

Volatile Nitrosamines in Fried Bacon

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This study included 75 samples of traditionally produced pork bacon and 37 samples of 4 bacon-like products which were manufactured from turkey, beef, pork and turkey, and beef and turkey. All samples were purchased at commercial outlets in the United States, fried, and analyzed for volatile nitrosamines. Volatile nitrosamines detected included *N*-nitrosodimethylamine (NDMA), *N*-nitrosodiethylamine (NDEA), *N*-nitrosodibutylamine (NDBA), *N*-nitrosopiperidine (NPIP), *N*-nitrosopyrrolidine (NPYR), and *N*-nitrosothiazolidine (NTHZ). All traditional pork bacon samples contained NPYR (mean 6.7 $\mu\text{g}/\text{kg}$, range 0.7–25 $\mu\text{g}/\text{kg}$), and all but one contained NDMA (mean 0.95 $\mu\text{g}/\text{kg}$, range none detected to 3.0 $\mu\text{g}/\text{kg}$). NPIP was detected only in samples which contained pepper. NDEA and NDBA occurred sporadically while NTHZ was detected rather consistently throughout the bacon samples. Overall, volatile nitrosamine levels detected in traditional pork bacon confirm the downward trend observed over the past several decades, although 16% of the traditional pork bacon samples did contain NPYR above the 10 ppb violative level. Every type of bacon-like product contained significantly lower levels of NDMA and NPYR as compared to the regular traditional pork bacon. This is an important observation since bacon-like products are a relatively new entree in the marketplace.

Keywords: *Volatile nitrosamines; bacon*

INTRODUCTION

Nitrite and nitrate are added to bacon and other cured meats to prevent outgrowth and toxin formation by *Clostridium botulinum*. Nitrite is responsible for the development of the characteristic flavor of cured meats. In addition, nitrite reacts with pigments in meat to impart a desirable pink color. Nitrite, however, is converted to nitrosating agents that may react with amines and amino acids in meat to produce carcinogenic nitrosamines (Scanlan, 1983; Shahidi *et al.*, 1994). Volatile nitrosamines were first reported in fried bacon in 1971 (Fazio *et al.*, 1971). *N*-Nitrosopyrrolidine (NPYR) was the major volatile nitrosamine found, with lower levels of *N*-nitrosodimethylamine (NDMA), *N*-nitrosodiethylamine (NDEA), and *N*-nitrosothiazolidine (NTHZ) (Havery and Fazio, 1985).

The mechanism of NPYR formation has been extensively studied. It is generally believed that free proline is the most probable precursor (Skrypec *et al.*, 1985). NPYR is formed after cooking, and its concentration is dependent on cooking method, frying temperature and time, residual and/or added nitrite concentration, ascorbate or erythorbate concentration, concentration of nitrosamine precursor, slice thickness, pre-processing procedures and conditions, moisture content, lean to adipose tissue ratio, presence of nitrosation catalysts and inhibitors, and possibly smoking (Gray *et al.*, 1982; Hotchkiss and Vecchio, 1985; Miller *et al.*, 1989). The structure of the nitrosating agent is not known, but evidence suggests that it is a reaction product of nitrite and lipids in the bacon (Liu *et al.*, 1988).

The formation of NTHZ has been proposed to occur

via the cysteamine–formaldehyde–nitrite pathway linked to the heating–smoking step in bacon processing (Pensabene and Fiddler, 1985). Its formation can be inhibited by addition of α -tocopherol to the cure solution prior to pumping (Gray *et al.*, 1982). It can also be significantly reduced by using sodium ascorbate when the pork belly is sprayed with liquid smoke solution prior to and during processing (Pensabene and Fiddler, 1985).

Efforts to reduce nitrosamine levels in bacon have included discontinuation of the use of nitrite–spice premixes, reduction of nitrite levels in bacon to 120 ppm, exclusion of the use of nitrate, and increase in ascorbate or isoascorbate (erythorbate) levels to 550 ppm (Havery and Fazio, 1985). Inclusion of α -tocopherol as a curing adjunct has also been shown to be efficient in reducing nitrosamine levels (Skrypec *et al.*, 1985; Bernthal *et al.*, 1986).

Although the levels of nitrosamines in bacon have been decreasing steadily, knowledge of current levels of volatile nitrosamines in bacon is useful to regulatory officials and others who make assessments of the health hazard arising from consumption of these products. Furthermore, several different bacon-like products have become popular in recent years, and relatively little information exists on the levels of volatile nitrosamines in these products. The objective of this study is to provide current information on the volatile nitrosamine levels in fried traditional pork bacon as well as in fried bacon-like products manufactured in the United States.

MATERIALS AND METHODS

Samples. Different types of traditional pork bacon and bacon-like products were purchased at retail stores in the states of Oregon, California, Washington, Maryland, and Massachusetts between September 1993 and December 1994. Samples included different types of traditional pork bacon such as regular bacon, bacon with

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Table 1. Volatile Nitrosamines in Traditional Pork Bacon and Bacon-like Products

type of bacon	no. of samples	mean (range) levels of nitrosamines ^a						total
		NDMA	NDEA	NDBA	NPIP	NPYR	NTHZ	
traditional pork bacon								
regular	61	1.0 ± 0.6 (0.3–3.0)	0.2 ± 0.6 (ND–2.6)	0.2 ± 0.4 (ND–1.5)	ND	7.1 ± 5.5 (0.9–25)	1.1 ± 1.3 (ND–7.3)	9.9 ± 6.6 (1.2–30.2)
with pepper	8	0.6 ± 0.1 (0.4–0.7)	0.1 ± 0.3 (ND–0.9)	0.1 ± 0.3 (ND–0.7)	2.0 ± 1.3 (0.6–4.2)	3.3 ± 2.0 (0.7–6.6)	2.1 ± 1.3 (0.8–4.7)	8.1 ± 4.4 (3.4–14.5)
thick slice	6	0.7 ± 0.5 (ND–1.6)	ND	ND	ND	4.1 ± 2.9 (0.9–8.4)	0.9 ± 0.8 (ND–2.0)	5.8 ± 3.6 (1.5–9.9)
bacon-like products								
beef	5	0.7 ± 0.2 (0.4–0.9)	0.2 ± 0.3 (ND–0.7)	ND	ND	2.6 ± 1.6 (0.3–4.0)	ND	3.5 ± 1.8 (1.3–5.6)
turkey	18	0.5 ± 0.2 (ND–1.1)	0.2 ± 0.3 (ND–0.9)	0.1 ± 0.2 (ND–0.5)	ND	1.1 ± 1.3 (ND–4.0)	0.4 ± 0.3 (ND–1.1)	2.4 ± 1.7 (0.4–6.6)
beef and turkey	7	0.6 ± 0.3 (0.3–1.1)	0.5 ± 0.9 (ND–2.0)	0.1 ± 0.2 (ND–0.4)	ND	3.5 ± 1.1 (2.1–4.8)	0.4 ± 0.6 (ND–1.5)	5.1 ± 2.5 (2.9–9.5)
pork and turkey	7	0.5 ± 0.1 (0.4–0.6)	0.2 ± 0.4 (ND–0.9)	ND	ND	2.6 ± 0.8 (1.4–3.6)	0.1 ± 0.1 (ND–0.5)	3.4 ± 1.1 (1.9–4.9)

^a Mean value (±standard deviation) in $\mu\text{g}/\text{kg}$; zero was used for ND (none detected) nitrosamine levels $<0.2 \mu\text{g}/\text{kg}$.

pepper, and thick sliced bacon, as well as bacon-like products manufactured from beef, turkey, beef and turkey, and pork and turkey. The authors readily recognize that the bacon samples in this study are not a representative sampling of either bacon production or sales throughout the U.S. Rather it was felt that analyzing bacon from several locations in the country could provide more useful information than if all the samples were purchased locally, which is often the case in these kinds of reports.

Analysis. The samples were fried in an electric skillet (Farberware Model 310-B) at 177 °C for 3 min each side, and the fried-out fat was discarded. The edible fried bacon was blended with liquid nitrogen in a Warring blender to obtain homogeneous samples. The comminuted bacon samples were stored at –20 °C in sealed containers until they were analyzed.

Volatile nitrosamines were recovered from 25 g bacon samples by the vacuum mineral oil distillation procedure and analyzed by gas chromatography–thermal energy analyzer (GC-TEA) as described by Hotchkiss *et al.* (1980) with the following differences in the GC-TEA procedure. The gas chromatograph was a Varian Model 3700 equipped with a 2 m × 1.6 mm i.d. column packed with 15% Carbowax 20M–terephthalic acid (TPA) on Chromosorb P 60–80 mesh. The column temperature was 120 °C for 10 min, programmed to 180 °C at 4 °C/min, and maintained at 180 °C for 30 min. The injection port temperature was 190 °C. The carrier gas was helium at a flow rate of 30 mL/min. The GC column was interfaced to a Model 502 TEA. The TEA trap was maintained at –150 °C with liquid nitrogen and isopentane, the pyrolysis chamber was kept at 475 °C, and the vacuum was maintained at 1.0 torr. Identification and quantification of the nitrosamines were accomplished by injecting known amounts of nitrosamine standard solutions containing NDMA, NDEA, *N*-nitrosodipropylamine (NDPA), NDBA, NPIP, NPYR, *N*-nitrosomorpholine (NMOR), and NTHZ. NDPA was used as an internal standard.

Safety. Nitrosamines are potent carcinogens in many animal species and must be handled with appropriate safety precautions.

RESULTS AND DISCUSSION

The amounts of nitrosamines detected in the traditional pork bacon samples are shown in Table 1. As was the case in many previous investigations, NPYR

contributed the most to total nitrosamine levels. Furthermore, NPYR was detected in every sample of traditional pork bacon analyzed in this study (mean 6.7 $\mu\text{g}/\text{kg}$, range 0.7–25 $\mu\text{g}/\text{kg}$). All but one sample of traditional pork bacon contained NDMA (mean 0.95 $\mu\text{g}/\text{kg}$, range ND–3.0 $\mu\text{g}/\text{kg}$). NTHZ was detected rather consistently (79%) while NDEA and NDBA occurred sporadically in 13 and 15% of the samples, respectively.

NPIP was detected in 11% of the traditional pork bacon samples. It was detected only in bacon samples which contained pepper as an ingredient, and it was detected in every sample which did contain pepper. NPIP has been reported in a variety of cured meat products (Sen *et al.*, 1979; Spiegelhalter *et al.*, 1980). The formation of NPIP has been ascribed to nitrosation of piperine and piperidine which occur in the spice pepper (Nakamura *et al.*, 1981; Shenoy *et al.*, 1992).

The amounts of nitrosamines in the bacon-like products are also shown in Table 1. Statistical analysis indicated that each type of bacon-like product contained significantly lower levels of NDMA and NPYR as compared to the regular traditional pork bacon (*T* test, $p \leq 0.05$). This is an important observation since bacon-like products are a relatively new entree in the marketplace.

The U.S. Food and Drug Administration first reported the occurrence of volatile nitrosamines in U.S. produced fried bacon approximately 25 years ago (Fazio *et al.*, 1971). Since that time, the levels of volatile nitrosamines in fried bacon have decreased as reported by Havery and Fazio (1985). In 1978, the U.S. Department of Agriculture initiated a bacon monitoring program (Angelotti, 1978). Under this program, fried bacon found to contain NPYR at levels of 10 ppb and above were in violation. Furthermore, manufacturers were not permitted to market their product until subsequently produced bacon was found to be in compliance. Undoubtedly this monitoring program provided an incentive to produce bacon with reduced nitrosamine levels.

The data reported in this study generally substantiate the downward trend of volatile nitrosamines in fried bacon. It is interesting to observe, however, that, although the volatile nitrosamine levels in the traditional pork bacon samples (Table 1) are relatively low as compared to reports of past years, 12 of the 75 samples did contain NPYR above the 10 ppb violative level. This is consistent with a recent report by Fiddler

and Pensabene (1996) which reported NPYR above 10 ppb in 2 of 18 samples of fried bacon. Although nitrosamine levels have been reduced, it is apparent that additional efforts will be required to ensure complete compliance with the 10 ppb violative level for NPYR in fried bacon. Further efforts toward reduction of levels are warranted since nitrosamines such as NPYR and NDMA have been shown to produce cancer in a variety of animal species (Tricker and Preussmann, 1991; Lijinsky, 1987).

LITERATURE CITED

- Angelotti, R. Nitrates, nitrites, and ascorbates (or isoascorbates) in bacon. *Fed. Regist.* **1978**, *43*, 32136–32137.
- Berenthal, P. H.; Gray, J. I.; Mandaguere, A. K.; Ikins, W. G.; Cuppett, S. L.; Booren, A. M.; Price, J. F. Use of antioxidant-coated salts as *N*-nitrosamine inhibitors in dry- and brine-cured bacon. *J. Food Protect.* **1986**, *49*, 58–61.
- Fazio, T.; White, R. H.; Howard, J. W. Analysis of nitrite- and/or nitrate-processed meats for *N*-nitrosodimethylamine. *J. Assoc. Off. Anal. Chem.* **1971**, *54*, 1157–1159.
- Fiddler, W.; Pensabene, J. W. Supercritical fluid extraction of volatile *N*-nitrosamines in fried bacon and its drippings: method comparison. *J. Assoc. Off. Anal. Chem.* **1996**, *79*, 895–900.
- Gray, J. I.; Reddy, S. K.; Price, J. F.; Mandaguere, A. K.; Wilkens, W. F. Inhibition of *N*-nitrosamines in bacon. *Food Technol.* **1982**, *36*, 39–45.
- Havery, D. C.; Fazio, T. Human exposure to nitrosamines from foods. *Food Technol.* **1985**, *39*, 80–83.
- Hotchkiss, J. H.; Vecchio, A. J. Nitrosamines in fried-out bacon fat and its use as a cooking oil. *Food Technol.* **1985**, *39*, 67–73.
- Hotchkiss, J. H.; Libbey, L. M.; Scanlan, R. A. Confirmation of low $\mu\text{g}/\text{kg}$ amounts of volatile *N*-nitrosamines in foods by low resolution mass spectrometry. *J. Assoc. Off. Anal. Chem.* **1980**, *63*, 74–79.
- Lijinsky, W. Structure-activity relation in carcinogenesis by *N*-nitroso compounds. *Cancer Metastasis Rev.* **1987**, *6*, 301–356.
- Liu, R. H.; Conboy, J. J.; Hotchkiss, J. H. Nitrosation by nitro-nitroso derivatives of olefins: a potential mechanism for *N*-nitrosamine formation in fried bacon. *J. Agric. Food Chem.* **1988**, *36*, 984–987.
- Miller, B. J.; Billedeau, S. M.; Miller, D. W. Formation of *N*-nitrosamines in microwaved versus skillet-fried bacon containing nitrite. *Food Chem. Toxicol.* **1989**, *27*, 295–299.
- Nakamura, M.; Katoh, K.; Kawabata, T. Precursors to nitrosopyrrolidine and nitrosopiperidine in black pepper treated with nitrous acid. *Agric. Biol. Chem.* **1981**, *45*, 1257–1259.
- Pensabene, J. W.; Fiddler, W. Formation and inhibition of *N*-nitrosothiazolidine in bacon. *Food Technol.* **1985**, *39*, 91–94.
- Scanlan, R. A. Formation and occurrence of nitrosamines in food. *Cancer Res. (Suppl.)* **1983**, *43*, 2435s–2440s.
- Sen, N. P.; Seaman, S.; Miles, W. F. Volatile nitrosamines in various cured meat products: effect of cooking and recent trends. *J. Agric. Food Chem.* **1979**, *27*, 1354–1357.
- Shahidi, F.; Pegg, R. B.; Sen, N. P. Absence of volatile *N*-nitrosamines in cooked nitrite-free cured muscle foods. *Meat Sci.* **1994**, *37*, 327–336.
- Shenoy, N. R.; Choughuley, A. S. U.; Shetty, T. K.; Bhattacharya, R. K. Nitrosation of piperine using different nitrosating agents: characterization and mutagenicity of the products. *J. Agric. Food Chem.* **1992**, *40*, 2211–2215.
- Skrypec, D. J.; Gray, J. I.; Mandaguere, A. K.; Booren, A. M.; Pearson, A. M.; Cuppett, S. L. Effect of bacon composition on *N*-nitrosamine formation. *Food Technol.* **1985**, *39*, 74–79.
- Spiegelhalter, B.; Eisenbrand, G.; Preussmann, R. Occurrence of volatile nitrosamines in food: a survey of the West German market. In *N-Nitroso Compounds: Analysis, Formation and Occurrence*; Walker, E. A.; Castegnaro, M.; Griecute, L.; Borzsonyi, M. Eds.; International Agency for Research in Cancer: Lyon, France, 1980; Pub. No. 31, pp 467–479.
- Tricker, A. R.; Preussmann, R. Carcinogenic *N*-nitrosamines in the diet: occurrence, formation, mechanisms and carcinogenic potential. *Mutat. Res.* **1991**, *259*, 277–289.

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