

Taurine Supplementation of All-plant Protein Diets for Rainbow Trout (*Oncorhynchus mykiss*)

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Abstract.—Taurine has been demonstrated to be conditionally indispensable for several carnivorous fish species. Current trends in trout production include decreasing levels of fish-meal content in feeds, along with faster growing strains of fish. Taurine may be a limiting nutrient in support of elevated planes of growth for rainbow trout. A 9-wk feeding trial was conducted using a factorial treatment design with protein source (fish meal or plant) and taurine supplementation (four levels) as the main effects. The fish-meal diet series included 23% herring meal and contained 1.76% total sulfur amino acids (TSAA). The plant diet series did not contain any animal proteins and substituted protein from soy protein concentrate in place of the herring-meal protein and contained 1.5% TSAA. Taurine was supplemented at 0, 5, 10, and 15 g/kg dry diet to each of the diets in the plant series and the fish-meal series of diets. All diets were formulated to contain 43.8% crude protein and 20% lipid with an estimated physiological fuel value of 4.2 kcal/g. Fifteen fish were stocked in each of 24 tanks with a mean initial weight of approximately 26.8 g per fish. The unsupplemented fish-meal diet contained 2 g/kg taurine, and the unsupplemented plant diet had taurine levels below the detection limit of 0.1 g/kg diet. Taurine supplementation improved growth, feed conversion ratios, protein retention efficiencies, and energy retention efficiencies of fish fed the plant protein diets. No effects of taurine supplementation were observed for these response factors in fish fed the fish-meal series diets. This study demonstrates that taurine supplementation may be necessary for rainbow trout fed plant-protein-based feeds.

The removal of fish meal from the diet of rainbow trout and other carnivorous fish species has had wide interest globally. Current diet formulations often utilize a variety of protein sources to replace all but a small portion of fish meal.

Substituting the last portion of fish-meal protein with plant-derived products often results in reduced growth rates. Animal renderings from industry, including meat and bone meals, poultry meals, feather meals, and blood products, have been widely evaluated as substitutes for fish meal, but these products also have limits based on nutrient profiles and nutrient digestibility for fish (Gaylord and Rawles 2005).

A number of researchers have attempted to replace all the animal protein in trout feeds with plant proteins. Soybean meal has gained the most interest because of its abundance and relatively low cost per unit protein. Plant protein concentrates also have shown promise in trout feeds, including soy protein concentrate (Adelizi et al. 1998), canola protein concentrate (Thiessen et al. 2004), as well as corn gluten and wheat gluten. Although these concentrates have been shown to be effective in replacing some of the fish-meal component, cost considerations often limit their utilization in feed formulations. Other locally available products have also gained interest; however, each has specific limitations in fish feed formulations (Francis et al. 2001).

Cheng et al. (2003) replaced up to 50% of the fish meal in the control diet with a mixture of plant proteins without a reduction in growth of rainbow trout. This equated to approximately 25% of the dietary protein coming from fish meal to support comparable growth to the control diet containing approximately 22% fish-meal protein. Further reduction of the fish-meal protein in the diets utilizing soybean meal and wheat gluten caused a reduction in growth and feed efficiency (Cheng et al. 2003). Additionally, Gomes et al. (1995) demonstrated that palatability may be reduced when feeding all-plant diets to rainbow trout.

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Specific amino acid deficiencies are another factor limiting the complete replacement of fish meal in trout feeds, and supplementation with lysine and/or methionine has improved growth in some cases (Cheng et al. 2003). Even when all the indispensable amino acid requirements are met in a plant-based trout feed, growth rate remains low relative to a fish-meal-based feed. Consequently, nutrients other than indispensable amino acids may be supplied by fish meals that are not present in plant proteins. For example, taurine is an amino acid that has been determined to be conditionally indispensable for some carnivorous species (Takeuchi 2001). Rainbow trout have the capacity to synthesize taurine from cysteine (Yokoyama et al. 1997), but rainbow trout may not be capable of producing the quantities required for maximum growth when fed a diet devoid of taurine. Olive flounder have been reported to require taurine, at least in the juvenile stages, to maximize growth rates (Takeuchi 2001). The taurine synthetic capacity of olive flounder may not be sufficient to maintain optimal taurine levels in support of the rate of growth achieved in commercial aquaculture. Fish meals and animal by-product meals contain significant amounts of taurine. Levels found in

menhaden fish meal and poultry by-product meals are often in excess of 0.5 g/100 g.

Rainbow trout are carnivorous in nature, eating predominately insects during the juvenile stages. Finke (2002) reported that nymph and adult stages of the house cricket (*Acheta domestica*) contained 0.35–0.46 g taurine per 100 g dry tissue, a level comparable to those quantitated in whole fish and fish meals. This suggests that trout evolved on a high taurine diet, and although the biochemical capacity to synthesize taurine is still present, trout may not be capable of synthesizing sufficient quantities when fed a taurine-free diet. Against this background, the current study was undertaken to determine whether taurine supplementation to plant-protein-based diets would improve production performance of rainbow trout.

Materials and Methods

Two series of diets were formulated (Table 1). The fish-meal diet series contained 23% herring meal as the primary protein source (38% of dietary protein) and the only source of animal protein in the diet. The plant diet series contained soy protein concentrate in lieu of fish-meal protein. To each of these diet series,

TABLE 1. Formulations of two diet series with graded levels of supplemental taurine (% dry weight basis).

Ingredient	% Dry diet							
	Fish meal				Plant			
	0	0.5	1.0	1.5	0	0.5	1.0	1.5
Herring meal ^a	23.6	23.6	23.6	23.6	0.0	0.0	0.0	0.0
Corn gluten meal ^a	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Wheat gluten meal ^a	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Soybean meal 48% ^a	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Profine [®] VF ^b	0.0	0.0	0.0	0.0	23.0	23.0	23.0	23.0
GEMGEL pregelatinized wheat starch ^c	16.65	16.15	15.65	15.15	13.6	13.1	12.6	12.1
Menhaden fish oil ^a	17.0	17.0	17.0	17.0	19.5	19.5	19.5	19.5
Stay-C 35 ^a	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Choline Cl 50% ^a	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Vitamin premix ^a	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Trace mineral premix ^a	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dicalcium phosphate ^a	1.35	1.35	1.35	1.35	2.5	2.5	2.5	2.5
Taurine ^d	0.0	0.5	1.0	1.5	0.0	0.5	1.0	1.5
Sum	100	100	100	100	100	100	100	100

^a Purchased from Rangen Inc., Buhl, Idaho, USA.

^b Purchased from The Solae Company, Fort Wayne, Indiana, USA.

^c Manildra Group USA, Shawnee Mission, Kansas, USA.

^d Sigma-Aldrich Co., St. Louis, Missouri, USA.

taurine was supplemented at 0, 5, 10, and 15 g/kg dry diet. All diets were formulated to contain 43.8% crude protein and 20% lipid with an estimated physiological fuel value of 4.2 kcal/g. The fish-meal diet series was formulated to contain 1.01% methionine and 0.75% cysteine for a total of 1.76% total sulfur amino acids (TSAA) in the diet (4.02% of the dietary protein). The plant diet series was formulated to contain 0.74% methionine and 0.75% cysteine for a total of 1.49% TSAA in the diet (3.4% of the dietary protein) and meets the TSAA requirement established for rainbow trout (Hardy 2002). The dietary lysine content was 2.28 and 2.21% of the diet for the fish-meal and plant diet series, respectively.

All diets were blended in a V-mixer (Blend-master Lab Blender, Patterson-Kelly, Stroudsburg, PA, USA) and cold pelleted using a laboratory pelleter (Advanced Hydrolysing Systems, Seattle, WA, USA). The diets were then air-dried to approximately 93% dry matter and stored at -20°C until fed. Fifteen fish were stocked in each of 24, 140-L tanks with a mean initial tank weight of 402.4 ± 8.2 g (mean \pm SD) or 26.8 g per fish. Each diet was then randomly assigned to three tanks of fish. Fish were fed by hand to apparent satiation three times each day. The amount of feed consumed was determined daily. All fish within a tank were counted and weighed as a group every 3 wk.

At the termination of the 9-wk experiment, all fish were counted and weighed. Three fish per tank were bled, euthanized, and dissected to determine body condition indices. The condition indices determined included

$$\text{Muscle ratio} = \frac{\text{fillet mass with ribs}}{\text{fish mass}} \times 100$$

$$\text{Hepatosomatic index} = \frac{\text{liver mass}}{\text{fish mass}} \times 100$$

$$\text{Intraperitoneal fat ratio} = \frac{\text{peritoneal fat mass}}{\text{fish mass}} \times 100$$

Blood was collected in heparinized syringes, and plasma was separated for amino acid analysis.

Feed consumption, weight gain, and feed conversion ratios (FCR) were calculated according to the following formulas:

$$\text{Feed consumption} = \frac{\text{grams of dry feed consumed}}{\text{body mass/d}} \times 100$$

$$\text{Weight gain} = \frac{\text{final weight} - \text{initial weight}}{\text{initial weight}} \times 100$$

$$\text{FCR} = \frac{\text{grams of dry feed fed}}{\text{grams of wet weight gain}}$$

For the determination of whole-body protein and energy retention, 10 fish were sampled at the time of stocking and 3 additional fish per tank were sampled at the end of the feeding trial. Protein retention and energy retention efficiencies (PRE and ERE, respectively) were calculated as follows:

$$\text{PRE} = \frac{\text{protein gain}}{\text{protein fed}} \times 100$$

$$\text{ERE} = \frac{\text{energy gain}}{\text{energy fed}} \times 100$$

Dry matter and ash analysis of ingredients and diets was performed according to standard methods (AOAC 1995) on a Leco thermogravimetric analyzer (TGA701, LECO Corporation, St. Joseph, MI, USA). Protein (N \times 6.25) was determined by the Dumas method (AOAC 1995) on a Leco nitrogen determinator (TruSpec N, LECO Corporation). Total energy was determined by adiabatic bomb calorimetry (Parr 6300, Parr Instrument Company Inc., Moline, IL, USA).

Plasma and dietary taurine and methionine were quantified according to Fleming et al. (1992) utilizing an Agilent 1100 series HPLC and *o*-phthaldialdehyde precolumn derivatization of amino acids. Prior to separation, 50 μL of plasma was diluted with 50 μL water. Plasma proteins were then precipitated with 150 μL of 1.5 M perchloric acid, followed by centrifugation at 3000g for 5 min. Next, 100 μL of the resulting supernatant was prepped for injection with 1.2 mL water, 100 μL 1.2% benzoic acid,

TABLE 2. Effect of taurine supplementation on growth, feed consumption and conversion, and protein and energy retention of rainbow trout.

Diet type Taurine supplement	Fish-meal diet series				Plant diet series			
	0	0.5	1.0	1.5	0	0.5	1.0	1.5
Weight gain ² (%)	473.9A	464.3A	433.2A	433.6A	364.7b	413.4a	443.6a	453.8a
FCR ³	0.92A	0.99A	0.99A	0.97A	1.13b	0.96a	0.95a	0.98a
FC ⁴ (%/d)	2.52A	2.68A	2.60A	2.54A	2.82a	2.52b	2.58b	2.68ab
PRE ⁵ (%)	38.9A	36.4A	39.5A	37.1A	30.4b	38.5a	36.9a	34.2ab
ERE ⁶ (%)	44.8A	41.7A	41.5A	42.2A	36.0b	42.9a	42.7a	44.2a

¹ Probability associated with the *F* statistic for the factorial ANOVA. Within a row, capital letters indicate differences within the fish-meal-type diets and lowercase letters indicate differences within the plant-type diets at $P \leq 0.05$ when interactions occurred for the full model.

² Weight gain = (final weight – initial weight) \times 100/initial weight.

³ FCR: feed conversion ratio = grams of dry feed fed/grams of wet weight gain.

⁴ FC: feed consumption = grams feed consumed \times 100/100 g body mass/d.

⁵ PRE: protein retention efficiency = grams of protein gain \times 100/grams of protein fed.

⁶ ERE: energy retention efficiency = kcal energy gain \times 100/kcal energy fed.

and 100 μ L saturated potassium tetraborate. After vortexing, the mixture was filtered through a 0.22- μ m syringe filter. Samples were derivatized with *o*-phthaldialdehyde (Sigma-Aldrich Co., St. Louis, MO, USA) immediately prior to injection on a 5- μ m Agilent Hypersil AA ODS column (Agilent Technologies, Palo Alto, CA, USA) using an automated injection sequence. Dietary taurine levels were quantified following acid hydrolysis with 6 N HCl at 110 C for 16 h (AOAC 1995). Hydrolysates were neutralized with 2 M potassium carbonate and prepped for injection as described for plasma. Recoveries of spiked samples were 98.7% with a coefficient of variation of 4.4%.

The SAS software program Proc GLM (Version 7, SAS Institute, Cary, NC, USA) was used

to conduct factorial ANOVA to determine the effects of four taurine levels (0, 0.5, 1.0, and 1.5% of diet) and diet type (fish meal versus plant based) on each of the measured responses in juvenile rainbow trout. When interaction between taurine level and diet type was statistically significant for a particular response, differences among taurine levels within each diet type were determined using Tukey's mean separation (Tukey, unpublished data; Kramer 1956). Treatment effects and interactions were considered significant at $P < 0.05$.

Results

The basal fish-meal diet (no added taurine) contained 2 g taurine/kg dry diet, and the basal plant diet contained taurine below the

TABLE 3. Effect of taurine supplementation on body composition index and plasma amino acid levels.

Diet type Taurine supplement	Fish-meal diet series				Plant diet series			
	0	0.5	1.0	1.5	0	0.5	1.0	1.5
Hepatosomatic index ² (%)	1.44	1.33	1.39	1.31	1.42	1.39	1.41	1.44
Intraperitoneal fat ratio ³ (%)	2.19	2.60	2.33	2.42	2.81	3.40	2.79	2.94
Muscle ratio ⁴ (%)	37.8	36.9	38.0	38.9	35.3	38.4	38.9	39.3
Whole-body lipid (%)	14.9	13.6	13.2	15.2	13.6	16.2	15.3	15.2
Plasma taurine (nmol/mL)	1285	1869	1851	1661	1473	2189	1730	2007
Plasma methionine (nmol/mL)	45.6	42.1	53.7	49.5	38.9	36.8	36.4	28.7

¹ Probability associated with the *F* statistic for the factorial ANOVA. Within a row, superscripts in capital letters indicate differences within the fish-meal-type diets and superscripts in lowercase letters indicate differences within the plant-type diets at $P \leq 0.05$ when interactions occurred for the full model.

² Hepatosomatic index = liver mass \times 100/fish mass.

³ Intraperitoneal fat ratio = peritoneal fat mass \times 100/fish mass.

⁴ Muscle ratio = fillet mass \times 100/fish mass.

TABLE 2. *Extended.*

Pooled SE	Pr > F ¹			
	Tau	Type	Tau × type	
15.22	0.4163	0.0083	0.0020	Plant < fish meal
0.018	0.0150	0.0081	0.0001	Plant > fish meal
0.0395	0.221	0.0397	0.0002	Plant > fish meal
1.059	0.0165	0.0011	0.0014	Plant < fish meal
1.077	0.1184	0.1710	0.0003	

detection limit of analyses (0.1 g/kg of dry diet). Supplementation of the fish-meal diets with taurine had no effect on weight gain of rainbow trout. Taurine supplementation of plant diets did improve weight gain compared to fish consuming the unsupplemented plant-based diet (Table 2). The lowest level of taurine supplemented (5 g/kg diet) increased growth rate of the fish fed the plant diet equivalent to the fish fed the fish-meal diets. Increasing taurine supplementation to 10 or 15 g/kg diet did not further increase growth rate. The same treatment effect was observed regarding FCR. Fish consuming the fish-meal-based diets had FCRs of <1.0 while FCRs of fish consuming the plant protein diet were <1.0 only when taurine was supplemented to the diet (Table 2). Taurine supplementation had no effect on feed consumption when determined as a percentage of body weight per day, but fish fed the plant protein diets consumed more feed relative to the fish fed

the fish-meal diets. This effect was predominately caused by the elevated feed consumption in fish receiving the all-plant protein diet without taurine supplementation, and supplementing this series of diets reduced feed consumption.

Composition of growth was minimally altered by diet. Trout consuming the plant series diets deposited more fat in the intraperitoneal cavity than trout consuming the fish-meal series diets (2.99 versus 2.39%, respectively) (Table 3). This difference was not of adequate magnitude to influence the whole-body lipid deposition, where no dietary influence was detected. Muscle ratio and hepatosomatic index also were unresponsive to dietary treatment.

PRE and ERE were affected by dietary treatment (Table 2). Fish fed the unsupplemented plant diet had lower protein and energy retention than fish fed the taurine-supplemented plant diets or the fish-meal diets. Retention of dietary energy (ERE) as growth products also was influenced by

TABLE 3. *Extended.*

Pooled SE	Pr > F ¹			
	Tau	Type	Tau × type	
0.1238	0.7514	0.3292	0.7473	
0.5099	0.3385	0.0055	0.9400	Plant > fish meal
2.113	0.1846	0.9182	0.3889	
0.95	0.6842	0.2137	0.1715	
405.9	0.0518	0.2726	0.7415	
9.89	0.7107	0.0039	0.4755	Plant < fish meal

diet with significant interactions. The interaction indicated that ERE within the fish-meal series diets was unaffected by taurine supplementation, while taurine supplementation improved ERE within the plant protein series diets.

Circulating amino acids also were affected by dietary treatments (Table 3). Circulating methionine was higher in fish consuming the fish-meal series diets compared to the plant series. Circulating taurine was marginally influenced by taurine supplementation ($P = 0.0518$), and diet type had no effect on plasma taurine levels.

Discussion

Current trout diet formulations often contain other animal protein sources or plant protein sources in addition to fish meal, but growth can be reduced if fish-meal content is significantly reduced. Animal derived feed ingredients have taurine present in appreciable quantities. Poultry by-product meals generally contain around 4 g taurine/kg ingredient (J. Walls, Tyson Foods Inc., Rogers, AR, USA, personal communication), and menhaden fish meal contains approximately 5 g taurine/kg ingredient (Special Select™ Menhaden Meal, Omega Protein Corp., Inc., Houston, TX, USA). These levels could equate to as much as 3 g/kg diet in a 40% crude protein trout diet. Plant products do not contain taurine; therefore, replacement of animal-derived ingredients with plant-derived ingredients results in lower dietary levels of taurine.

Trout and other fish species have shown some capacity for synthesis of taurine (Divakaran et al. 1992; Yokoyama et al. 1997). Taurine is synthesized from methionine via cysteine. Activity of cysteine sulfinic acid decarboxylase (CSAD), an important enzyme in the conversion of cysteine to taurine, has been measured at 0.55–0.67 nmol/min/mg protein in trout (Yokoyama et al. 2001). This rate is higher than many other fish species but substantially lower than in mice and rats, at 4.25 and 7.86 nmol/min/mg protein, respectively (Yokoyama et al. 2001). Therefore, although trout may have limited ability to convert cysteine to taurine, it could become conditionally indispensable as faster growing strains of trout are developed.

Increased growth rate may place added demand on the taurine synthetic mechanisms that cannot be met, especially as levels of fish meal in the diet are reduced or eliminated.

In the current trial, we demonstrated that taurine supplementation to an all-plant protein diet appears critical for maintaining growth rates and FCRs equivalent to fish fed fish-meal-containing diets. Supplementation with 5 g/kg diet of taurine to a plant-based diet was sufficient to increase growth to levels equivalent to those seen in fish fed the fish-meal diets. Additional supplementation did not increase growth within the fish-meal series of diets. This would appear to indicate that a level of dietary taurine of 2.0 g/kg diet (measured in the fish basal diet), coupled with any endogenous production, is sufficient to maintain growth and feed efficiency. One caveat of the experimental design was the unequal methionine and cysteine contents between the two experimental diet series. Although the dietary content of methionine and cysteine in the plant protein diet series was theoretically adequate to meet the TSAA requirement for rainbow trout, a marginal deficiency may have occurred if availability was limited. The metabolic effects of supplemental taurine in the all-plant protein formulation were not as a result of increased feed consumption as feed consumption was elevated in the plant series diets without taurine supplementation but declined to levels equivalent to fish consuming the fish-meal series diets when taurine was added to the diet. This observation could indicate that the fish were trying to obtain additional taurine by increasing feed consumption.

The current study demonstrates the need to consider total taurine levels in conjunction with dietary methionine and cysteine concentrations for rainbow trout, especially in reduced fish-meal diets or all-plant diets. Ingredient interactions can influence the net availability of the nutrient under consideration. This also has been shown to be true with dietary taurine. Dietary rice bran, for example, reduces the taurine status of cats (Stratton-Phelps et al. 2002), presumably because of the conjugation of bile salts, including taurine, to the fiber fractions, leading to excretion of the taurine instead of reabsorption.

Another postulated factor leading to reduced taurine status with rice bran inclusion is through modification of the intestinal microflora that can degrade taurine (Stratton-Phelps et al. 2002). All these factors should be considered when utilizing alternative protein sources for rainbow trout feeds.

As observed in the current experiment with rainbow trout, other species of fish have a conditional requirement for a dietary supply of taurine, at least during specific life stages. Kim et al. (2003) observed that juvenile Japanese flounder (0.4 g) showed improved growth performance with dietary taurine supplementation, but no improvements in growth were observed in a follow-up experiment with fingerling Japanese flounder (15 g). The differences were postulated to be an age-dependent requirement and ability to synthesize taurine. Park et al. (2002) had previously noted similar growth improvement with taurine supplementation for juvenile Japanese flounder (0.9 g). Takeuchi et al. (2001) noted a buildup of whole-body cystathionine in Japanese flounder fed a low taurine diet. Park et al. (2002) also noted a buildup of cystathionine in the muscle and liver of fingerling Japanese flounder consuming a low taurine diet, and Kim et al. (2005) observed increased cystathionine in liver, brain, muscle, and whole body in Japanese flounder juveniles fed low taurine diets. These authors noted that supplementing taurine to a level of 8 g/kg diet alleviated the cystathionine buildup. An improvement in growth was also noted with supplemental taurine up to 14 g/kg diet, which could only be partially compensated for by supplemental cysteine (Kim et al. 2003). Supplementation of cysteine also failed to block the accumulation of cystathionine in Japanese flounder juveniles (Park et al. 2002).

Taurine is known to play a physiological role in osmoregulation in fish and other animals (Schaffer et al. 2000; Buentello and Gatlin 2002). The osmoregulatory role of taurine may be one reason why Japanese flounder raised in seawater have a greater demand for dietary taurine, at least in the juvenile stages, than that observed for rainbow trout raised in freshwater in the current experiment. The higher demand in Japanese flounder also may be due, in part,

to the lower CSAD activity in Japanese flounder than rainbow trout (Yokoyama et al. 2001). Accordingly, Goto et al. (2001) demonstrated that the relative activity of CSAD in rainbow trout is 13.7 times higher than that measured in Japanese flounder. Other fish species also demonstrate the potential for widely divergent CSAD activity. Divakaran et al. (1992) had previously noted that red hybrid tilapia had CSAD activity similar to Wistar rats but that dolphin fish (*Coryphaena hippurus*) had no detectable CSAD activity. Therefore, differences may occur in quantitative conversion of cysteine to taurine based on a fish's environmental salinity requirements. Another theory may be that the fish's natural feeding history (herbivory versus omnivory versus carnivory/insectivory) may influence the fish's ability to form taurine from cysteine. Therefore, tilapia may still have the capacity to synthesize taurine to meet metabolic demands where dolphin fish may not.

The physiological role of taurine is not completely clear within a fish species or across species. Tissue taurine levels have been demonstrated to be responsive to osmotic pressure, and taurine is thought to serve some form of antioxidative capacity. Taurine has been demonstrated to attenuate the detrimental effects of oxidative damage from a number of sources. Hwang et al. (2000) observed that taurine supplementation reduced thiobarbituric acid-reactive substances, a marker of lipid peroxidation, in the liver of rats fed oxidized fish oils. Also reduced were aspartate transaminase, alkaline phosphatase, and alanine transaminase in the plasma, which are indicators of liver function. Taurine supplementation to rat diets was shown to ameliorate the toxic effects of copper (Hwang et al. 1998). Furthermore, Kim and Kim (2002) demonstrated reduced hepatotoxicity with taurine supplementation in rats injected with lipopolysaccharide, but the mode of action is as yet unclear.

Although the physiological modes of action of taurine are not well defined in fish across species, it does appear that the metabolic functions of taurine may not be met from endogenous synthesis in rainbow trout. From the current experiment one cannot rule out the potential limitation of methionine and cysteine in the diet

for conversion to taurine by rainbow trout. Although the diets were formulated to meet the known requirements for rainbow trout, an imbalance of methionine and cysteine between the two diet series, 1.35:1 methionine:cysteine in the fish-meal diet series versus 1:1 in the plant diet series, could in part confound the taurine effects observed in the current trial. Further refinement of the interactions of dietary TSAA and taurine is warranted, as well as determining the dietary taurine supplementation levels for plant protein diets for rainbow trout.

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