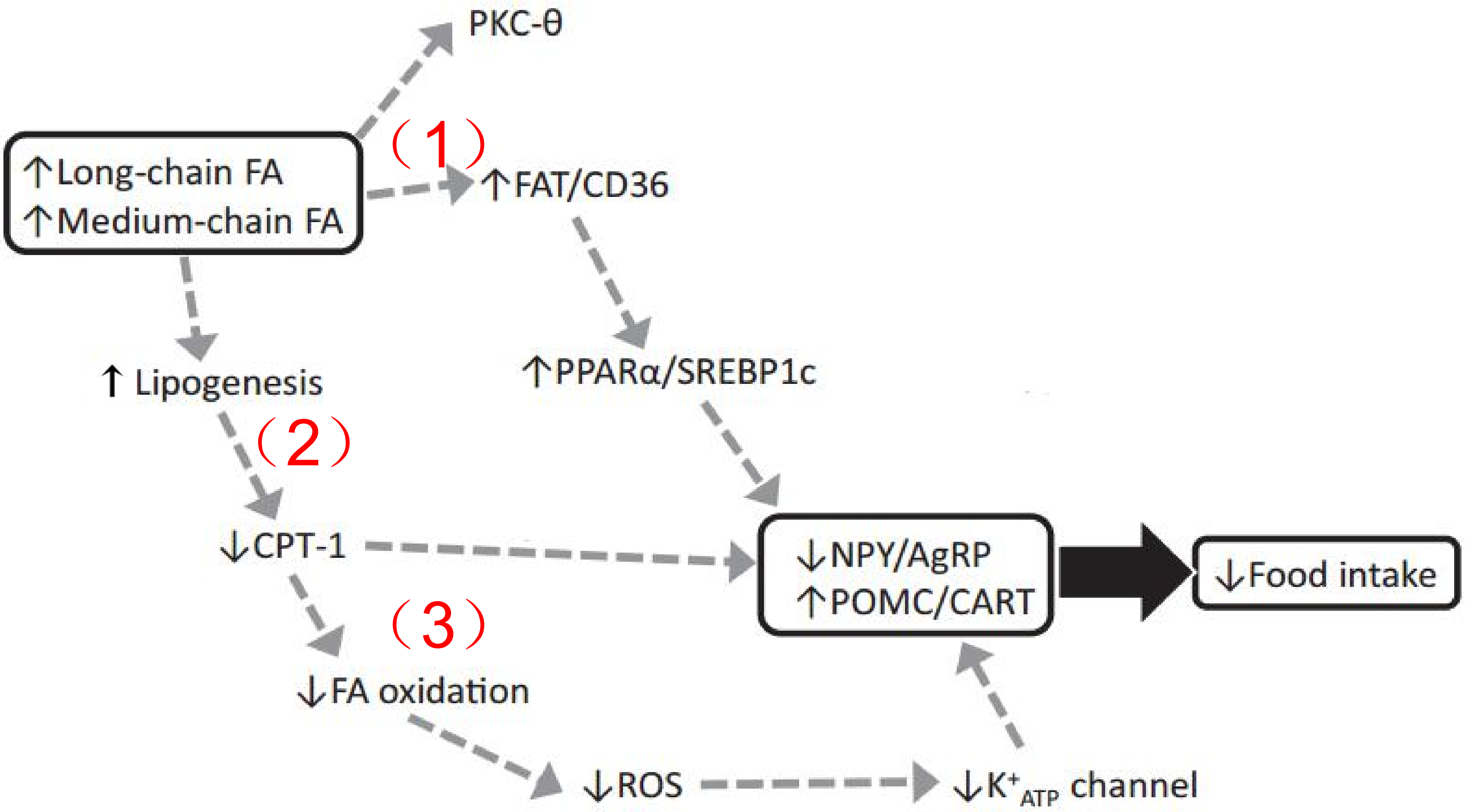
Carlier, 1991; Ramırez et al. 2001; **Tocher, 2003**; Mu et al. 2004

2）内源脂质代谢



Modified after Trattner et al., 2008, Lipids, 43:999–1008

1.3 鱼类脂感知



哺乳动物下丘脑脂感知细胞机制

1.3 鱼类脂感知

河南师范大学
水产学院

Am J Physiol Regul Integr Comp Physiol 302: R1340–R1350, 2012.
First published April 11, 2012; doi:10.1152/ajpregu.00070.2012.

Evidence of a metabolic fatty acid-sensing system in the hypothalamus and Brockmann bodies of rainbow trout: implications in food intake regulation

Marta Librán-Pérez,[1] Sergio Polakof,[2] Marcos A. López-Patiño,[1] Jesús M. Míguez,[1] and José L. Soengas[1]

Comparative Biochemistry and Physiology, Part A 164 (2013) 241–248

Response of hepatic lipid and glucose metabolism to a mixture or single fatty acids: Possible presence of fatty acid-sensing mechanisms

Marta Librán-Pérez [a], A. Cláudia Figueiredo-Silva [b], Stephane Panserat [b], Inge Geurden [b], Jesús M. Míguez [a], Sergio Polakof [c], José L. Soengas [a,*]

Comparative Biochemistry and Physiology, Part A 165 (2013) 288–294

In vitro response of putative fatty acid-sensing systems in rainbow trout liver to increased levels of oleate or octanoate

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Marta Librán-Pérez, Marcos A. López-Patiño, Jesús M. Míguez, José L. Soengas *
Laboratorio de Fisioloxía Animal, Departamento de Bioloxía Funcional e Ciencias da Saúde, Facultade de Bioloxía, Universidade de Vigo, E-36310 Vigo, Spain

OPEN ACCESS Freely available online PLOS | ONE

Main researchers

J.L. Soengas J.M. Miguez R. Alvarez M.A. López

· a Fall in Circulating
ut. Possible Involvement
nterrenal Axis

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Míguez, José L. Soengas*

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mykiss Is Direct in
Bodies

ús M. Míguez, José L. Soengas*

鱼类脂类感知相关研究

河南师范大学
水产学院

腹腔注射中长链FA后，虹鳟下丘脑FA感应元件mRNA水平(在体)

	Oleic Acid		Octanoic Acid	
	60 μg/kg[1]	300 μg/kg	60 μg/kg	300 μg/kg
Fatty acid transport				
CD36	+2.39*	+2.06*	+1.28	+1.04
FATP1	+1.24	+1.17	−1.06	−1.82*
Fatty acid metabolism				
ACLY	−1.58*	−27.0*#	−16.9*	−27.8*#
ACO	−1.24	−26.7*#	−2.44*	−154.1*#
CPT1c	−1.41*	−1.78*	−1.01	−1.32
CPT1d	−1.15	−1.17	+1.12	+1.18
CS	−1.63*	−4.21*#	−2.67*	−9.65*#
FAS	−1.48*	−5.01*#	−2.16*	−1.99*
K_{ATP} channel				
Kir6.x-like	−1.98*	−3.26*#	−2.35*	−5.04*#
SUR-like	−2.26*	−2.49*	−2.12*	−3.41*
Transcription factors				
LXR	−1.27	−2.10*#	−1.33	−3.30*#
PPARα	+1.87*	+5.89*#	+6.61*	+8.55*
SREBP1c	+1.54*	+1.72*	+1.14	+1.03
Neuropeptides				
CART	−1.53*	+1.24#	+1.12	−1.75*#
NPY	−2.14*	−1.09#	+1.35	+1.14
POMC	+1.85*	+2.02*	+1.16	+1.01

中长链FA孵育虹鳟下丘脑，其FA感应元件mRNA(离体)

	Oleic acid (μM)			Octanoic acid (μM)		
	1	10	100	1	10	100
Fatty acid transport						
FAT/CD36	−1.78*a	−2.21*ab	−2.94*b	−2.56*a	−3.12*b	−3.03*ab
Fatty acid metabolism						
ACC	−1.13a	−1.85*b	−1.57*b	−1.33*a	−1.37*a	−1.69*b
ACLY	−1.05a	−1.41*ab	−1.79*b	−1.13	−1.48*ab	−2.03*b
CPT1c	−1.03a	+1.06a	+1.48*b	+1.59*	+1.74*	+1.43*
CPT1d	−1.06	−1.02	+1.01	+5.01*	+4.98*	+4.82*
CS	−1.81*	−1.98*	−2.12*	−1.54*	−1.81*	−1.56*
FAS	+1.04a	−1.22ab	−1.43*b	−1.13a	−1.18a	−1.46*b
MCD	+1.02a	+1.71*b	+2.61*b	+1.25a	+1.87*b	+2.03*b
Mitochondrial uncoupling						
UCP2a	+1.08a	2.12*b	2.22*b	1.85*	1.97*	2.42*
K_{ATP} channel						
Kir6.x-like	−1.33*	−1.42*	−1.66*	−1.47*a	−1.82*ab	−2.50*b
SUR-like	1.16a	1.62*b	1.80*b	+1.07a	1.40*b	1.39*b
Transcription factors						
LXRα	−1.35*a	−1.40*a	−1.87*b	−1.23a	−1.37*a	−1.64*b
PPARα	+1.04a	+1.32*b	+1.41*b	+1.01a	+1.41*b	+1.50*b
SREBP1c	+1.17	+1.01	+1.02	+1.58*	+1.44*	+1.56*
Food intake control						
CART	+1.31a	+1.44*ab	+1.78*b	+1.19	+1.39*	+1.57*
NPY	−1.14a	−1.39*a	−1.98*b	−1.08	+1.07	+1.12
POMC	+1.55*	+1.43*	+1.49*	+1.51*a	+1.73*ab	+2.32*b

抑制剂对虹鳟下丘脑FA感应元件响应中长链FA的影响

	Inhibitors															
	C75		Etomoxir		Trolox		Genipin		Diazoxide		Triacsin C		SSO		TOFA	
Parameters	**Ol**	**Oc**	**Ol**	**Oc**	**Ol**	**Oc**	**Ol**	**Oc**	**Ol**	**Oc**	**Ol**	**Oc**	**Ol**	**Oc**	**Ol**	**Oc**
Metabolite levels																
Fatty acid																
Triglyceride		+		+		+		+	+		+		+		+	
Total lipid	+	+		+		+	+	+				+				
Enzyme activities																
ACLY	+	+	+	+											+	+
CPT	+	+	+	+							+	+			+	
FAS	+	+	+	+		+		+	+							+
mRNA abundance																
FAT/CD36	+								+		+		+	+	+	
ACC	+	+		+											+	+
ACLY									+		+	+				
CPT1c			+	+							+	+			+	
CPT1d												+				
CS		+	+	+							+	+			+	+
FAS	+		+					+			+	+			+	
MCD	+	+	+	+					+		+	+			+	
UCP2a					+	+	+	+	+	+			+			
Kir6.x-like					+		+	+	+	+						+
SUR-like					+	+	+	+	+	+						
LXRα		+	+		+	+		+	+	+			+	+		
PPARα						+	+		+		+		+	+		
SREBP1c					+	+	+	+	+				+	+		
CART												+				
NPY	+			+	+		+		+		+		+		+	+
POMC				+	+	+	+	+	+			+	+		+	+

注:"+"表示抑制剂阻止了中长链FA对FA感应元件的影响。

(Librán-Pérez et al, 2013, *Plos One*)

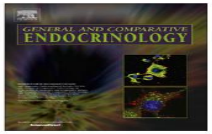
河南师范大学
水产学院

General and Comparative Endocrinology 205 (2014) 36–48

Contents lists available at ScienceDirect

General and Comparative Endocrinology

journal homepage: www.elsevier.com/locate/ygcen



Review

Contribution of glucose- and fatty acid sensing systems to the regulation of food intake in fish. A review

José L. Soengas *

Laboratorio de Fisioloxía Animal, Departamento de Bioloxía Funcional e Ciencias da Saúde, Facultade de Bioloxía, Universidade de Vigo, Spain

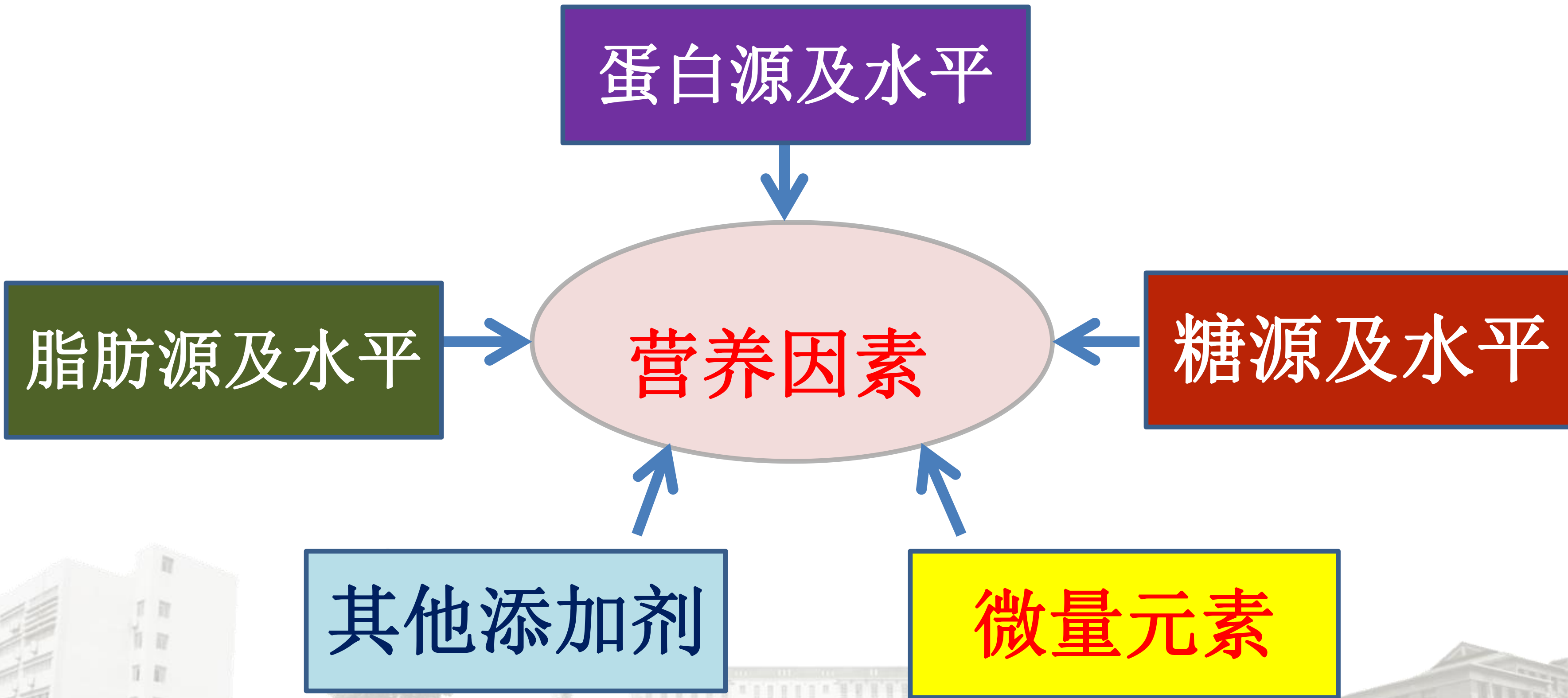
鱼脂感知体系

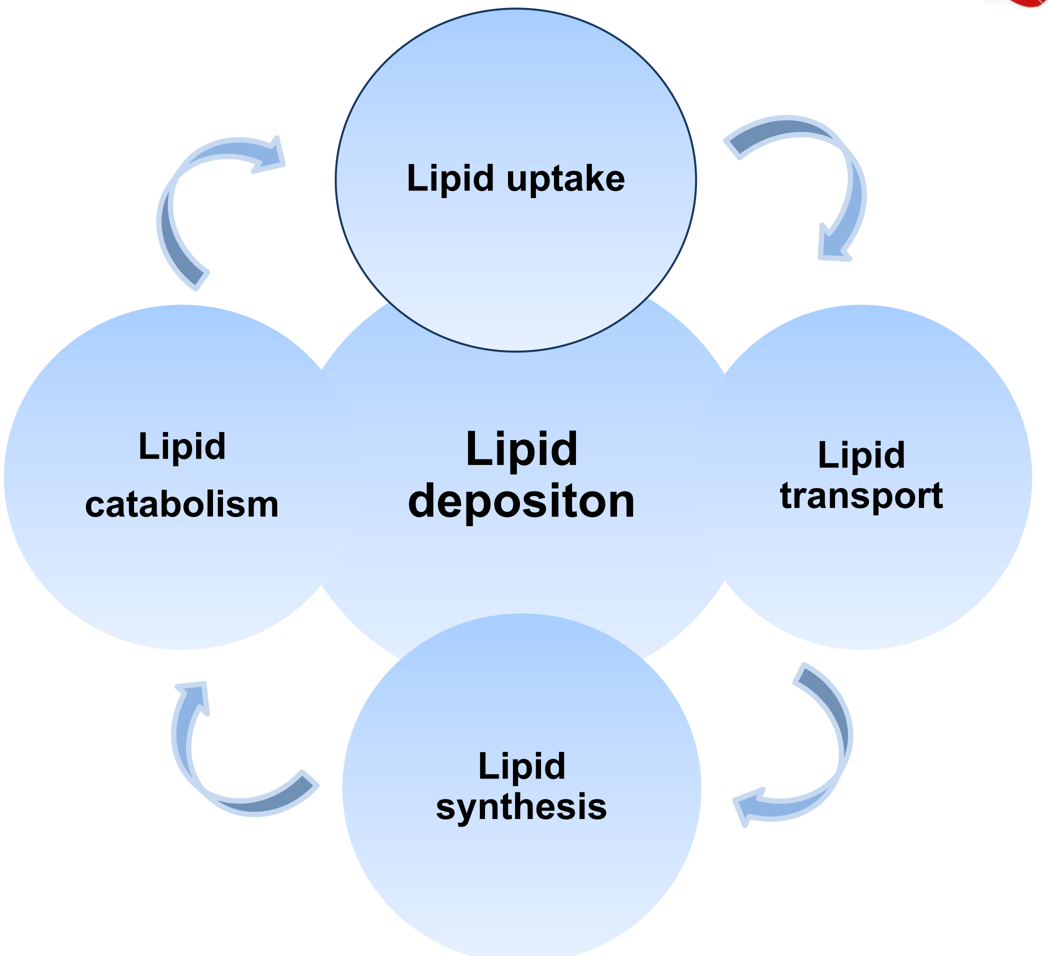
1）基于FAT/CD36及转录因子

2）基于脂肪酸氧化代谢（CPT1）

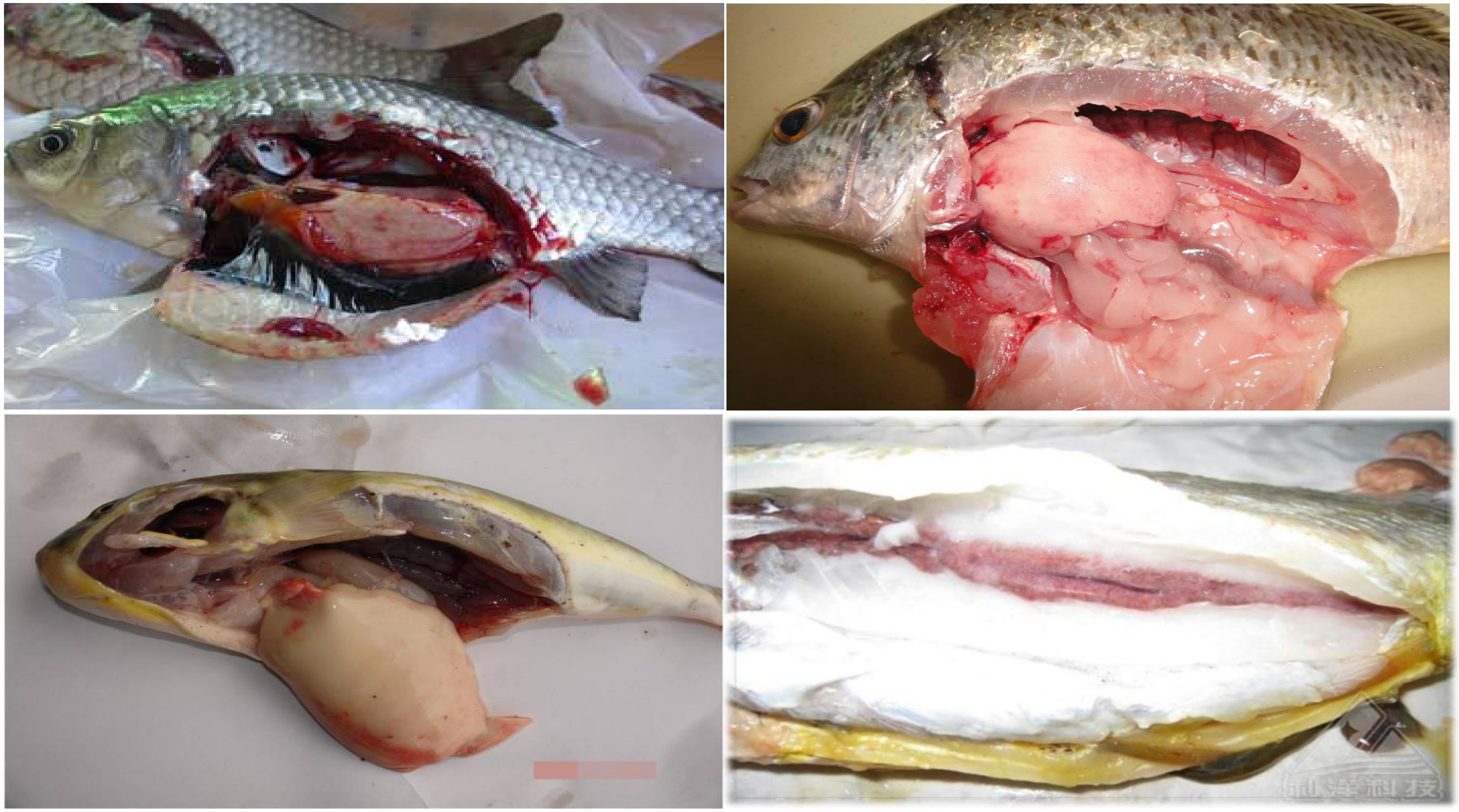
3）基于线粒体ROS和K^{+}_{ATP}通道

2. 脂质代谢营养调控





Lipid metabolism is complex process in animals



Lipid was abnormally deposited in liver or abdomial capvity

a. 脂肪源对脂代谢的影响

Growth performance, lipid deposition and hepatic lipid metabolism related gene expression in juvenile turbot (*Scophthalmus maximus* L.) fed diets with various fish oil substitution levels by soybean oil

Mo Peng [a,b], Wei Xu [a,b,c], Kangsen Mai [a,b], Huihui Zhou [a,b], Yanjiao Zhang [a,b], Zhiguo Liufu [a,b], Kaikai Zhang [a,b], Qinghui Ai [a,b,*]

[a] Key Laboratory of Aquaculture Nutrition and Feed (Ministry of Agriculture), Ocean University of China, Qingdao 266003, People's Republic of China
[b] Key Laboratory of Mariculture (Ministry Education of China), Ocean University of China, Qingdao 266003, People's Republic of China
[c] College of Food Science and Technology, Ocean University of China, Qingdao 266003, People's Republic of China

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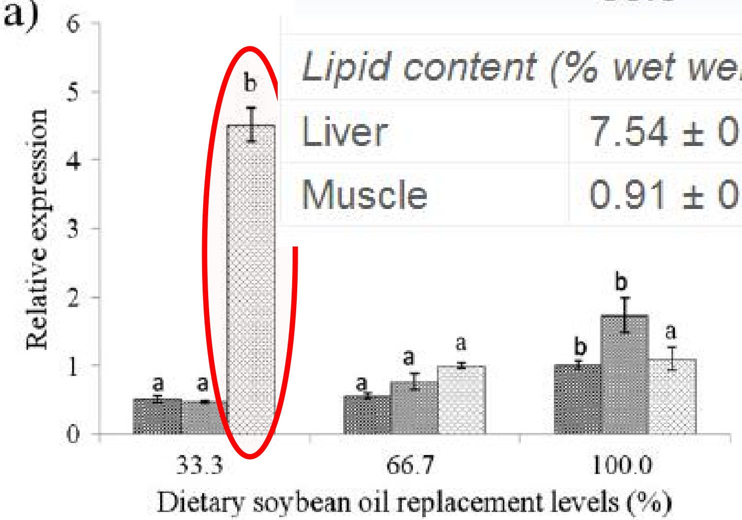
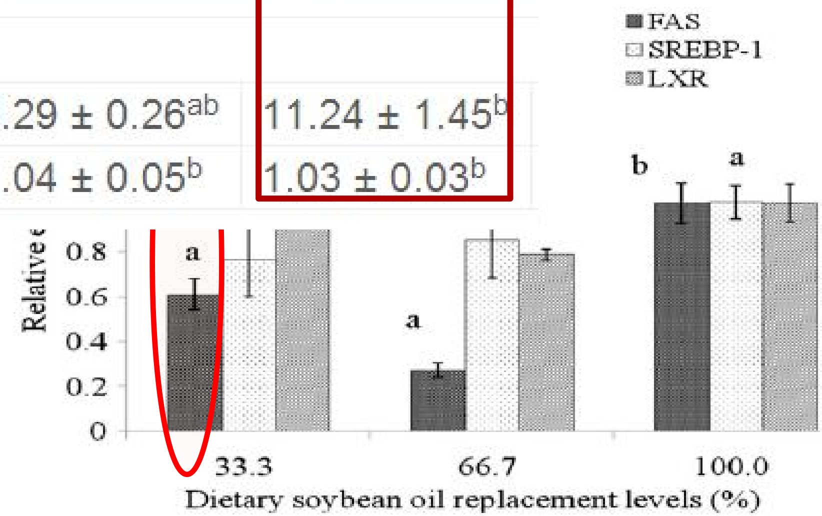
Index	Dietary SO replacement level (%)		
	33.3	66.7	100
Lipid content (% wet weight)			
Liver	7.54 ± 0.55[a]	9.29 ± 0.26[ab]	11.24 ± 1.45[b]
Muscle	0.91 ± 0.04[a]	1.04 ± 0.05[b]	1.03 ± 0.03[b]





鱼油替代对比目鱼脂质沉积和肝脂类代谢相关基因表达的影响
（Peng et al. 2014）

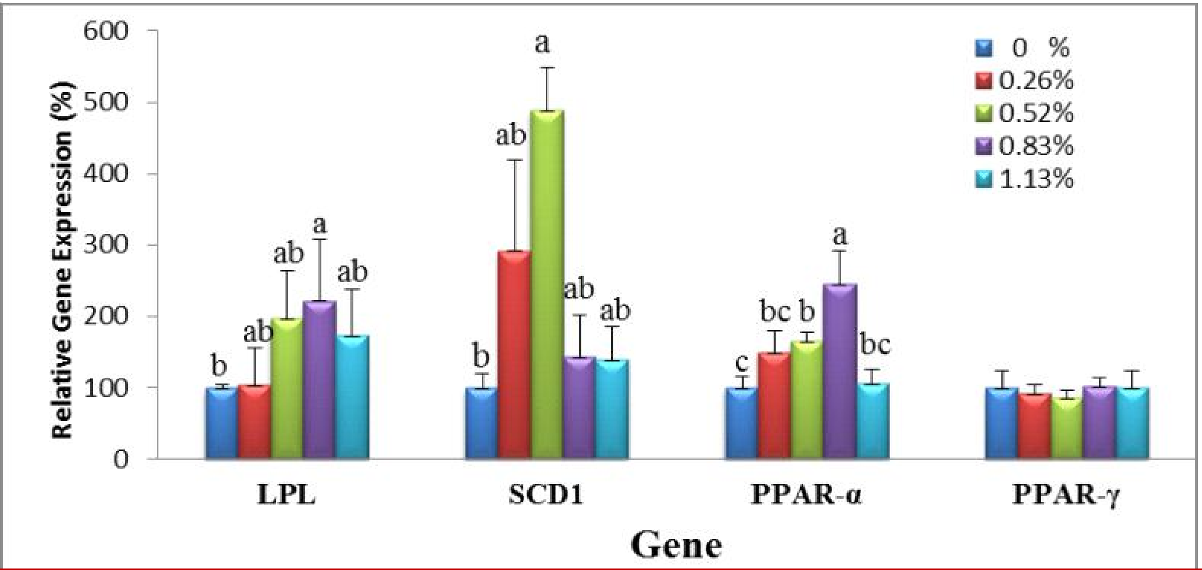
HUFA对鱼类脂代谢影响

Regulation of growth performance and lipid metabolism by dietary n-3 highly unsaturated fatty acids in juvenile grass carp, *Ctenopharyngodon idellus*

Hong Ji [a,b,*], Jie Li [a], Pin Liu [a]

Table 5
Effects of dietary HUFAs content on muscle and hepatopancreas composition of grass carp.

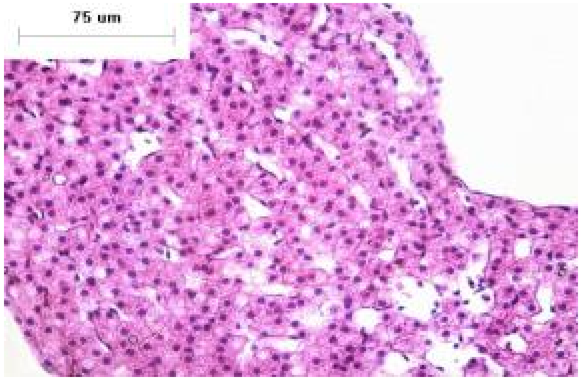
	Group				
	0%	0.26%	0.52%	0.83%	1.13%
Muscle (g kg^{-1})					
Moisture	802.7 ± 3.8	799.5 ± 0.5	802.5 ± 4.0	800.4 ± 1.7	800.8 ± 0.5
Lipid	10.05 ± 0.68^{b}	10.08 ± 0.5^{b}	10.07 ± 0.35^{b}	11.81 ± 0.61^{a}	11.53 ± 0.29^{a}
Protein	179.32 ± 1.07	178.03 ± 2.96	176.87 ± 1.55	178.72 ± 1.58	175.89 ± 4.87
Hepatopancreas lipid (g kg^{-1})	124.2 ± 14.5^{a}	110.8 ± 9.1^{ab}	92.8 ± 12.6^{b}	95.8 ± 8.1^{b}	107.4 ± 11.2^{ab}



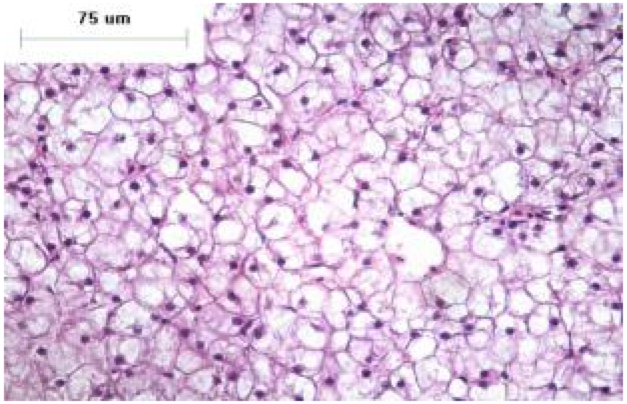
These results indicate that adequate dietary HUFAs supplementation significantly promotes growth performance and lipid metabolism in grass carp.

b. 饲料脂水平对脂代谢的影响

2% 饲料脂肪



10% 饲料脂肪



Du et al., Aquaculture Nutrition 2005 11; 139–146

c. 蛋白源对脂肪代谢的影响

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Aquaculture

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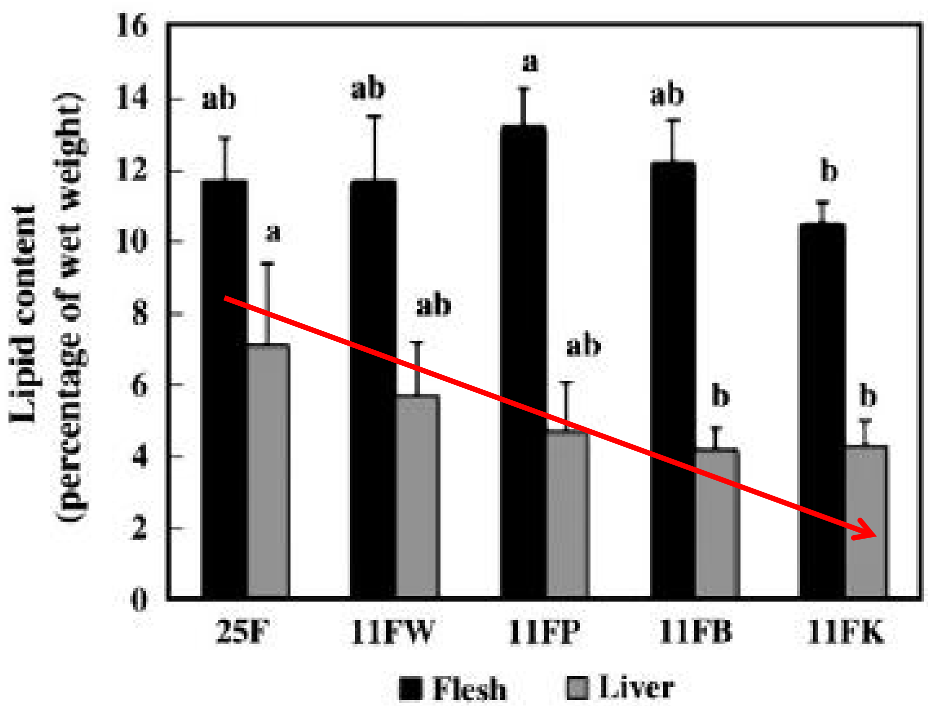
Effects of different blends of protein sources as alternatives to dietary fishmeal on growth performance and body lipid composition of Atlantic salmon (*Salmo salar L.*)

J. Pratoomyot [a,*], E.Å. Bendiksen [b], P.J. Campbell [b], K.J. Jauncey [a], J.G. Bell [a], D.R. Tocher [a]

[a] Institute of Aquaculture, University of Stirling, Stirling FK9 4LA, Scotland, UK

[b] BioMar AS, Nordregt. 11, N-7484 Trondheim, Norway



25F: 25% 鱼粉

11FW: 11%鱼粉+ 谷朊粉

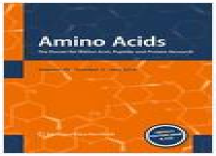
11FP: 11%鱼粉+ 豌豆蛋白粉

11FB: 11%鱼粉 + 血球蛋白粉

11FK: 11%鱼粉 + 蚕豆粉

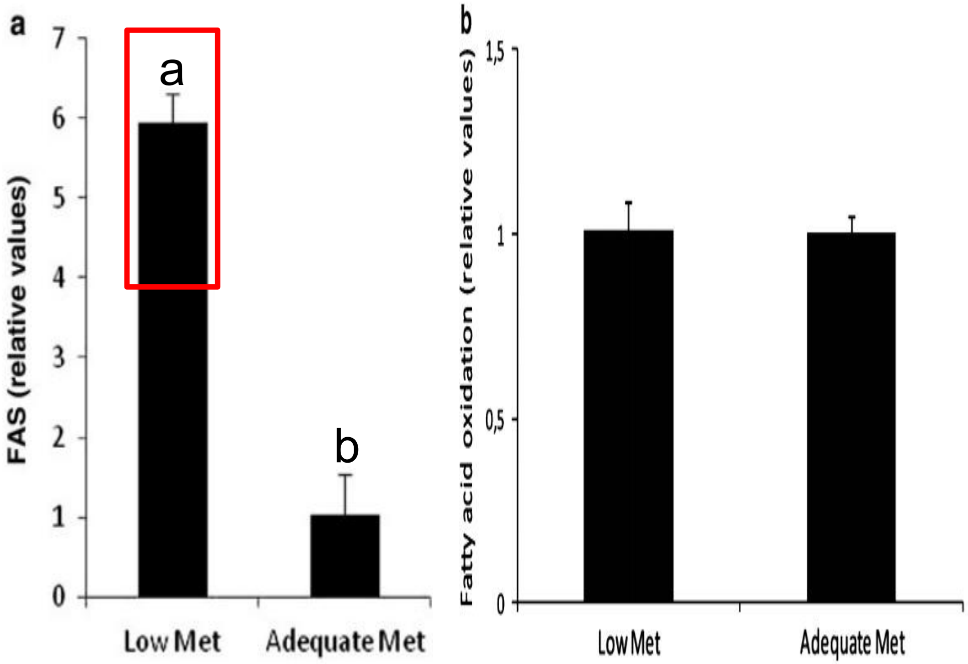
植物蛋白源对大西洋鲑肌肉和肝脏脂质含量的影响

氨基酸对鱼类脂代谢的影响



Amino Acids
July 2010, Volume 39, Issue 2, pp 449–460

Methionine limitation results in increased hepatic FAS activity, higher liver 18:1 to 18:0 fatty acid ratio and hepatic TAG accumulation in Atlantic salmon, *Salmo salar*



肝脏FAS和脂肪酸氧化活性

表：肝脏生化指标

Diets	Low methionine	Adequate methionine	*p* Value
Relative hepatic size	1.74 ± 0.05	1.48 ± 0.02	**0.025**
Gram liver	18.4 ± 1.2	16.6 ± 0.9	0.31
Met	0.58 ± 0.03	0.55 ± 0.02	0.58
Gly	3.07 ± 0.13	2.93 ± 0.13	0.32
Ser	3.05 ± 0.10	2.10 ± 0.10	**0.006**
SAM	31.66 ± 4.90	47.46 ± 2.35	**0.095**
SAH	13.21 ± 0.32	15.54 ± 0.92	**0.063**
SAM:SAH	1.9 ± 0.6	3.1 ± 0.6	0.29
Taurine	9.17 ± 0.58	15.79 ± 1.27	**0.012**
TAG	23.0 ± 1.7	14.3 ± 0.9	**0.030**
PE	7.7 ± 0.1	8.9 ± 0.8	0.145
PC	18.4 ± 0.6	20.9 ± 1.7	0.19
PC:PE	2.4 ± 0.1	2.4 ± 0.02	0.74
PL	36.3 ± 1.2	37.2 ± 3.4	0.80
Free FA	4.8 ± 0.1	3.7 ± 0.6	0.16
Sterol esters	1.15 ± 0.13	0.79 ± 0.07	0.13
Cholesterol	3.8 ± 0.1	3.8 ± 0.5	0.89

蛋氨酸负荷致轻度同型半胱氨酸升高对大鼠肝脏脂代谢的影响及机制研究

孙珍珍 彭川 郑金英 李继斌

【摘要】：目的了解高蛋氨酸摄入对肝脏脂质代谢的影响及可能机制。方法选取6周龄健康SD雄性大鼠20只，随机分为对照组和蛋氨酸负荷组。适应性喂养两周后，对照组饲以正常饮食并采用PBS灌胃，蛋氨酸负荷组在正常饮食基础上采用蛋氨酸灌胃，持续喂养8周，每周称取体重，处死后收集血液和肝脏组织。肝脏称重并比较脏器系数；肝组织切片HE染色进行组织学观察；血清各项生化指标采用血生化分析仪测定；采用ELISA法测定血清同型半胱氨酸水平；Real-time PCR检测大鼠肝脏脂代谢相关酶FAS、ACC、SCD-1、CPT1α基因表达水平。在体外培养的Hep G2细胞中，采用油红O染色法，与普通培养基相比，观察Hep G2细胞在高蛋氨酸和高同型半胱氨酸处理后脂质沉积情况及n-SREBP-1c蛋白表达水平。结果蛋氨酸灌胃对动物体重增长无显著影响，但肝脏/体重比值高于对照组。肝组织学观察表明蛋氨酸灌胃组动物肝脏出现轻微小泡性脂肪变性，但未出现炎症和明显肝功能损害，血清AST和ALT水平增高无显著性差异。蛋氨酸负荷导致动物血液中同型半胱氨酸、TC及HDL水平升高。油红O染色结果表明Hep G2细胞在蛋氨酸或同型半胱氨酸作用下发生明显脂质蓄积，Western blotting结果提示Hep G2细胞经同型半胱氨酸处理后成熟形式的n-SREBP-1c水平增高。蛋氨酸组动物肝脏FAS、ACC、SCD-1、CPT-1α脂代谢相关酶mR NA表达水平无显著改变。结论蛋氨酸摄入过量将导致肝脏轻微脂肪变性，与血液中同型半胱氨酸水平升高有关。蛋氨酸负荷导致的轻度同型半胱氨酸水平升高可通过调节肝细胞脂质代谢关键转录因子的活化，从而对肝脏脂质代谢造成影响。

d. 糖类对脂代谢的影响

World Journal of Diabetes

ORIGINAL ARTICLE

Observational Study

CD36 expression and lipid metabolism following an oral glucose challenge in South Asians

Table 4 Changes in metabolic factors absolute monocyte CD36 expression pre and post administration of oral glucose

	Circulating concentrations following the administration of glucose			*P*
	0 min	30 min	120 min	
Monocyte CD36 on Mon1 (Mon CD36+ per μL)	300 (240, 324)	223 (187, 254)	353 (323, 382)	< 0.001
Monocyte CD36 on Mon2 (Mon CD36+ per μL)	23.9 (17.9, 32.3)	21.3 (17.2, 30.8)	29.9 (18.1, 39.6)	0.011
Monocyte CD36 on Mon3 (Mon CD36+ per μL)	36.7 (24.3, 53.2)	26.1 (18.4, 45.8)	34.4 (31.3, 48.7)	0.03
Total monocyte CD36 (Mon CD36+ per μL)	361 (308, 432)	278 (240, 324)	422 (394, 458)	< 0.001
Plasma glucose (mmol/L)	5.09 (4.5, 5.47)	6.68 (4.93, 8.12)	5.2 (4.64, 6.07)	0.08
Serum NEFA (mmol/L)	0.416 (0.264, 0.514)	0.215 (0.098, 0.326)	0.094 (0.071, 0.207)	< 0.001
Serum cholesterol (mmol/L)	3.41 (2.95, 3.96)	3.29 (2.95, 3.95)	3.44 (3.06, 3.80)	0.52
Serum triglycerides (mmol/L)	0.9 (0.67, 1.44)	0.83 (0.55, 1.19)	1.01 (0.54, 1.35)	0.26
VLDL cholesterol (mmol/L)[1]	1.26 (0.97, 1.44)	1.31 (0.94, 1.50)	1.42 (1.27, 1.62)	0.001
LDL cholesterol (mmol/L)[1]	1.39 (0.89, 1.71)	1.61 (0.8, 1.82)	1.92 (1.58, 2.24)	0.003
HDL_2 cholesterol (mmol/L)[1]	0.600 (0.425, 0.735)	0.470 (0.360, 0.725)	0.540 (0.415, 0.820)	0.19
HDL_3 cholesterol (mmol/L)[1]	0.395 (0.285, 0.505)	0.330 (0.205, 0.450)	0.325 (0.250, 0.570)	0.43
VLDL triglyceride (mmol/L)[1]	0.338 (0.223, 0.440)	0.263 (0.213, 0.365)	0.265 (0.105, 0.353)	0.37
LDL triglyceride (mmol/L)[1]	0.270 (0.170, 0.505)	0.250 (0.170, 0.360)	0.275 (0.125, 0.385)	0.16
HDL_2 triglyceride (mmol/L)[1]	0.080 (0.055, 0.138)	0.070 (0.043, 0.093)	0.060 (0.028, 0.100)	0.09
HDL_3 triglyceride (mmol/L)[1]	0.058 (0.035, 0.083)	0.035 (0.013, 0.045)	0.038 (0.025, 0.065)	0.12

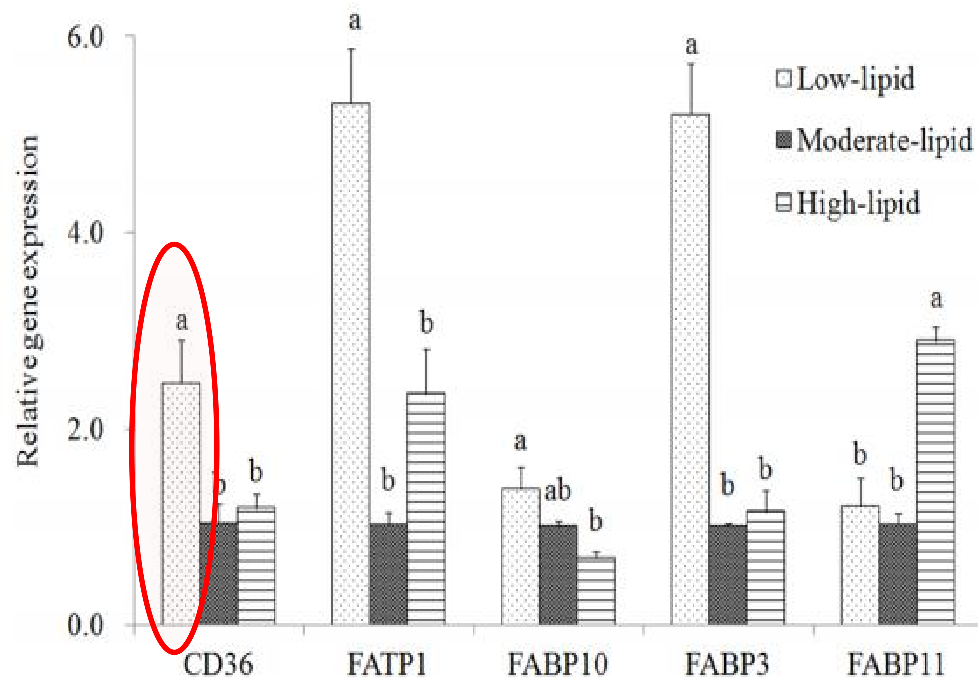
PLOS | ONE

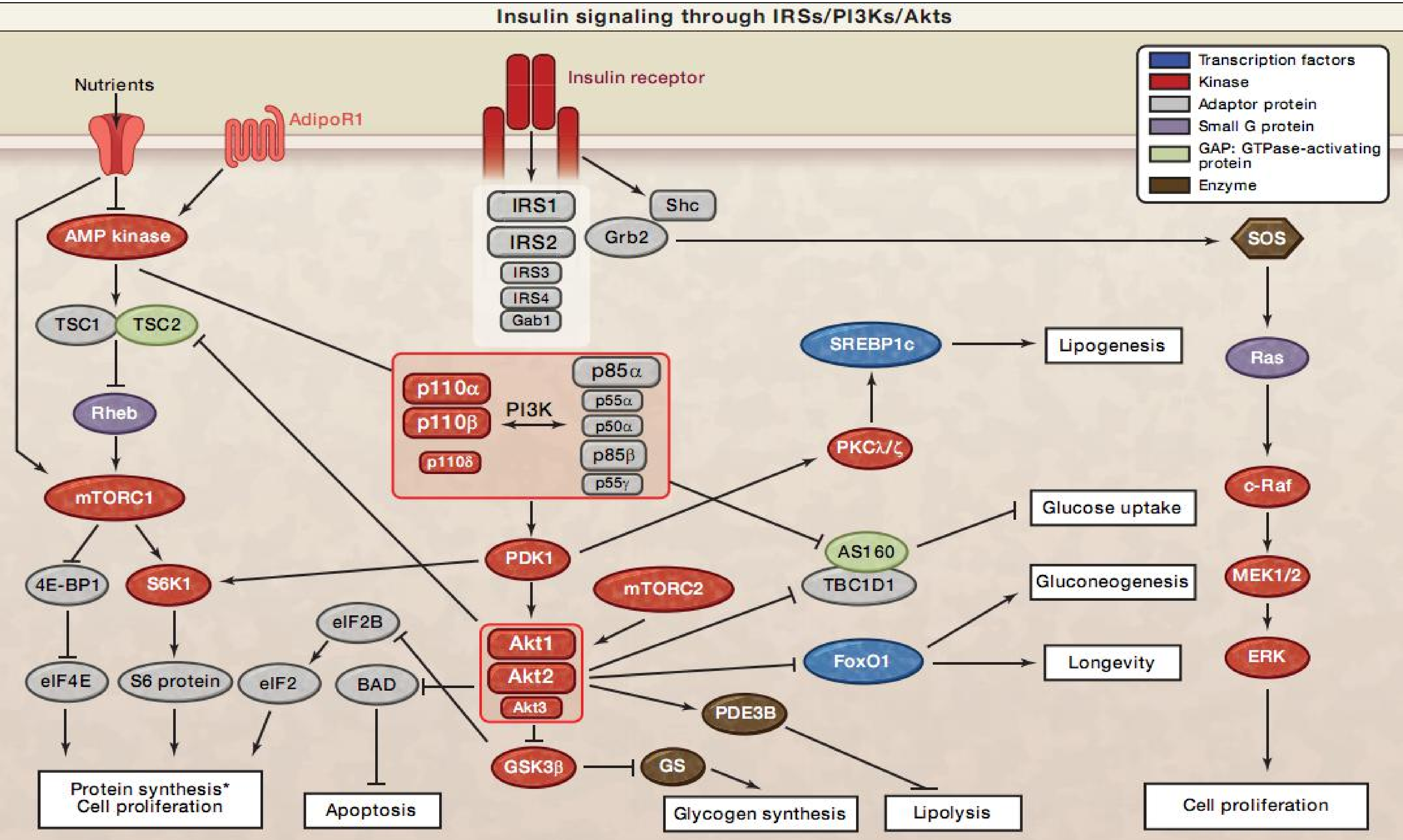
RESEARCH ARTICLE

Dietary Lipid Levels Influence Lipid Deposition in the Liver of Large Yellow Croaker (*Larimichthys crocea*) by Regulating Lipoprotein Receptors, Fatty Acid Uptake and Triacylglycerol Synthesis and Catabolism at the Transcriptional Level

Table 1. Formulation and proximate composition of the experimental diets.

	Dietary lipid levels (%)		
	Low (6)	Moderate (12)	High (18)
Ingredients (g/100 g)			
Fish meal[1]	39.0	39.0	39.0
Soybean meal[1]	20.0	20.0	20.0
Wheat meal[1]	23.3	23.3	23.3
Wheat starch[1]	12.0	6.0	0
Fish oil[1]	0	6.0	12.0
Soybean lecithin[1]	1.5	1.5	1.5
Vitamin premix[2]	2.0	2.0	2.0
Mineral premix[3]	2.0	2.0	2.0
Attractant[4]	0.1	0.1	0.1
Mold inhibitor[5]	0.1	0.1	0.1
Proximate composition (g/100 g)			
Moisture	9.5	9.4	9.2
Crude protein	43.1	42.6	43.2
Crude lipid	6.1	11.5	17.8





胰岛素信号通路图

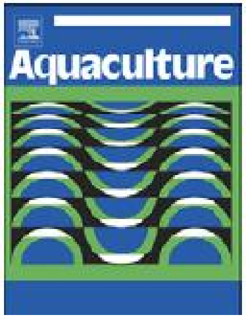
（Kadowaki et al, 2011, Cell）

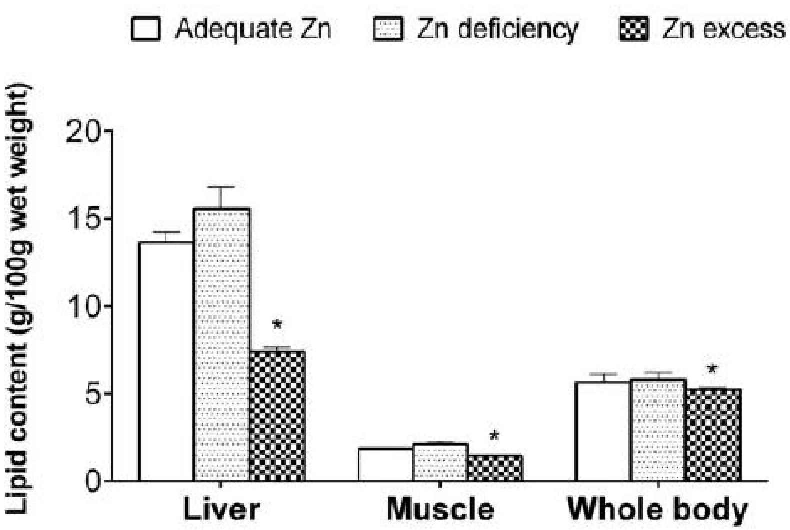
e. 微量元素对脂代谢的影响

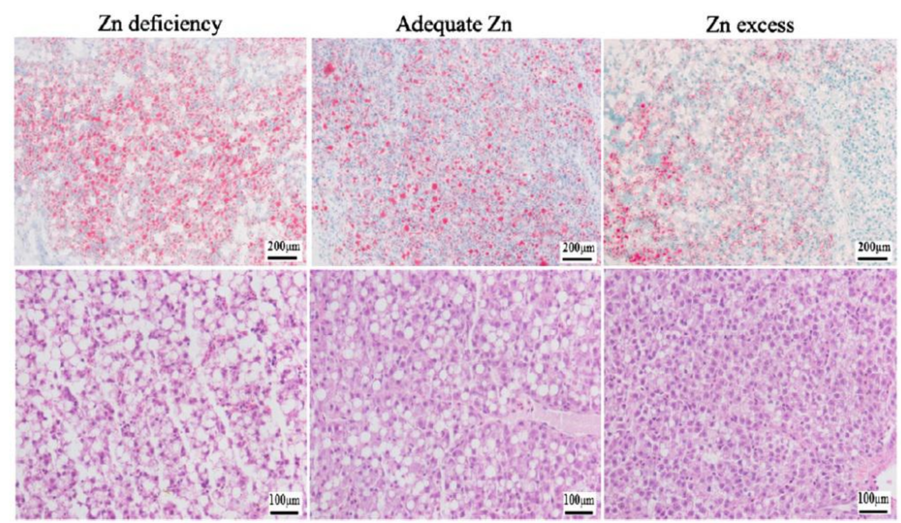
Different effects of dietary Zn deficiency and excess on lipid metabolism in yellow catfish *Pelteobagrus fulvidraco*

Jia-Lang Zheng [1], Zhi Luo *, Wei Hu, Cai-Xia Liu [2], Qi-Liang Chen, Qing-Ling Zhu, Yuan Gong

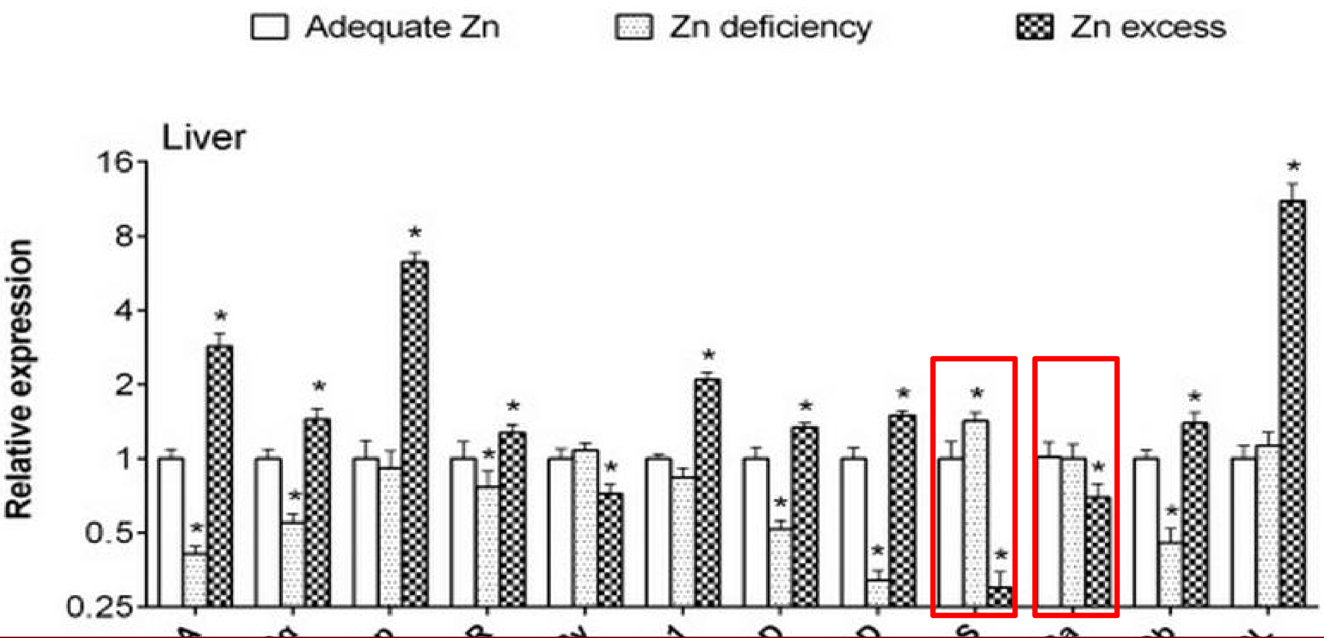
Key Laboratory of Freshwater Animal Breeding, Ministry of Agriculture, Fishery College, Huazhong Agricultural University, Wuhan 430070, China
Freshwater Aquaculture Collaborative Innovative Centre of Hubei Province, Wuhan 430070, China



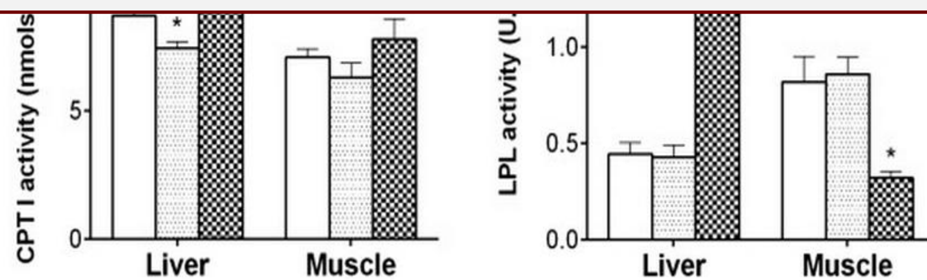




饲料中不同的锌水平对黄颡鱼脂质代谢的影响（**Zheng et al. 2015**）



Dietary Zn deficiency significantly down-regulated the transcriptional levels of CPT 1A, PPAR α, LepR, G6PD, 6PGD and ACCb, but up-regulated FAS mRNA levels. Dietary Zn excess up-regulated mRNA levels of CPT 1A, PPAR α, Lep, LepR, SREBP-1, G6PD, 6PGD, ACCb and LPL, but down-regulated mRNA levels of FAS, ACCa and PPAR γ.



饲料中不同的锌水平对黄颡鱼脂质代谢的影响（**Zheng et al. 2015**）

e. 维生素对鱼类脂代谢影响

《广东海洋大学》 2015年 加入收藏

VA、VD对两种规格斜带石斑鱼生长、饲料利用、脂肪代谢及FAS、HL mRNA表达量的影响研究

丁明岩

项目)0

FAS).04b

HL 0.05b

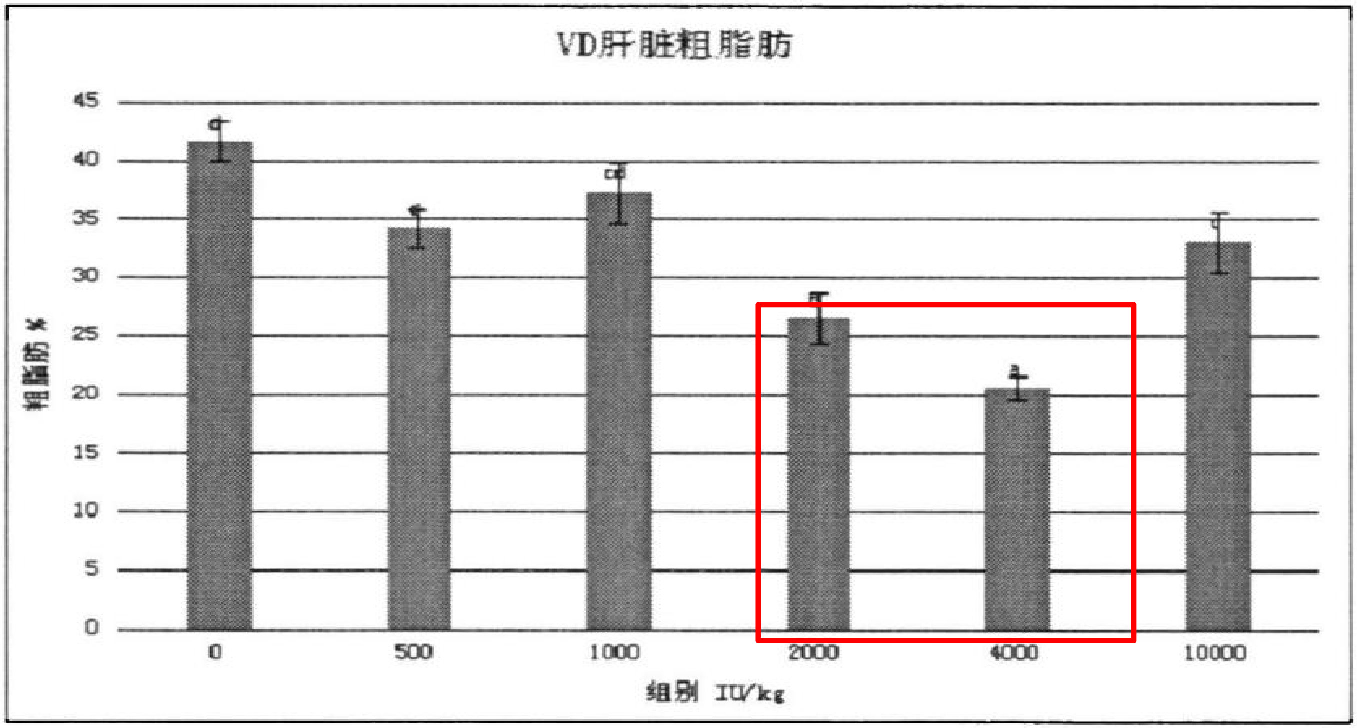


图 3-3 中鱼实验 VD 对斜带石斑鱼肝脏脂肪含量的影响（*n*=3）