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<td>Author(s)</td>
<td>Caulfield, Catherine D.; Kelly, John P.</td>
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<td>Publication Date</td>
<td>2008</td>
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Effects of Gamma Irradiation and Pasteurization on the Nutritive Composition of Commercially Available Animal Diets

Catherine D Caulfield, Joseph P Cassidy, and John P Kelly

Gamma radiation is used to sterilize diets for specific pathogen-free (SPF) animals. Because a gamma-irradiated diet was linked to leukoencephalomyelopathy in SPF cats, we investigated the effects of ‘typical’ (28.9–34.3 kGy) and ‘high-end’ (38.4–48.7 kGy) doses of gamma irradiation and of pasteurization (at 107 °C for 15 min) on the amounts of fat; protein; carbohydrate (and taurine in cat diet); vitamins A, E, B6, B12; and peroxide in commercially available dry cat, dog, and rodent diets. The only treatment-related changes occurred with vitamin A and peroxide. The typical and high-end doses of gamma irradiation reduced the vitamin A level of the cat diet to 42% and 30% of the untreated value, respectively—levels below recommended allowances for growth and reproduction. Only the higher irradiation dose reduced vitamin A in the rodent diet, and neither dose altered the canine diet. Pasteurization reduced the vitamin A content of the cat diet to 50% of its original level, which was within the recommended level for this species. Irradiation increased the peroxide content of all 3 animal diets: by approximately 11-fold with the typical dose and by 14- to 25-fold with the high-end dose. Therefore gamma irradiation can have profound, selective effects on the vitamin A and peroxide contents of dry diets, and caution is advised when feeding such diets long-term and exclusively to SPF animals, particularly cats. Furthermore, pasteurization (with its fewer deleterious effects) may represent an alternative method of decontaminating diets for rodents, dogs, and cats.

Abbreviations: AAFCO, Association of American Food Content Officials; LAC, Laboratory Animals Centre; NRC, National Research Council; SPF, specific pathogen-free

The increasing use of germ-free and specific pathogen-free (SPF) animals and genetically modified rodents (of known or uncertain immunocompetence) in research has led to a growing demand for sterilized animal diets.1,11,43 The methods used to sterilize diets include the application of heat by pasteurization70,43 or gamma irradiation.16,17,43 Food irradiation is used extensively to destroy microorganisms, a necessary process in the production of diets suitable for feeding to SPF animals.12,43 Pasteurization, which is the partial sterilization of foods at a temperature that destroys harmful microorganisms without marked changes in the chemistry of the food also can be used to ‘sterilize’ animal diets used in a barrier or SPF facility.12,43 Because these treatment processes are designed to kill microorganisms through destroying their proteins and other cellular components, it is not surprising that these methods also alter constituents of these diets.40,43 The physicochemical and biochemical changes in a food due to the application of gamma irradiation cause the formation of radiolytic products, whose risks are still the subject of ongoing research.52

The irradiation dose applied to a food product is measured in terms of kiloGrays (kGy). One kiloGray is equivalent to 1000 grays (Gy), 0.1 megarad (Mrad), or 100,000 rads. Exposure to gamma irradiation doses below 10 kGy is effective in enhancing food safety through the inactivation of pathogenic microorganisms such as Salmonella and Campylobacter and in extending the shelf-life of the diet by eliminating the microorganisms responsible for food spoilage.14,41 Irradiation doses of between 20 to 25 kGy12,43 and between 20 to 30 kGy11 are used most frequently to treat diets intended for SPF animals, whereas larger doses of 40 to 50 kGy are recommended for diets intended for gnotobiotic or germ-free animals, where absolute sterility is essential.11,43 During the irradiation process, the food is exposed to a controlled amount of gamma rays from a radioactive source, such as cobalt-60. The gamma rays evenly penetrate the food, rapidly killing food-poisoning bacteria, harmful parasites, and insects.36 The radiation dose and quantity of radiation energy absorbed by the food are the most critical factors in food irradiation.46 The ability of irradiation to kill a particular microbe is measured as the ‘D value,’ the amount of energy to kill 90% of the microbial population.46 Pasteurization of animal diets is achieved by exposure to a temperature of 107 °C for 15 to 20 min in an autoclave.12 Unlike sterilization, pasteurization does not kill all microorganisms in the food but instead achieves a ‘log reduction’ in the number of viable organisms.5

Animal diets vary in composition depending on the unique nutritional biochemistry of the species that it is intended for. The nutrient requirements of dogs and cats are described in the AAFCO Dog and Cat Food Nutrient Profiles15 from the Association of American Feed Content Officials (AAFCO). The values developed by the National Research Council (NRC) Committee on Animal Nutrition are the minimal nutrient requirements and recommended allowance for dogs and cats.29 The nutrient requirements of rodents have been described in the reports of the Laboratory Animals Centre (LAC) Diets Advisory Committee10 and those of the National Research Council.28 Because rodents are classified as omnivorous,28 the nutritional composition of
rods of various irradiation treatments, respectively. Pasteurization modestly increased this parameter to 117% of its untreated value.

**Other nutritional components.** Fat, protein, and carbohydrate levels were not affected by either gamma irradiation dose or by pasteurization. Taurine levels were only minimally affected by irradiation and by pasteurization, and the values remained well above the AAFCO and NRC recommended minimal levels for cats.

**Nutritive composition of dry dog food (Table 3 and Figures 1 and 2).** Analysis of untreated dry dog food showed that all measured constituents exceeded the NRC 2006 recommended allowance and the AAFCO 2007 minimal requirements for dogs, where such levels have been set. The content of each analyte in treated dog, cat, and rodent diets are shown in Tables 2 through 4; the values in parentheses are the percentage of preirradiation diet figures. The typical recommended daily intake of each diet by its respective species is 105 g for adult cats, 200 to 350 g for adult medium-sized dogs, 5 g for mice, and 20 g for rats, as recommended by the manufacturers of the diets.

**Results**

The content of each analyte in treated dog, cat, and rodent diets are shown in Tables 2 through 4; the values in parentheses are the percentage of preirradiation diet figures. The typical recommended daily intake of each diet by its respective species is 105 g for adult cats, 200 to 350 g for adult medium-sized dogs, 5 g for mice, and 20 g for rats, as recommended by the manufacturers of the diets.

**Nutritive composition of dry cat diet (Table 2 and Figures 1 and 2).** Analysis of untreated cat diet showed that all measured constituents met or exceeded the NRC 2006 recommended allowance and the AAFCO 2007 minimal requirements for cats, where such levels have been set.

**Vitamins.** Although most parameters measured in the dry cat diet were unaffected by either the low or high gamma irradiation dose, vitamin A was reduced to 42% (typical dose) and 31% (high-end dose) of its untreated value. For the typical dose, these data corresponded to approximately 72% of the AAFCO minimal recommended level for growth and reproduction and 98% of the NRC recommended allowance. Pasteurization of the dry cat diet reduced vitamin A to 50% of its original value, but this value was still within the AAFCO minimal and NRC accepted levels for cats.

**Peroxide.** Concentration of peroxide in the dry cat diet was increased to 11- and 21-fold after the typical and high-end irradiation treatments, respectively. Pasteurization modestly increased this parameter to 117% of its untreated value.

**Other nutritional components.** Fat, protein, and carbohydrate levels were not affected by either gamma irradiation dose or by pasteurization. Taurine levels were only minimally affected by irradiation and by pasteurization, and the values remained well above the AAFCO and NRC recommended minimal levels for cats.

**Nutritive composition of dry dog food (Table 3 and Figures 1 and 2).** Analysis of untreated dry dog food showed that all measured constituents exceeded the NRC 2006 recommended allowance and the AAFCO 2007 minimal requirements for dogs, where such levels have been set. With the exception of peroxide, all other parameters analyzed were unaffected by either irradia-
Table 1. Selected nutritional components in the control cat, dog, and rodent diets as provided on product specification sheets

<table>
<thead>
<tr>
<th>Diet</th>
<th>A (retinol; IU/kg)</th>
<th>E (tocopherol; mg/kg)</th>
<th>B₁ (thiamine; mg/kg)</th>
<th>B₂ (riboflavin; mg/kg)</th>
<th>B₆ (niacin; mg/kg)</th>
<th>B₁₂ (cobalamin; mg/kg)</th>
<th>Carbohydrate (g/kg)</th>
<th>Protein (g/kg)</th>
<th>Fat (g/kg)</th>
<th>Peroxide (mEq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat</td>
<td>12,000</td>
<td>150</td>
<td>12.0</td>
<td>8.0</td>
<td>6.0</td>
<td>0.05</td>
<td>140</td>
<td>310</td>
<td>505</td>
<td>1800</td>
</tr>
<tr>
<td>Dog</td>
<td>10,000</td>
<td>100</td>
<td>2.0</td>
<td>10.0</td>
<td>4.0</td>
<td>0.05</td>
<td>120</td>
<td>240</td>
<td>415</td>
<td>&lt;5.0</td>
</tr>
<tr>
<td>Rodent</td>
<td>15,400</td>
<td>101</td>
<td>16.5</td>
<td>14.9</td>
<td>18.5</td>
<td>0.08</td>
<td>60</td>
<td>189</td>
<td>573</td>
<td>–</td>
</tr>
</tbody>
</table>

–, not reported

Table 2. Vitamin and nutritional components in dry cat food before and after gamma irradiation or pasteurization

<table>
<thead>
<tr>
<th>Diet</th>
<th>A (retinol; IU/kg)</th>
<th>E (tocopherol; mg/kg)</th>
<th>B₁ (thiamine; mg/kg)</th>
<th>B₂ (riboflavin; mg/kg)</th>
<th>B₆ (niacin; mg/kg)</th>
<th>B₁₂ (cobalamin; mg/kg)</th>
<th>Carbohydrate (g/kg)</th>
<th>Protein (g/kg)</th>
<th>Fat (g/kg)</th>
<th>Peroxide (mEq/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>20,700</td>
<td>207</td>
<td>8.6</td>
<td>8.8</td>
<td>5.6</td>
<td>0.2</td>
<td>133</td>
<td>355</td>
<td>357</td>
<td>2050</td>
</tr>
<tr>
<td>Irradiated (28.9–34.4 kGy)</td>
<td>8710</td>
<td>181</td>
<td>7.1</td>
<td>8.5</td>
<td>4.3</td>
<td>0.2</td>
<td>134</td>
<td>353</td>
<td>345</td>
<td>1890</td>
</tr>
<tr>
<td>Irradiated (38.4–48.7 kGy)</td>
<td>6500</td>
<td>181</td>
<td>6.0</td>
<td>9.2</td>
<td>4.3</td>
<td>0.2</td>
<td>135</td>
<td>354</td>
<td>345</td>
<td>1820</td>
</tr>
<tr>
<td>Pasteurized</td>
<td>10,300</td>
<td>173</td>
<td>5.8</td>
<td>8.5</td>
<td>5.4</td>
<td>0.2</td>
<td>136</td>
<td>348</td>
<td>343</td>
<td>1760</td>
</tr>
<tr>
<td>AAFCO</td>
<td>9000</td>
<td>30</td>
<td>5.0</td>
<td>4.0</td>
<td>4.0</td>
<td>0.02</td>
<td>90</td>
<td>300</td>
<td>–</td>
<td>1000 (E)</td>
</tr>
<tr>
<td>NRC</td>
<td>6666</td>
<td>31</td>
<td>6.3</td>
<td>4.0</td>
<td>2.5</td>
<td>0.02</td>
<td>90</td>
<td>300</td>
<td>–</td>
<td>1000 (E)</td>
</tr>
</tbody>
</table>

–, not reported; C, canned; E, extruded

Samples of dry cat food (500g) were analyzed for the content of the above nutrients after gamma irradiation at 2 different doses (typical, 28.9–34.4 kGy; high end, 38.4–48.7 kGy) and pasteurization at 107 °C for 15 min. The values in parenthesis are the percentage change from preirradiation levels. Also included are the recommended minimal daily intake values of each nutrient for growth and reproduction for cats from the Association of American Feed Control Officials (AAFCO; 2007) and National Research Council (NRC; 2006), based on dry matter.

**Vitamins.** Although most parameters were unaffected by either gamma irradiation or pasteurization, and all values exceeded the NRC 2006 and the AAFCO 2007 accepted levels.

**Peroxide.** The concentration of peroxide in the rodent diet was increased to 11.5- and 25-fold after the typical and high-end irradiation treatments, respectively. Pasteurization modestly increased this parameter to 175% of its untreated value. With the exception of peroxide, all parameters measured were unaffected by pasteurization and remained at or above the LAC Diets Advisory Committee and the NRC guidelines, where such levels have been set.

**Other nutritional components.** Fat, protein, and carbohydrate levels were not affected by either gamma irradiation at either dose or by pasteurization.

**Nutritive composition of rodent diet** (Table 4 and Figures 1 and 2). Analysis of untreated rodent diet showed that all measured constituents exceeded the LAC Diets Advisory Committee 1977 guidelines and the NRC 1995 requirements of rodents, where such levels have been set.

**Discussion**

The results of this study confirm that gamma irradiation, at the doses used, has profound effects on the vitamin A (retinol) and peroxide content of the dry cat food analyzed. Interestingly, although the level of this vitamin was reduced after equivalent gamma irradiation of canine and rodent diets, the relative reduction was much smaller than in cat diet, despite the fact that peroxide levels were increased in all diets to a similar extent. Why the reduction in vitamin A was not similar across the 3 diets is unclear but may be due to diet manufacture, the fat source and content of the diet, the diet’s water content, the...

Preirradiation values. In addition, the recommended level of each nutrient to be added per kilogram of diet for rodents is included (Laboratory

Samples of dry rodent diet (500 g) were analyzed for the content of the above nutrients after gamma irradiation at 2 different doses (typical, 28.9–34.4 kGy; high end, 38.4–48.7 kGy) and pasteurization at 107 °C for 15 min. The values in parenthesis are the percentage change from preirradiation levels. Also included are the recommended minimal daily intake values of each nutrient for growth and reproduction for cats from the Association of American Feed Control Officials (AAFCO; 2007) and National Research Council (NRC; 2006), based on dry matter. – = Not Reported.

Table 4. Vitamins and nutritional components in dry rodent food before and after gamma irradiation or pasteurization

<table>
<thead>
<tr>
<th>Vitamins</th>
<th>Other nutritional components</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (retinol; IU/kg)</td>
<td>E (tocopherol; mg/kg)</td>
</tr>
<tr>
<td>----------</td>
<td>-----------------------------</td>
</tr>
<tr>
<td>Untreated</td>
<td>12,700</td>
</tr>
<tr>
<td>Irradiated (28.9–34.4 kGy)</td>
<td>12,200</td>
</tr>
<tr>
<td>Irradiated (38.4–48.7 kGy)</td>
<td>11,900</td>
</tr>
<tr>
<td>Pasteurized</td>
<td>12,100</td>
</tr>
<tr>
<td>AAFCO</td>
<td>5000</td>
</tr>
<tr>
<td>NRC</td>
<td>5050</td>
</tr>
</tbody>
</table>

Samples of dry rodent food (500 g) were analyzed for the content of the above nutrients after gamma irradiation at 2 different doses (typical, 28.9–34.4 kGy; high end, 38.4–48.7 kGy) and pasteurization at 107 °C for 15 min. The values in parenthesis are the percentage change from preirradiation values. In addition, the recommended level of each nutrient to be added per kilogram of diet for rodents is included (Laboratory Animals Centre [LAC] Diets Advisory Committee, 1977; National Research Council [NRC], 1995). – = Not Reported.

pretreatment concentration of vitamin A, or the ratios of the various dietary components.

Another interesting finding was that irradiation of rodent diet generated levels of peroxide that were roughly equivalent to those generated in the other diets, despite the fact that the rodent diet, with 6% fat, had less than half the fat content of the feline and canine diets (13% fat). The relatively greater levels of peroxide generated after irradiation of the rodent diet may be related to the larger component of polyunsaturated fatty acids (3.3%) in this diet as compared with the feline (2.91%) or canine (2.75%) rations19 and may suggest a direct relationship between the level of peroxide generated in the irradiated diet and the diet’s preexisting polyunsaturated fatty acid content. The fatty acid composition of the fat in the diet and especially the degree of unsaturation of these acids is particularly important.45 Saturated and monounsaturated fatty acids such as oleic acid

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are resistant to the effects of radiation, linoleic acid is relatively resistant, whereas polyunsaturated fatty acids containing 3 or more double bonds are destroyed readily by irradiation.23 Although the rodent diet largely consisted of linoleic and linolenic acid, which should be less prone to oxidative attack, the cat diet contained arachidonic, eicosapentaenoic, and docosahexaenoic acid, which are fatty acids that are more susceptible to radiation damage. A previous study23 reported that doses of ionizing radiation within the 200 to 1000 krad (2 to 10 kGy) range recommended for food preservation are likely to cause extensive changes to the lipid component of the food, particularly if a large quantity of highly unsaturated omega 3, C22.5, and C22.6 fatty acids are present, because these are particularly sensitive to irradiation damage. The formation of peroxide in irradiated fat is dependent on factors such as the chemical composition of the fat, type of radiation used, total dose-rate of the radiation, dispersion of fat in the diet, nature of the medium used for dispersion, and the presence of water.35 In the present study, a gamma irradiation dose of 38.4 to 48.7 kGy reduced vitamin A levels to 98% of the NRC recommended allowance but to approximately 72% of the AAFCO minimal recommended level for cats. This result is similar to that of a previous study,19 which found that irradiation at 2.5 Mrad (25 kGy) of several commercially available dry cat diets resulted in a loss of vitamin A content and an increase in the peroxide value, an estimate of the oxidative rancidity of the fat. Our study found that irradiation also produced modest reductions in vitamin A (retinol) content and large increases in peroxide content in the dry dog food and rodent diet analyzed, and the dose of irradiation was directly related to the reduction in the level of vitamin A. The increase in the peroxide content of all 3 dry diets analyzed is similar to that of previous studies.11,19,43 To date, the NRC and AAFCO have not set recommended limits for peroxide levels in animal diets.

Vitamin A deficiency is associated with a variety of disorders, including impaired growth, visual deficits, decreased reproductive fitness, decreased disease resistance, altered bone growth, and neurologic disease.26,32,42 Common neurologic signs associated with vitamin A deficiency include convulsions, seizures, incoordination, and ataxia.5,8,13,21 Vitamin A deficiency has previously been implicated in causing ataxic syndromes in both lions26,31 and cheetahs33 and is suspected to be involved in the development of leukoencephalomyelopathy in SPF cats.9 In this study, irradiation (36 to 47 kGy) reduced vitamin A content by 42% of its untreated value, which is comparable to findings in the present study.9 Vitamin A deficiency is thought to cause neuronal degeneration26,31 indirectly through compression of the CNS after thickening of the cranial bones31 or through elevating cerebrospinal fluid pressure.26 Elevation of cerebrospinal fluid pressure is the earliest detectable change associated with vitamin A deficiency,24 and has been attributed to an increased resistance to the bulk absorption of cerebrospinal fluid into the bloodstream.7,15,21 Although the irradiation doses we used reduced vitamin A to levels lower than the AAFCO minimal recommendations (9000 IU/kg) and the NRC recommended allowance (6666 IU/kg) for growth and reproduction for cats, the resultant vitamin concentrations are higher than the recommended adult maintenance levels of AAFCO (5000 IU/kg) and NRC (3333 IU/kg).

In contrast, pasteurization had a relatively modest effect on the vitamin A and peroxide contents of the dry cat, dog and rodent diet analyzed. Although the vitamin A content in all 3 dry diets was reduced after this treatment, the vitamin A concentration after pasteurization in all cases remained above the AAFCO and NRC minimal accepted level for dogs and cats and above the LAC and NRC guidelines for rodents.

Although analysis of the untreated laboratory diets showed differences from the composition listed on the product specification sheets, the listed constituent measurements are estimates and considerable variation between the stated and actual constituent values can occur.43

Our results raise questions regarding the suitability of gamma-irradiated diets for the long-term exclusive feeding of cats in particular, given that such feeding regimes have been associated with the development of leukoencephalomyelopathy in this species.9 Felids have a higher dietary requirement for vitamin A than other species because they do not convert β-carotene to vitamin A (retinol) and therefore rely on animal products for their source of retinol.39 Perhaps caution should also be applied to the long-term feeding of dogs exclusively on gamma-irradiated dry diets. However given that feeding diets irradiated 25 kGy to laboratory rodents in long-term toxicologic studies is well established with no apparent negative health effect, the findings of the present study may have less implications for the feeding of rodents.30,34,38

In conclusion, this study has shown that gamma irradiation, at the doses used, has profound and selective effects on the vitamin A and peroxide contents of dry animal diets, particularly on dry diets formulated for cats. As a consequence, irradiated diets should be used with caution during long-term exclusive feeding of cats. The findings of this study suggest that pasteuri-
zation may provide an alternative option in decontaminating animal diets given that it has less effect on important dietary constituents.

References

38. Scientific Committee on Food, European Commission [Internet]. Revision of the opinion of the scientific committee on food on the irradiation of food. Available at: http://ec.europa.eu/food/fs/sc/scf/out193_en.pdf