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Taurine concentrations in animal feed ingredients; cooking influences taurine content

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Summary

The aim of this study was to determine the taurine content in a variety of animal feeds. There is very little information on the taurine content of ingredients used in home-prepared diets for dogs and cats, and foods fed to wild animals in captivity. This study reports the taurine content of both common and alternative feed ingredients, and compares taurine loss as a result of different methods of food preparation. Foods were selected based on their use in commercial and home-prepared diets. Animal muscle tissue, particularly marine, contained high taurine concentrations. Plant products contained either low or undetectable amounts of taurine. The amount of taurine that remained in a feed ingredient after cooking depended upon the method of food preparation. When an ingredient was constantly surrounded by water during the cooking process, such as in boiling or basting, more taurine was lost. Food preparation methods that minimized water loss, such as baking or frying, had higher rates of taurine retention.

Introduction

Taurine is a sulphonated beta amino acid, thus taurine is neither incorporated into proteins, nor degraded by mammalian tissues. Most herbivores and omnivores synthesize all the taurine they need from the dietary sulphur amino acids, methionine and cysteine. In carnivores, dietary intake of taurine is essential to maintain normal taurine concentrations in the body. Most animal tissues contain high concentrations of taurine, particularly muscle, viscera and brain, whereas higher plants contain no measurable taurine.

In order to formulate diets to contain known quantities of the essential nutrients, the nutrient composition of the ingredients must be known. Currently there is very little published information on the taurine content of foods commonly used in the diets of domestic and non-domesticated species. With the increasing popularity of home-cooked formulations for dogs and cats, and an effort to provide more 'natural' diets for domesticated captive and non-domesticated animals, it is important to know the taurine content of the foods used in these diets. The purpose of this report is to provide information on the taurine content of a variety of foods commonly used in animal diets.

Materials and methods

The foods analysed in this study were obtained from local supermarkets or industry suppliers. Samples were analysed in the Amino Acid Laboratory at the University of California, Davis, School of Veterinary Medicine unless otherwise noted. After purchase, ingredients were either processed immediately, or frozen at −20 °C and then processed. All processed products were then frozen at −20 °C until analysis. For those ingredients that

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were fried, a standard, non-stick frying pan was used with no added oils or butter. The same sample was tested raw and fried. One half was fried and collected with juices, while the other half was fried and separated from juices. Boiled samples were boiled long enough to be cooked to completion and the remaining water was retained for analysis. Cooked ingredients were tested immediately, or frozen at −20 °C until analysis.

Before testing, each ingredient was processed to extract all available free taurine for analysis. Two grams of each sample was added to 18 ml of distilled water and homogenized (Polytron; Brinkman Instruments, Westbury, NY, USA). The sample was homogenized until all of the taurine was sufficiently released into the water. The sample was then refrigerated (to prevent bacterial contamination) for approximately 30 min to allow solids to settle. After separation, 500 μl of the supernatant was added to 500 μl of 6% sulphosalycylic acid in a 1.5-ml microcentrifuge tube. The sample was mixed by vortexing and then centrifuged for 25 min at 16 000 *g* and 10 °C. After centrifugation, the aqueous layer was transferred into a new 1.5-ml microcentrifuge tube and stored at −20 °C until analysis. At the time of analysis, the samples were thawed, vortexed, and then centrifuged at 16 000 *g* and 10 °C. Muscle tissue was considered to contain high concentrations of taurine, while all other products were considered to contain low concentrations. Samples that contained high concentrations of taurine were diluted 1 : 4 with buffer (Li-S Beckman System 7300/6300 High Performance Amino Acid Sample Dilution Buffer, Beckman Instruments Inc., Palo Alto, CA, USA). The dilution was made using 120 μl of dilution buffer and 30 μl of sample. Samples that did not contain high concentrations of taurine were diluted by adding 30 μl of 0.65 N LiOH Buffer to 120 μl of sample. Samples were then loaded on to vacuum-dried coils. The coils were loaded onto an amino acid analyser (Models 6300 and 121-MB automated amino acid analyzers, Beckman Instruments, Inc., Palo Alto, CA, USA) for taurine analysis. All samples were run in duplicate.

Dry weights were obtained by drying 10 g of each sample in a vacuum oven for 24 h. Samples were then weighed for water loss and dry matter was calculated. This procedure was repeated until no further loss of water was detected.

Results

Table 1 summarizes the results from the foods analysed by the Amino Acid Laboratory at the University of California, Davis, as well as taurine concentrations from previous publications (Roe and Weston, 1965; Kataoka and Ohnishi, 1986; Laidlaw et al., 1990). Taurine concentrations are expressed on both a wet-weight and dry-weight basis when available. Results from the Amino Acid Laboratory, and those reported by Roe and Weston (1965) are expressed as the mean taurine concentration of the food samples analysed and the range of taurine concentrations for those samples. Taurine concentrations from the other two publications were only reported as the mean taurine concentration and standard deviation for the samples analysed, and therefore these results are listed similarly in Table 1 (Kataoka and Ohnishi, 1986; Laidlaw et al., 1990).

In addition to the categories listed in the table, fruits, grains, legumes, nuts, seeds and vegetables were investigated for taurine content. Fruit and fruit juice samples tested include apple, cranberry, and orange juice, canned peaches, raisins and fresh tomatoes. All of these samples contained no taurine. Grain and grain products analysed include white, white-enriched and whole-wheat bread, cream of wheat, wheat germ, long grain white rice, extra long grain enriched white rice, and brown California rice, single grain rice cereal, pasta noodles, low- sodium corn flakes, high-protein cereal infant food, barley, bulgar, crackers, rye and oat flour, oatmeal and homemade pancakes. None of the samples contained taurine with the exception of the high protein cereal infant food. The one sample analysed had 18.1 mg taurine/kg on a wet weight, and 22 mg taurine/kg on a dry-weight basis. There was no taurine detected in any of the legumes analysed, which included garbanzo, lima, red and pinto beans; pinto bean juice, garden and blackeye peas and lentils. Tofu, a product of

Table 1. **Taurine content of common foodstuffs***

Ingredients	Reference	Number of items (n)**	mg taurine/kg wet weight [mean (range)]****	mg taurine/kg dry weight [mean (range)]****
Animal products				
Beef				
Beef, mechanically deboned	a	1	77	197
Beef, carcass	a	1	296	872
Beef	b	5	430 ± 80	–
Beef, road kill	a	3	296 (61–625)	–
Beef, lean	a	2	313 (277–348)	1505 (1328–1682)
Beef, boiled	b	9	380 ± 10	–
Ground, <30% fat	a	6	363.5 (334–385)	810.5 (765–856) (n = 2)
Ground, <25% fat	a	2	283 (283–283)	678 (670–686)
Ground, premium, <15% fat	a	1	398	1275
Ground, fried without juices, <25% fat	a	1	501	–
Ground, fried without juices, <30% fat	a	2	509 (501–517)	927 (n = 1)
Ground sirloin, fried without juices	a	2	816 (775–856)	2006 (1899–2114)
Ground sirloin fried with juices	a	2	993 (969–1017)	2527 (2465–2589)
Ground, fried with juices, <25% fat	a	2	353 (320–385)	515 (n = 1)
Ground, fried with juices, <30% fat	a	2	552 (488–616)	830 (n = 1)
Gullet	a	3	804 (790–817)	2000 (1902–2057)
Heart	a	3	652 (254–851)	3461 (3390–3531) (n = 2)
Kidney	c	9	225 (180–247)	–
Kidney, baked	c	9	138 (130–144)	–
Kidney, boiled	c	9	76 (68–88)	–
Liver	a	8	688 (401–1023)	2359 (1308–3511)
Liver	c	9	192 (144–270)	–
Liver, baked	c	9	141 (68–184)	–
Liver, boiled	c	9	73 (36–95)	–
Livers meal, animal	a	1	3672	3833
Lung	a	3	956 (781–1033)	3938 (3300–5016)
Meat and bonemeal	a	14	386 (85–1056)	405 (87–1109)
Meat meal	a	1	1150	1196
Round	c	9	362 (150–472)	–
Round, boiled	c	9	60 (58–63)	–

Table 1. **Continued**

Ingredients	Reference	Number of items (n)**	mg taurine/kg wet weight [mean (range)]****	mg taurine/kg dry weight [mean (range)]****
Salami, cured, cotto beef	b	6	590 ± 80	–
Spleen	a	4	874 (659–1114)	3302 (2858–3930)
Tongue, muscle	a	2	1752 (1726–1778)	5848 (4446–7251)
Tongue, muscle and skin	a	2	1110 (717–1502)	4158 (2627–5688)
Udder	a	3	222 (189–254)	720 (431–1059)
Combined meat products				
Bologna, cured, pork/beef	b	6	310 ± 40	–
Poultry and beef animal digest	a	1	894	2909
Poultry by-products and tuna digest	a	1	819	2263
Poultry by-products and salmon digest	a	1	771	2106
Poultry by-products and fish digest	a	1	582	1563
Dairy				
Cheese	a	1	61.3	63.5
Cheese, cheddar	b	7	0	–
Cheese, Swiss	b	1	0	–
Cheese, cottage, creamed, 2% fat	a	1	5.8	28.3
Cheese, cottage, uncreamed, small curd	a	1	4.81	21.4
Large (grade AA) eggs	a	1	0	0
Eggs (non-free-flow)	a	1	641	658
Large (grade AA) egg whites	a	3	0	0
Large (grade AA) egg yolks	a	2	12.14 (12.14–12.14)	24.47 (24.42–24.52)
Egg, dried	a	4	187 (142–256)	202 (154–270)
Ice cream, vanilla	b	1	19***	–
Milk, cow's, regular	a	1	8.3	64.6
Milk, cow's, homogenized	c	3	151 (104–200)***	–
Milk, cow's, 3.5% fat (whole)	b	11	24 ± 3***	–
Milk, cow's, 2% fat (low-fat)	b	12	23 ± 2***	–
Milk, cow's, 2% fat (low-fat)	a	1	8.1	65.6
Milk, 0.5% fat (non-fat)	b	9	25 ± 3***	–
Milk, non-fat, dried	b	1	70***	–
Whey	a	1	660	691
Yogurt, low-fat plain	b	2	33 ± 5***	–

Yogurt, low-fat peach	b	2	78 ± 9***	–
Yogurt, non-fat plain	a	1	0***	0
Horse				
Horse meat	a	1	314	–
Horse, road kill	a	3	398 (81–800)	–
Lamb				
Kidney	c	8	239 (128–440)	–
Kidney, baked	c	8	154 (81–290)	–
Kidney, boiled	c	8	51 (47–55)	–
Lamb and lamb broth, infant food	a	1	702	3676
Leg	c	11	473 (446–510)	–
Leg, baked	c	11	257 (220–284)	–
Leg, boiled	c	11	126 (91–184)	–
Stew, domestic boneless	a	1	2157	7393
Pork				
Gullet	a	2	651 (602–700)	2818 (2342–3293)
Kidney	a	5	773 (655–814)	3028 (2216–3533)
Liver	a	10	855 (498–2080)	2455 (1770–3565) (n = 9)
Liver	c	9	169 (110–228)	–
Liver, baked	c	9	85 (70–100)	–
Liver, boiled	c	9	43 (30–54)	–
Loin	b	6	610 ± 110	–
Loin	c	9	496 (394–690)	–
Loin, roasted	b	5	570 ± 120	–
Loin, baked	c	9	219 (126–390)	–
Loin, boiled	c	9	118 (91–184)	–
Lung	a	8	775 (407–1188)	3359 (1845–4876)
Processed ham, boiled deli meat	a	1	350	1305
Processed ham, smoked deli meat	a	1	277	986
Processed ham, picnic, baked	b	7	500 ± 60	–
Sirloin, stir-fry strips	a	1	560	1874
Poultry				
Chicken, raw, boneless skinless breast	a	2	159 (102–216)	606 (369–842)
Chicken, fried with juices, breast	a	2	186 (145–227)	519 (423–614)
Chicken, fried without juices, breast	a	2	129 (0)	400 (394–405)
Chicken, boiled, breast, without juices	a	2	103 (85–120)	366 (297–434)

Table 1. **Continued**

Ingredients	Reference	Number of items (n)**	mg taurine/kg wet weight [mean (range)]****	mg taurine/kg dry weight [mean (range)]****
Chicken, broth from boiled breast	a	2	103 (95–110)	20524 (19022–22025)
Chicken, light meat	b	6	180 ± 30	–
Chicken, broiled, light meat	b	6	150 ± 40	–
Chicken, dark meat	b	6	1690 ± 370	–
Chicken, broiled, dark meat	b	6	1990 ± 270	–
Chicken, leg	c	12	337 (300–380)	–
Chicken, baked, leg	c	12	229 (140–310)	–
Chicken, boiled, leg	c	12	82 (71–180)	–
Chicken and chicken broth, infant food	a	1	934	4010
Chicken, mechanically deboned	a	1	457	852
Chicken, parts	a	1	407	951
Chicken, paste	a	1	991	2406
Chicken, whole carcass	a	1	996	4358
Chicken, viscera	a	3	1004 (899–1073)	3803 (3095–4271)
Chicken, head and feet	a	2	500 (419–581)	1513 (1311–1715)
Chicken, necks and backs	a	7	584 (420–990)	1192 (710–1855) (n = 6)
Chicken, heart and liver	a	3	1179 (888–1561)	5132 (4315–6441)
Chicken, liver	a	1	1100	4668
Duck, leg meat	a	2	1780 (1722–1837)	7372 (7057–7687)
Duck, leg skin	a	2	617 (583–651)	808 (789–827)
Poultry	a	2	3285 (2994–3575)	3474 (3197–3750)
Poultry, low ash	a	1	3564	3757
Poultry, regular ash meal	a	1	2849	2914
Poultry, animal liver meal	a	1	4878	5093
Poultry, liver animal digest	a	1	1264	5825
Poultry and poultry liver animal digest	a	1	1365	4196
Poultry, animal digest	a	4	1509 (663–3401)	2709 (1681–3535) (n = 3)
Poultry, by-product meal	a	12	3049 (685–5046)	3270 (1894–5352) (n = 10)
Poultry, liver	a	4	1537 (1300–1784)	6763 (4997–9096)
Turkey	a	3	932 (781–1150)	2318 (1873–3096)
Turkey, road kill	a	3	2028 (1339–3214)	–
Turkey, breast with portions of backs and ribs	a	1	93.4	298

Turkey and turkey broth, infant food	a	1	2031	9733
Turkey, ground, 7% fat	a	4	2095 (1953–2369)	7050 (6447–8085)
Turkey, ground, fried with juices, 7% fat	a	4	2629 (2260–3249)	7768 (5535–10617) (n = 3)
Turkey, ground, fried without juices, 7% fat	a	4	2619 (2503–2793)	6490 (5660–7162) (n = 3)
Turkey, light meat	b	6	300 ± 70	–
Turkey, roasted light meat	b	7	110 ± 10	–
Turkey, dark meat	b	8	3060 ± 690	–
Turkey, roasted dark meat	b	7	2990 ± 520	–
Turkey, roasted deli meat	a	1	296	1175
Turkey, cured bologna	b	6	1230 ± 50	–
Rabbit				
Ground, whole	a	2	373 (347–399)	–
Seafood				
Capelin, whole	a	1	1436	6174
Clam	b	1	5200 ± 970	–
Clams, fresh	c	1	2400	–
Clams, baked, fresh	c	1	1017	–
Clams, boiled, fresh	c	1	446	–
Cod	c	1	314	–
Cod, baked	c	1	294	–
Cod, boiled	c	1	161	–
Crab meat, cooked, dungeness	a	2	1402 (1397–1407)	5964 (5960–5968)
Digest, seafood	a	1	4102	4327
Digest, condensed fish protein	a	1	2283	4601
Digest, dried fish protein	a	1	12266	12913
Fish	a	5	1138 (920–1542)	6168 (4478–8949)
Fish, scrap	a	3	1083 (969–1211)	4441 (4175–4638)
Fish, mix	a	1	991	8057
Fish, meal	a	2	3201 (2880–3522)	3562 (n = 1)
Fish, frozen mix	a	1	1112	8478
Fish, protein hydrolysate	a	1	7501	7895
Herring, whole	a	1	1544	4903
Mackerel, whole	a	6	2070 (1463–3524)	9295 (6517–13279)
Mussel	b	1	6550 ± 720	–
Oysters, fresh	c	1	698	–
Oysters, baked, fresh	c	1	264	–

Table 1. **Continued**

Ingredients	Reference	Number of items (n)**	mg taurine/kg wet weight [mean (range)]****	mg taurine/kg dry weight [mean (range)]****
Oysters, boiled, fresh	c	1	89	–
Oyster	b	1	3960 ± 290	–
Salmon, fillet, Atlantic fresh	a	2	1300 (743–1857)	4401 (2590–6211)
Salmon, canned, Alaskan	a	2	1231 (1226–1236)	3948 (3881–4014)
Salmon, juice from canned salmon without meat	a	3	22132 (16268–28698)	174902 (117888–209472)
Salmon, meal	a	1	3106	3485
Salmon, smoked	a	1	651	1591
Scallop	b	1	8270 ± 150	–
Shrimp, freshwater, de-shelled, large	a	2	310 (305–315)	1644 (1582–1705)
Shrimp, medium	b	1	390 ± 130	–
Shrimp, cooked, small	b	1	110 ± 10	–
Shrimp, slurry	a	1	277	6255
Shrimp, meal	a	3	1094 (698–1732)	1172 (759–1854)
Smelt, Columbia River, whole	a	1	687	2969
Squid	b	1	3560 ± 950	–
Tuna	a	1	1999	7495
Tuna, whole	a	5	2840	–
Tuna, albacore, canned	b	1	420 ± 130	–
Tuna, red meat	a	1	2798	8699
Tuna, chunk light	b	1	390 ± 130	–
Tuna, chunk light, in vegetable oil	a	1	534	1274
Tuna, chunk light, in water	a	1	557	3149
Tuna, condensed soluble	a	3	8670***	–
Tuna, meal	a	6	1060 (870–1365)	1309 (1077–1532)
Whitefish	b	1	1510 ± 230	–
Whitefish, orange roughy fillet	a	2	367 (334–400)	1299 (1168–1430)
Whitefish, cooked	b	1	1720 ± 540	–
Whitefish, fried with juices, orange roughy fillet	a	2	379 (339–419)	930 (835–1025)
Whitefish, fried without juices, orange roughy fillet	a	2	380 (372–388)	1011 (996–1026)

Veal				
Veal	b	5	400 ± 130	–
Veal, broiled	b	6	470 ± 100	–
Venison				
Venison, stewed	a	2	1490 (1457–1522)	5376 (5297–5454)
Venison, road kill	a	3	603 (589–616)	–
Plants and fungi				
Bryophyta, Sugigoke (*Polytrichum juniperium*)	d	3	0.158 ± 0.009	–
Bryophyta, Kosugigoke (*Pogonatum inflexum*)	d	3	0.469 ± 0.008	–
Bryophyta, Aoginugoke (*Brachythecium popelum*)	d	3	0.409 ± 0.003	–
Chlorophyta, Miru (*Codium fragile*)	d	3	1.89 ± 0.003	–
Fungi, Enokitake (*Flammulina velutipes*)	d	3	0.927 ± 0.029	–
Fungi, Shiitake (*Lentinus edodes*)	d	3	0.567 ± 0.007	–
Fungi, Shimejitake (*Lyphyllum aggregatum*)	d	3	0.487 ± 0.010	–
Yeast	a	3	112 (0–337)	124 (0–372)
Phaeophyta, Konbu (*Laminaria japonica*)	d	3	16.6 ± 0.004	–
Phaeophyta, Hondawara (*Sargassum fulvellum*)	d	3	6.4 ± 0.287	–
Pteridophyta, Inuwarabi (*Athyrium niponicum*)	d	3	0.219 ± 0.014	–
Pteridophyta, Itachishida (*Polystichum setosum*)	d	3	0.204 ± 0.004	–
Rhodophyta, Hirakusa (*Gelidium subcostatum*)	d	3	125 ± 1.96	–
Rhodophyta, Tanbanori (*Grateloupia elliptica*)	d	3	24.8 ± 0.663	–
Spermatophyta, Paseri (*Petroselium crispum*)	d	3	0	–
Spermatophyta, Negi (*Allium fistulosum*)	d	3	0	–

* All samples should be considered uncooked, unlesss otherwise indicated
** n is the number of samples analysed for both wet and dry weight concentrations, unless otherwise indicated within the entry
*** Values are expressed in units of mg taurine/1000 ml, rather than mg taurine/kg
**** All values are presented as means with accompanying ranges, except for references ‘b’ and ‘d’, which are presented as means with accompanying standard deviations

a. Analysed by the Amino Acid Laboratory at the University of California, Davis
b. Laidlaw, S. A., Grosvenor, M., Kopple, J. D., 1990: J. Parent. Ent. Nutr. *14*, 183
c. Roe, D. A., Weston, M. O., 1965: Nature. *205*, 287
d. Kataoka, H., Ohnishi, N., 1986: Agric. Biol. Chem. *50*, 1887

soya beans, did not contain detectable levels of taurine. Sunflower and sesame seeds, almonds, cashews, filberts, pecans, peanuts and walnuts were tested. None of the nuts and seeds analysed contained detectable taurine. Vegetables that were tested included steamed asparagus, fresh avocado, broccoli flower and stalk, carrot, celery, corn, cucumber, fresh green beans, lettuce, onion, russet potato with the skin (boiled and baked), potato chips, sweet relish and sweet potato including the skin. None of the vegetables contained any measurable amount of taurine. Tapioca was also tested and found to contain no taurine.

Discussion

The objective of this paper was to develop a reference for the taurine content of various foods fed to dogs and cats, as well as non-domesticated captive species. There is little published information on the taurine content of animal feed ingredients. However, the importance of such information with respect to feline diets is well described, and is becoming of greater concern and interest in dogs and captive, non-domesticated species.

In cats, inadequate provision of dietary taurine clearly results in deficiency. A deficiency of taurine results in clinical diseases including feline central retinal degeneration and dilated cardiomyopathy (Hayes et al., 1975; Pion et al., 1987). Taurine deficiency also adversely affects reproductive performance, growth and motor function and the immune system (Sturman et al., 1985; Schuller-Levis and Sturman, 1990). Taurine is an essential nutrient of cats because the rate of taurine synthesis from its dietary sulphur amino acid precursors, cysteine and methionine, is much less than the extent of loss through faecal bile acids and urine (Knopf et al., 1978). From an evolutionary standpoint, taurine was plentiful in the diet of a true carnivore, as high concentrations of taurine are found in muscle tissue. However, as most domesticated felines normally do not consume living prey, they are at risk to become taurine-deficient if not adequately supplied in the diet.

Historically, a need for dietary taurine is not generally recognized in dogs. This is because dogs are known, like many species, to have the metabolic capacity to synthesize taurine from the dietary sulphur amino acids, cysteine and methionine. Recently, however, nutritional paradigms have been recognized to result in taurine deficiency in dogs. In many cases, taurine deficiency was also associated with dilated cardiomyopathy (Backus, personal communication; Fascetti, unpublished data; Freeman et al., 1996; Sanderson et al., 2001). In recent reports, a majority of the dogs were consuming commercially manufactured dry foods containing lamb meal and rice as the primary ingredients, but a number of dogs were also eating home-cooked formulations prepared by the owner (Backus, personal communication; Fascetti, unpublished data). Postulated causes for the taurine deficiency in these dogs were considered to be (i) insufficient synthesis of taurine, (ii) extraordinary loss of taurine or its precursors in urine, (iii) extraordinary gastrointestinal loss of taurine in bile acid conjugates, as found in cats, or (iv) a reduction in sulphur amino acid bioavailability (Morris et al., 1994). These scientific and clinical observations suggest that dogs may require taurine in their diet under certain conditions.

Some of the samples tested in our laboratory were selected because they are used extensively by the Nutrition Support Service at the University of California, Davis in home-prepared diets. Other samples were tested based on their use by commercial pet food companies, availability in the grocery stores, or cost-effectiveness for pet owners who prepare home-cooked diets for their animals. However, the selection was random as no preferences were given to any brands or grocery stores.

Generally, seafood products were found to contain the highest concentrations of taurine. High concentrations of taurine in seafood have also been previously reported (Laidlaw et al., 1990; Jacobsen and Smith, 1968; Roe and Weston, 1965; Roe, 1966). Poultry products, especially turkey, also contained high concentrations of taurine. All plant products tested in our laboratory contained undetectable levels of taurine. This is in agreement with the results of Laidlaw et al. (1990). It was also not unexpected that all fruits, grains, legumes, nuts, seeds and vegetables tested contained no detectable taurine. The only exception was the high-protein infant cereal. Although only considered a conditionally essential amino acid in pre-mature newborns, taurine is now added to many human infant and toddler formulas as a measure of prudence to provide improved nourishment.

It was interesting to note that taurine was found in certain plants. Seaweeds contained higher amounts of taurine than land plants, which had undetectable levels. Plants within the same evolutionary division had much greater differences in taurine content than expected. The taurine content of yeast, a fungus, differed greatly compared with other fungus samples analysed. The physiological significance of taurine in these particular plants is unknown, as it does not appear to play the same role in animal tissues. Likewise, it is not known why taurine occurs in lower plant divisions while it is absent in upper plant divisions (KATAOKA and OHNISHI, 1986).

Although taurine is most commonly concentrated in animal muscle tissue, small amounts were detected in certain dairy products such as milk, yogurt, cheese, ice cream and eggs (LAIDLAW et al., 1990). As the nutrients in milk and eggs are provided primarily for the well-being of the infant or embryo, the presence of taurine was not unexpected.

There was a significant amount of variability, with respect to taurine concentrations, between similar samples. In particular, liver samples, animals found dead, animal meals and animal digests had broad ranges with respect to taurine concentrations. All of the beef, pork and poultry liver samples tested in our laboratory had values that differed on the order of 500–2000 mg/kg (dry weight). Different diets, husbandry practices, breeds and environments may have significantly affected the taurine content, although liver varied more than any other organ. One possible explanation may be that taurine is variably distributed throughout the liver. Alternatively, liver taurine stores may be depleted before other storage sites in the body because of conjugation with bile acids. Therefore, the taurine concentrations in the liver may vary with fluctuations in whole-body taurine stores.

The variability of the taurine content in the animal meals and animal digests most likely stems from the variety of different animal sources used in their preparation. Therefore, it was not unexpected that the taurine concentration will vary widely. Animal carcasses found along the road also contained a wide range of taurine concentrations. This was most likely due to secondary bacterial contamination. Bacteria destroy taurine, so the longer the animal has been dead, the lower the taurine content of the sample. As the exact time of death and extent of bacterial contamination were not determined in the analysed samples, the amount of taurine measured in each carcass may not have been representative of the taurine content of that animal's tissues when it was alive.

An important property of taurine is its high water solubility. Most of the taurine contained in tissues will be dissolved into water if exposed. Therefore, how a diet is prepared will affect the taurine that is retained in the food ingredient for consumption by the animal. As shown in Table 1, there was a trend of increasing taurine loss by method of preparation in the order of raw (no preparation at all), frying with juices retained, frying without juices retained, baking or boiling. Boiling resulted in the greatest taurine loss because the food was surrounded by water, thereby leeching the taurine from the product. Unless the water is included in the meal, the animal is consuming less taurine than predicted. LAIDLAW et al. (1990) also compared the effects of preparation on taurine content and found similar results.

This report provides information on the taurine content of commonly used animal feed ingredients. Animal muscle tissue, particularly marine, contained high taurine concentrations. Plant products contained either low or undetectable amounts of taurine. The amount of taurine that remained in a feed ingredient after cooking depended upon the method of food preparation. When an ingredient was constantly surrounded by water during the cooking process, such as in boiling or basting, more taurine was lost. Food preparation methods that minimized water loss, such as baking or frying, had higher rates of taurine retention.

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References

Freeman, L. M.; Michel, K. E.; Brown, D. J.; Kaplan, P. H.; Stamoulis, M. E.; Rosenthal, S. L.; Keene, B. W.; Rush, J. E., 1996: J. Am. Vet. Med. Assoc. *209*, 1592.

Hayes, K. C.; Carey, R. E.; Schmidt, S. Y., 1975: Science *188*, 949.

Jacobsen, J. G.; Smith, L. H., 1968: Physiol. Rev. *48*, 424.

Kataoka, H.; Ohnishi, N., 1986: Agric. Biol. Chem. *50*, 1887.

Knopf, K.; Sturman, J. A.; Armstrong, M.; Hayes, K. C., 1978: J. Nutr. *108*, 773.

Laidlaw, S. A.; Grosvenor, M.; Kopple, J. D., 1990: J. Parent. Ent. Nutr. *14*, 183.

Morris, J. G.; Rogers, Q. R.; Kim, S. W.; Backus, R. C., 1994: Dietary taurine requirement of cats is determined by microbial degradation of taurine in the gut. In: Huxtable, R. J.; Michalk, D. (eds), Taurine in Health and Disease. Plenum Press, New York, pp. 59–70.

Pion, P. D.; Kittleson, M. D.; Rogers, Q. R.; Morris, J. G., 1987: Science *237*, 764.

Roe, D. A., 1966: J. Invest. Dermatol. *46*, 420.

Roe, D. A.; Weston, M. O., 1965: Nature *205*, 287.

Sanderson, S. L.; Gross, K. L.; Ogburn, P. N.; Calvert, C.; Jacobs, G.; Lowry, S. R.; Bird, K. A.; Koehler, L. A.; Swanson, L. L., 2001: Am. J. Vet. Res. *62*, 1616.

Schuller-Levis, G. B.; Sturman, J. A., 1990: Evaluation of immunity in taurine deficient cats. In: Pasantes-Morales, H.; Martin, D. L.; Shain, W.; Martin Del Rio, R. (eds), Taurine: Functional Neurochemistry, Physiology, and Cardiology. Wiley-Liss, New York, pp. 431–438.

Sturman, J. A.; Gargano, A. D.; Messing, J. M.; Imaki, H., 1985: J. Nutr. *116*, 655.

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